Great Ships for the Great Lakes?

Commercial Vessels Free of Invasive Species in the Great Lakes-St. Lawrence Seaway System

A Scoping Report for the Great Ships Initiative

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Nicole Mays

Northeast-Midwest Institute
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NORTHEAST MIDWEST INSTITUTE

50 F St., NW. Suite 950
Washington DC 20001
www.nemw.org

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Executive Summary

Without implementation of effective prevention measures by ships, the Great Lakes will remain at high risk of invasion from organisms carried in ballast water. As the Great Lakes maritime industry seeks to sustain and increase cargo volumes and infrastructure investment from governments, biological pollution is an "Achilles' heel," undermining crucial public and political support. Concern over ship-mediated biological pollution has inspired strong interest within the Great Lakes maritime industry to resolve the problem, and a special opportunity for collaborative action.

This scoping report provides a fact base, rationale, and preliminary plan for a "Great Ships Initiative" (GSI), a collective industry-led response to the problem of ship-mediated introductions of aquatic invasive species in the Great Lakes. First, the report details key facets of transoceanic trade on the Great Lakes-St. Lawrence Seaway system (GLSLSS), including the system's physical features (ports, fleets, and cargoes); fiduciary players and transaction chains, including the supply chain and transportation chain (terminal owners, stevedores, and freight forwarders); and the regulatory players, internationally, domestically, and regionally. It also describes the drivers and contextual conditions that influence the nature and extent of transoceanic waterborne transportation in the GLSLSS, i.e., global trade trends and competitors. Second, the report details the ship-mediated biological pollution problem, the state-of-the-art of prevention methodology, and policy options for the Great Lakes region. Third, it describes relevant Environmental Management System models and makes recommendations regarding a systemwide, industry-sponsored response to the invasive species problem. This section projects the economic effects and environmental impact of a GSI. The report's conclusion proposes the GSI, charts a series of next steps for making the GSI a reality, and makes caveats for ensuring the efforts' effectiveness.

In light of the factors outlined in this scoping report, particularly the still-developing technology and policy for shipboard treatment of ballast water, the project team concludes that an industry response to the problem of ship-mediated invasive species does not fit the conventional understanding of an Environmental Management System, which is facility-specific and strictly implementation oriented. Instead, an industry response to the problem of ship-mediated invasive species needs to be an unconventional application of Environmental Management principles. In particular, it needs to be collective in nature—across both the GLSLSS geography and the GLSLSS maritime industry sectors—and requires three fundamental semi-sequential phases: treatment tool development, treatment tool installation throughout the salty fleet, and implementation assistance and monitoring. The first phase involves preparing promising treatment systems for installation and regulatory approval. The second phase involves a suite of financial incentives to speed deployment of effective treatment systems onto the fleet of ships that visit the Great Lakes from overseas. The third phase entails outreach to ensure effective installation and operation of treatment systems and to monitor any further discharge of organisms and treatment residuals.

The project team proposes a Great Ships Initiative that combines the resources and expertise of the maritime industry—particularly ports and carriers—with government and quasi-governmental entities, such as the St. Lawrence Seaway Development Corporation and St.

Lawrence Seaway Management Corporation, to accelerate the development, testing, installation, and fleetwide use of effective ballast treatment methods. The treatment development and testing phase will require creation of a treatment "incubator" to provide intensive bench, pilot, and shipboard evaluation services to vendors of ballast treatment prospects suitable to Seaway-sized vessels, with the goal of advancing meritorious systems as rapidly as possible to an approval-ready and market-ready condition.

At the same time, the GSI should establish with the states and provinces consistent monitoring of Great Lakes harbors for newly arrived alien species, and undertake studies to assess post-discharge implications of treatment system performance on receiving systems. The GSI also should prepare to deploy use of the ports' financing tools, grants, relief from tolls and fees, and/or shipper preference policies to drive rapid implementation of proven treatment systems throughout the entire salty fleet visiting the Great Lakes. Finally, the GSI should prepare to provide active technical assistance to shipyards, ship operators and crews through the St. Lawrence Seaway Management/Development Corporations and Sea Grant to ensure effective installation and use of installed treatment systems.

In response to this project effort, Canadian and American Great Lakes ports created a Great Ships Initiative at their January 20, 2006, meeting through a Memorandum of Agreement with the National Fish and Wildlife Foundation, which will serve as the GSI fiduciary. The MOA lays out an operating structure involving a decision-making executive committee composed of GSI contributors and stakeholders. The St. Lawrence Seaway Development Corporation/Management Corporations have allocated \$100,000, participating ports have committed almost \$100,000 (collectively) to support the first year of operations, the Maritime Administration has donated a retrofitted barge for pilot-scale tests (valued at over \$600,000), and the Universities of Wisconsin-Superior and Minnesota-Duluth have committed in-kind laboratory resources. Meanwhile, the Northeast-Midwest Institute responded to a funding opportunity sponsored by the National Oceanic and Atmospheric Administration for funds totaling over \$1 million. Congress has appropriated over \$800,000 to support the startup effort (through the Department of Transportation). If successful, the GSI and its test facility could provide a possible model for productive action by other regions. The official launch for the GSI is anticipated in summer 2006.

Table of Contents

List of Figures, Boxes and Tables

Figures

Boxes

Tables

I. Introduction

Healthy Great Lakes Ecosystem; Healthy Great Lakes Economy

The Great Lakes supply essential economic and ecological services to the Canadian and American heartland. Comprising 18 percent of the world's fresh surface water, they provide drinking water for 28 million Canadians and Americans; process water for power production facilities at a rate of 4.2 billion cubic meters per year; offer a habitat to support a multi-billion dollar recreational and commercial fishing industry; and supply irrigation water for agriculture and other uses (Environment Canada & GLNPO, 2002). Ecologically, the lakes' sand dunes, coastal wetlands, islands, rocky shorelines, prairies, savannas, forests, fens, and other landscape features are globally unique, supporting a rich and diverse variety of species. In particular, the lake's waterways, wetlands, and islands sustain over 180 species of indigenous fish and provide habitat for many species, including 131 globally imperiled or rare species (Environment Canada & GLNPO, 2002; The Nature Conservancy, 1994). Their value as a source of inspiration, education, and aesthetic beauty adds further immeasurable benefits to the tally.

Economic and ecological services are equally dependent upon the health of the Great Lakes. Pollution of any type can interfere with these beneficial uses, and the cost of mitigating that interference is often high. Moreover, even uses of the lakes we have come to take for granted, such as for drinking water or recreation, are vulnerable to pollution. This prospect fuels energetic interest in protecting the Great Lakes ecosystem from chemical, physical, and biological pollution.

The Great Lakes/St. Lawrence Seaway and Biological Pollution

Spanning 1,200 kilometers with a combined shoreline in excess of 16,000 kilometers, the Great Lakes have been a corridor for commercial transportation since the times of Native American and French traders. The lakes became an avenue for overseas shipping much more recently, in 1959, with the opening of the St. Lawrence Seaway. The Seaway circumvents natural barriers to navigation, such as Niagara Falls and rapids along the St. Lawrence River, through artificial waterways and locks. Over 3,700 kilometers in length, the Great Lakes-St. Lawrence Seaway system (GLSLSS) penetrates Quebec, and borders the eight U.S. Great Lakes states and the Canadian province of Ontario. Transoceanic waterborne trade through the system now connects ports in the region to others around the globe. Over time, the system has become well integrated with the rail and highway systems of the region, such that the major rail and highway hubs of the mid-continent are also major GLSLSS ports.

In total, the Great Lakes waterborne transportation system directly employs more than 44,000 people and provides $6 billion each year to the U.S. and Canadian economies (Martin Associates, 2001). Of the goods traded on and through the GLSLSS, overseas tonnage is diminutive relative to the tonnage traded domestically and between the United States and Canada. Still, it accounts for a disproportionately higher share of this employment and revenue impact (figs. 1-3). Of the approximately 220 million metric tons of cargo that move into, out of, and around the lakes each year, less than five percent is transoceanic trade. However, in 2000, steel imports (an effective surrogate for total overseas trade) represented approximately 2.6 percent of the cargo tonnage shipped on the GLSLSS, but accounted for 12.3 percent of the jobs and 23.2 percent of the revenue generated by the system (Martin Associates, 2001).

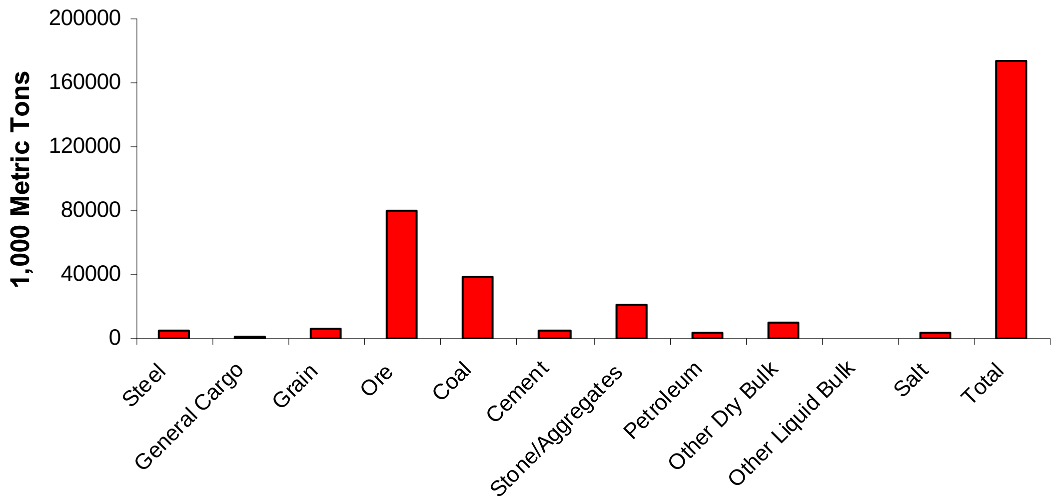


Fig. 1. Cargo tonnage transported on the Great Lakes-St. Lawrence Seaway system in 2000 (source: Martin Associates 2001)

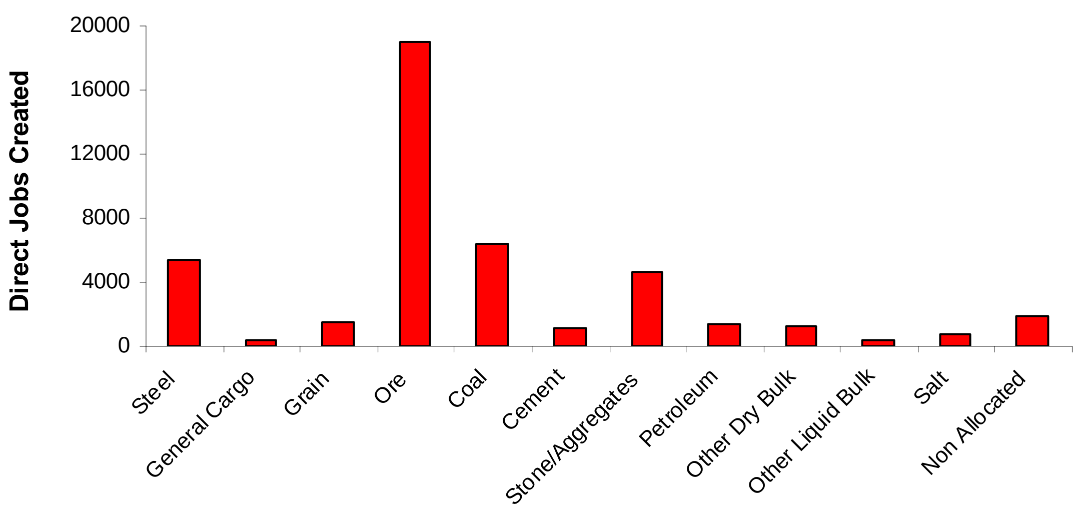


Fig. 2. Direct jobs created by major commodities transported on the Great Lakes-St. Lawrence Seaway system in 2000 (source: Martin Associates 2001)

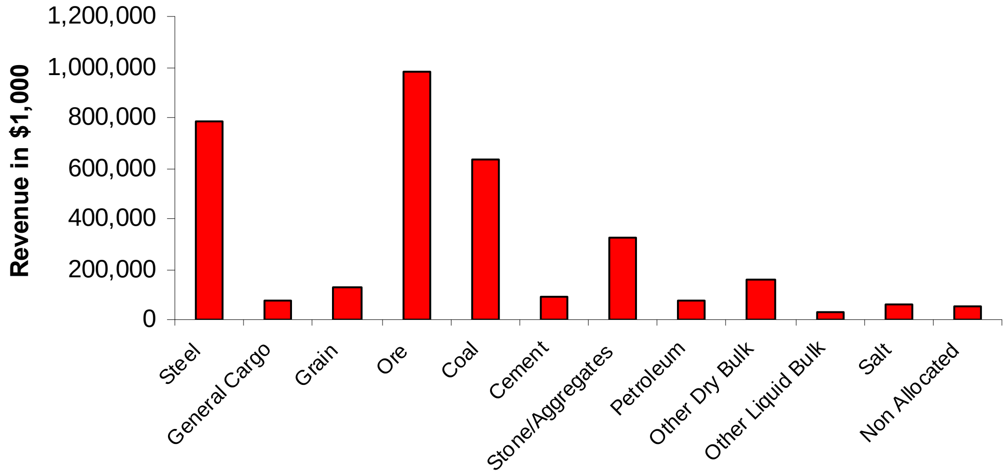


Fig. 3. Revenue impacts generated by major commodities transported on the Great Lakes-St. Lawrence Seaway system in 2000 (source: Martin Associates 2001)

In promoting its value to the region, the Great Lakes maritime industry also points to environmental advantages of waterborne transportation generally—such as lower air-pollutant emissions—relative to other modes (Great Lakes Regional Waterways Management Forum, 2002). In a period of less than one week, a ship can move the entire distance of the GLSLSS and carry a load of cargo equivalent to 870 trucks or 225 rail cars with a minimum of handling (St. Lawrence Seaway Development Corporation, 2004).

Unfortunately, an indirect cost of transoceanic waterborne shipping—related to introductions of alien aquatic organisms or biological pollution—seriously diminishes the net benefit of these cost and environmental advantages, and is eroding public support in the Great Lakes region for maritime trade. The GLSLSS circumvented natural barriers to navigation by ships, and in so doing opened the door to the movement of aquatic organisms into the otherwise isolated Great Lakes. Prior to the opening of the Seaway, commercial shipping was an uncommon vector, accounting for one introduction in each of the 1940s and 1950s (Mills *et al*., 1993). Following Seaway completion, the ballast water discharged by commercial transoceanic ships has been responsible for at least six introductions per decade (Mills *et al*., 1993), accounting for roughly 30 of the 43 established non-native aquatic species appearing in the Great Lakes since 1959 (Grigorovich *et al*., 2003a). Over 160 nonindigenous aquatic species are established in the Great Lakes. The majority of these species are native to Europe and Eurasia, particularly the Ponto-Caspian region—the geographic region of our greatest transoceanic trading partners (Mills *et al*., 1993; Ricciardi, 2001).

While organisms may be transferred by many ship components (including hulls, sea chests, and anchor chains) by far the most studied ship-mediated vector is ballast water. Numerous studies (e.g., Williams *et al*., 1988; Hallegraeff & Bolch, 1992; Carlton & Geller, 1993; McCarthy & Khambaty, 1994; Smith *et al*., 1996; Galil & Hulsmann, 1997; Pierce *et al*., 1997; Johengen *et al*., 2005) have documented the presence of aquatic organisms in ballast water and the invasion risk that such organisms present. Grigorovich *et al*. (2003a) went one step further and performed a predictive analysis for likely invaders to the Great Lakes via ballast water transport, based on donor regions, invasion histories, salinity and climate tolerances, availability for ballast uptake, and survivability in ballast tanks. This analysis determined that 16 species not yet reported in the lakes pose a high risk of invasion. An additional 31 species not yet reported in the Great Lakes pose a lower risk of invasion (Grigorovich *et al*., 2003a).

From a strictly economic standpoint, many nonindigenous species introductions to the Great Lakes and other ecosystems are considered either benign or even beneficial; these nonproblematic species introductions tend to be either planned importations that are amenable to human cultivation and control, or incidentally introduced with little propensity to spread. In contrast, invasive species—those nonindigenous species that, once introduced, proliferate beyond human purposes or control—incur costs. Sea lampreys, for example, have caused millions of dollars in damage to Great Lakes fisheries and cost over $10 million to control every year (Meersman, 2004). In a five-year study period in the 1990s, the zebra mussel cost Great Lakes raw-water users alone over $20 million per year in added maintenance (Park & Hushak, 1999). Moreover, to the extent that invasive species transported to North America by ships trading in the Great Lakes can and do subsequently spread, the footprint and associated economic cost estimates ultimately far exceed those associated with the basin. For example, the zebra mussel—transported throughout the Great Lakes in the ballast water of both overseas and domestic ships and to inland waterways via recreational vessels—now plagues two-thirds of the nation, and has an estimated overall price tag of $3.1 billion (GAO, 2002; fig. 4).

The negative environmental implications are far worse. All nonindigenous species that become established permanently alter the food web of the receiving system, and many have disastrous effects. Negative ecological effects of aquatic invaders of the Great Lakes system range from the highly visible, such as habitat destruction, to the insidious, such as the degradation of nutritional value in the forage base for predatory fish. Sea lampreys decimate lake trout populations. Round gobies compete with native fish species for food and habitat, displacing them from prime spawning sites. Zebra mussels profoundly alter trophic dynamics due to their rapid growth and tremendous filter-feeding. Today, invasive species are considered second only to habitat destruction in reducing biological diversity globally (Vitousek *et al*., 1997).

The seriousness of the problem has prompted international, federal, and state initiatives to better manage ship-mediated species invasions. In the Great Lakes region alone, in the past several years six of the eight U.S. states—Illinois, Indiana, Michigan, Minnesota, New York, and Wisconsin—have introduced, and in one case enacted, legislation concerning the discharge of ballast water.[1] Wisconsin Gov. Jim Doyle, the incoming chairman of the Council of Great Lakes Governors, indicated that solving the problem of ship-mediated invasive species would be one of his top priorities (Wisconsin Office of the Governor, 2004). A group of attorneys general from the Great Lakes region has submitted a legal petition to the U.S. Coast Guard demanding better enforcement of federal law to protect the lakes. The International Joint Commission has joined with The Nature Conservancy to fund a study of economic consequences of terminating saltwater trade to the Great Lakes.

[1] Michigan passed Public Act 114 of 2001. Throughout the Great Lakes states, ballast water regulatory bills have been introduced, but failed to pass, in Minnesota during 2001, in Illinois and Wisconsin during 2002, in New York during 2003, and in Indiana during 2004.

As the Great Lakes maritime industry seeks to sustain and increase cargo volumes from shippers and infrastructure investment from governments, biological pollution is viewed as its Achilles' heel, undermining crucial public and political support. This concern has inspired strong interest on the part of the industry itself to resolve the problem, and a special opportunity for constructive action.

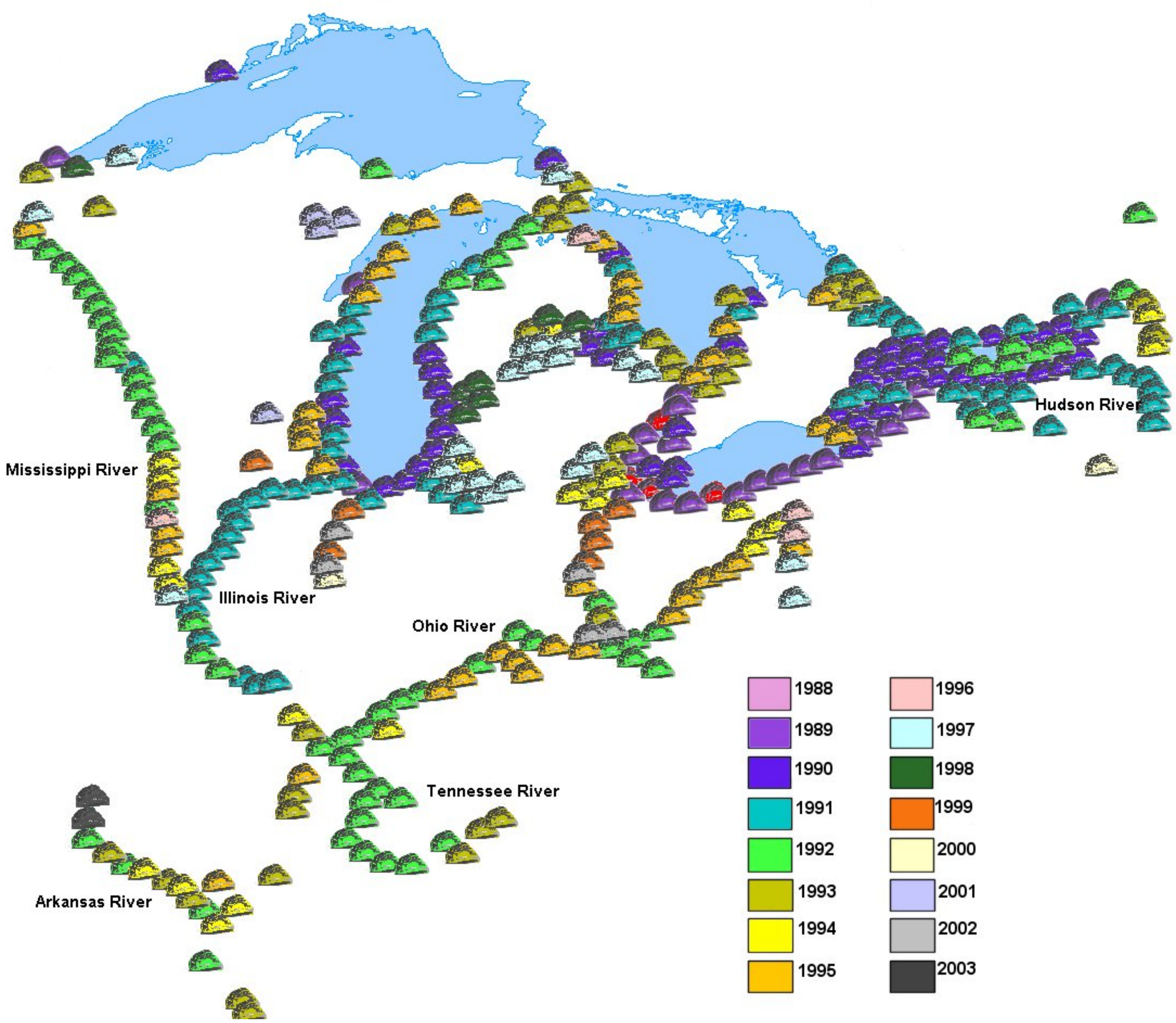


Fig. 4. Zebra mussel range expansion by year since first sighting in Lake St. Clair and Lake Erie in 1988 (source: USGS, 2004)

The Great Lakes Biological Pollution Prevention Project

A coalition of organizations (the Northeast-Midwest Institute, the Delta Institute, the National Wildlife Federation, and Kestrel Management Services) launched a project supported by the Great Lakes Protection Fund to stimulate a decisive effort by the public and private direct users of the waterborne transportation system in the GLSLSS to prevent further ship-mediated invasive species introductions in the Great Lakes. Called the Great Lakes Biological Pollution

Prevention Project, the project argued that users of the GLSLSS would benefit from getting ahead of the problem and solving it in the ways they consider best. This goal could be accomplished through implementing an Environmental Management System (EMS) specifically addressing the ship-mediated invasive organisms.

The goal of an EMS is to work with all the moving pieces of an industrial—or in this case, transportation—process, to influence financial flows toward a desired environmental protection outcome. If done well, the EMS will also in the end contribute to the economic footprint of the process. In this case, the EMS, termed the "Great Ships Initiative" (GSI), would take a collective approach, potentially involving ports, carriers, and cargo owners throughout the GLSLSS to eliminate the further introduction of aquatic invasive species by commercial vessels in the Great Lakes.

Purpose of the Scoping Report

This scoping report provides a fact base, rationale, and preliminary implementation plan for a GSI, a collective industry-led response to address the problem of ship-mediated introductions of aquatic invasive species in the Great Lakes. The primary sponsor of a GSI should be the maritime industry sector specifically involved in GLSLSS transoceanic trade that mediates the initial introductions of invasive organisms into the Great Lakes. First, the report describes in some detail many facets of transoceanic trade on the GLSLSS, including physical features, i.e., ports, fleets, and cargoes; the fiduciary players and financial flows, including the supply chain and transportation transaction chain, i.e., the terminal owners, stevedores, and freight forwarders; and the regulatory chain. It then describes drivers and other contextual conditions that influence the nature and extent of transoceanic waterborne transportation in the GLSLSS, i.e., global trade trends and competitors. Together these physical and financial entities comprise the moving pieces of transoceanic maritime commerce on the GLSLSS, which in response to prevailing external influences create both its economic and environmental footprint. Though moving pieces associated with the Salty trade receive the greatest emphasis in this section, information on the moving pieces exclusively associated with the domestic trades—a ready mechanism for subsequent spread of organisms once they are introduced to the system—appears in the scoping report's appendices.

Second, the report details the ship-mediated biological pollution problem, the state-of-the-art of prevention methodology, and policy options for the Great Lakes region. Third, it describes relevant EMS models and makes recommendations regarding a systemwide, industry-sponsored response to the invasive species problem—the GSI. This section also projects the economic effects and environmental impact of a GSI. The report's concluding section charts a series of next steps for making the GSI a reality, and makes caveats for assuring effectiveness of the effort.

II. Great Lakes Maritime Commerce: Moving Pieces … and What Moves Them

The physical features of the GLSLSS—locks, vessels, ports, and cargoes—are fairly familiar to residents of the Great Lakes region. Less apparent but equally important to transoceanic shipping are the intangible features of the GLSLSS, specifically, the fiduciary entities and financial flows that constitute transaction chains, and the constellation of regulations that govern commercial vessel movements and operation. Transaction chains include the supply chains, comprising cargo producers, bulk users (manufacturers and refiners), and consumers; and the transportation services chains, comprising stevedores, terminal owners, shipowners, and charterers. The regulatory pieces comprise port states, flag states, classification societies, international groups, and regional and subregional agencies. These moving pieces respond to each other, as well as external drivers and conditions such as prevailing regional and international economic trends, global trade rules and patterns, and new regulatory regimes. The outcome is the nature and extent of transoceanic waterborne transportation on the GLSLSS and its environmental footprint.

The first step to developing an EMS for the transoceanic maritime industry *vis-a-vis* invasive species is to fully understand these moving pieces, both tangible and intangible, and the drivers and conditions that influence them.

Physical Pieces

The visible, physical features of the GLSLSS transoceanic trade include the natural waterway, locks, and connecting channels; port facilities; vessels; and cargoes.

Natural Waterway

The GLSLSS—comprising Lakes Superior, Michigan, Huron, Erie, and Ontario, as well as connecting channels, the St. Lawrence River, and Gulf of St. Lawrence—spans more than 3,700 kilometers from east to west. The lakes alone contain approximately 23,000 cubic kilometers of water, and cover an area of 244,000 square kilometers (Environment Canada & GLNPO, 2002).

With an average depth approaching 150 meters, Lake Superior is by far the largest lake of the GLSLSS, containing almost 7,800 cubic kilometers of water. It stretches 560 kilometers from east to west, and 257 kilometers north to south. The second-largest lake of the GLSLSS by volume, Lake Michigan, holds just over 3,000 cubic kilometers of water, and is approximately 190 kilometers wide and 495 kilometers long. Averaging 85 meters in depth, the lake reaches 281 meters at its deepest point. The third-largest lake by volume, Lake Huron, contains 2,200 cubic kilometers of water, has an average depth of 59 meters, and measures 331 kilometers across and 294 kilometers north to south. Lake Erie, the smallest of the five lakes in volume (308 cubic kilometers), measures 388 kilometers across and 92 kilometers from north to south, and has an average depth of only 19 meters. Lake Ontario is similar to Lake Erie in length and breadth (310 kilometers by 85 kilometers), but its greater average depth (approximately 86 meters) holds almost four times the volume (1,020 cubic kilometers).

The natural channels that connect the Great Lakes are as important to the GLSLSS as the lakes themselves. The northernmost channel, the St. Mary's River, is a 154-kilometer waterway flowing from Lake Superior down to Lake Huron. The wide Straits of Mackinac join lakes Michigan and Huron. The St. Clair and Detroit rivers, and Lake St. Clair between them, form a 143-kilometer-long channel connecting Lake Huron with Lake Erie. The 56-kilometer Niagara River, including Niagara Falls, links lakes Erie and Ontario. From Lake Ontario, the water from the GLSLSS flows through the St. Lawrence River, emptying into the Atlantic Ocean at the Gulf of St. Lawrence—a distance of 1,600 kilometers.

Locks and Connecting Channels

In addition to natural connecting channels, the GLSLSS comprises a series of manmade locks and channels that allow vessels to travel between the Atlantic Ocean and ports throughout each of the Great Lakes. The dimensions of these locks and connecting waterways determine the size of vessels that can ply the St. Lawrence Seaway. Each lock in the GLSLSS is 233 meters long, just over 24 meters wide, and nine meters deep. The locks can accommodate vessels that are 225 meters long and 24 meters wide, with a draft of eight meters.

Today's system developed over time, and is a combination of individual systems sometimes created independently of each other. It currently has four major components (fig. 5):

Artificial Connecting Waterways: The first artificial waterway, the Lachine Canal, was constructed between 1821 and 1825 to bypass the Lachine Rapids of the St. Lawrence. The canal became obsolete in 1959, being replaced by the South Shore Canal of the St. Lawrence Seaway and was finally closed in 1969.

The oldest artificial waterway still in use in the GLSLSS is the Welland Canal, which navigationally connects Lake Ontario to Lake Erie. A major engineering feat of its time, the Welland Canal began as a private commercial venture in 1829. The Canadian provincial government purchased it in 1841, upgrading it a number of times throughout the remainder of the 19th century and early 20th century. Construction on the current version—a series of eight locks—was completed in 1932. The canal was deepened in the 1950s, and then further straightened in 1973. Since 1998, the canal has been managed by the St. Lawrence Seaway Management Corporation on behalf of the Canadian federal government.

In addition, the GLSLSS includes smaller connections with areas outside the Great Lakes basin. The Chicago Sanitary and Ship Canal/Illinois Waterway provides a connection between Lake Michigan and the Mississippi River. The Waterway consists of eight single chamber lock and dam projects, and allows for shallow draft navigation between the two regions. The New York State Canal System includes the Erie Canal which connects Lake Erie (at Buffalo) to the tidal Hudson River (at Albany). The channel depth in this canal system averages around four meters, and its locks can accommodate vessels up to 91 meters long and 13 meters wide. An additional component of this New York State Canal System connects the Erie Canal to Lake Champlain and the St. Lawrence River.

The Soo Locks: The Soo Locks allow vessel transit between Lake Huron and Lake Superior. This lock system was initiated in 1852 when the U.S. Congress passed an act to subsidize the construction of a canal connecting Lakes Huron and Superior. The canal was turned over to the State of Michigan in 1855, and then transferred back to the federal government in 1881, which placed it under the jurisdiction of the U.S. Army Corps of Engineers. Since this time, the U.S. federal government has periodically upgraded the connector, with the construction of four parallel locks between 1943 and 1968 creating the current Soo Locks system.

The St. Lawrence Seaway: The St. Lawrence Seaway between Montreal and Lake Ontario also represented a mammoth, joint Canadian and U.S. federal government effort. Constructed in the 1950s, it took five years and an army of 22,000 workers to connect the Great Lakes to the Atlantic Ocean via this intricately linked system of two U.S. and five Canadian locks, channels, canals, dams, dikes and several associated hydroelectric dams. The total project's overall construction cost was $1 billion, equal to roughly $6.85 billion in 2006 dollars. Following completion of the Seaway in 1959, ocean-going vessels were able to travel from the Atlantic all the way to ports on Lake Superior.

Connecting Channels: Naturally occurring connecting channels also enable passage from one part of the Great Lakes system to another. These channels are dredged at times to accommodate the shipping. The St. Mary's River connects Lake Superior and Lake Huron. Within this connecting channel are the Soo locks, which allow vessels to bypass the St. Mary's Falls. The channel depth of the St. Mary's River is between eight and nine meters. In recent years, between $16 million and $19 million in operation and maintenance funding has been appropriated annually to the U.S. Army Corps of Engineers for the St. Mary's River.

The St. Clair River-Lake St. Clair-Detroit River system connects Lakes Huron and Erie. The channel depth in the St. Clair River is between eight and nine meters. Lake St. Clair has a relatively shallow average depth of three meters. As a result, the navigation channel in Lake St. Clair is dredged to 8.4 meters. The channel depth in the Detroit River is between 8.4 and 9.0 meters. Operation and maintenance funding in recent years has varied between $694,000 and $1.6 million for the St. Clair River, $3.5 million and $4.3 million for the Detroit River, and $97,000 and $466,000 for channels in Lake St. Clair.

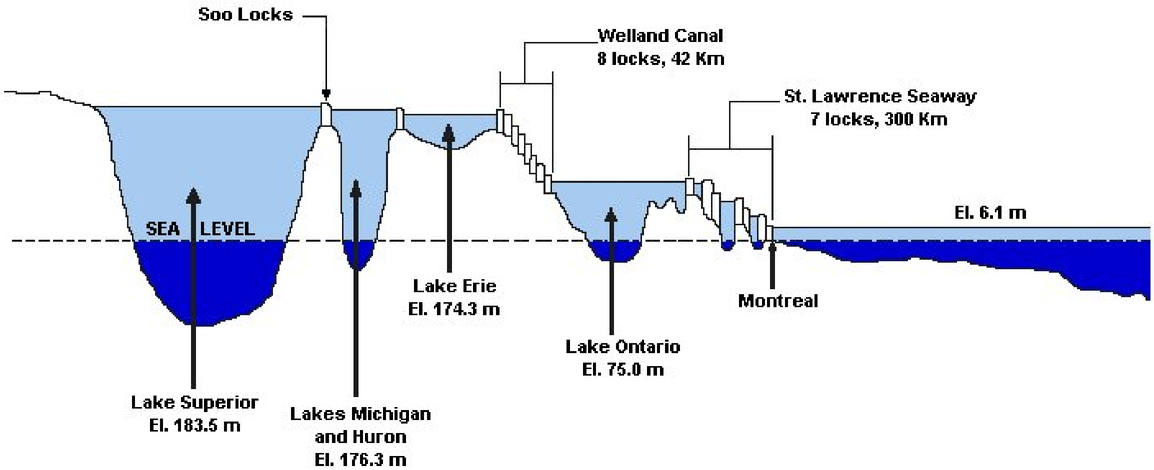


Fig. 5. Great Lakes-St. Lawrence Seaway system profile, including the Soo Locks, Welland Canal, and St. Lawrence Seaway locks (source: St. Lawrence Seaway Development Authority)

Since 1959, the GLSLSS has remained relatively unchanged. While some maintenance dredging does occur, it is currently minimal. Some, believing that the region's economic well-being is directly tied to the amount of shipping through the Seaway, have periodically proposed—for example, in the Great Lakes-St. Lawrence Seaway Study (box 1)— further improvement of the system's infrastructure or maintenance to allow larger vessels including container ships and/or a longer navigation season. However, environmental advocates and other resource users raise concerns about the impacts and cost of such changes. Besides the likelihood of introducing more aquatic invasive species to the lakes, enlarging the system may also increase water flow out of the lakes, worsening the problems of lower lake levels seen in recent years.

Port Facilities

Port facilities and the network of development and industrial capacity that has grown around them embody significant capital investment by industry, Great Lakes states and provinces, and the U.S. and Canadian federal governments. Though they are relatively expensive to modify, ports are also moving pieces of the Great Lakes maritime system. The number of ports in the region has diminished through a process of port rationalization and consolidation. This process, retarded at times by local political pressures to maintain operations at some marginal ports, would likely accelerate if economic forces were given free rein. There continues to be new investment in some of the major public port infrastructure, and the two federal governments continue to invest in the port system by dredging channels (including channels to private ports). Currently, there are 65 commercial ports in the Great Lakes. Of these, 12 are major ports in the United States (Burns Harbor, Chicago, Cleveland, Detroit, Duluth, Erie, Green Bay, Milwaukee, Monroe, Oswego, Superior, and Toledo), and five are major Canadian ports (Hamilton, Oshawa, Thunder Bay, Toronto, and Windsor) (fig. 6).

Port facilities can be large and generalized to a range of cargoes or small and specialized to a specific cargo or even a specific carrier. Port infrastructure varies depending on the types of cargoes they process and their roles as destination- and/or transit-ports. A port is considered a destination port if the shippers/receivers of the majority of cargoes are located within a 75-mile radius. In the Great Lakes region, ports that receive steel and steel products from overseas for steel making, refinement, and manufacturing—including Burns Harbor, Cleveland, and Detroit—tend to be destination ports. Infrastructure at these ports, in a sense, includes the nearby manufacturing facilities that process the cargoes. Major rail connectors near these port facilities are designed to transport the production output of manufacturing facilities to consumers.

The port infrastructure is made up of one or more docks. A dock typically consists of the following elements: 1) a navigation channel dredged to provide underwater clearance for ships to reach land; 2) a defined seawall separating land and water; 3) landside improvements such as outdoor or indoor cargo storage areas; 4) cargo handling equipment such as cranes, forklifts, conveyors, etc.

Ports are considered transit ports when the shippers/receivers of most of the goods passing through are outside a 75-mile radius. Transit ports mark the beginning or end of only one leg of a journey for cargoes. Other significant legs of the cargoes' journey may involve rail, truck or other vessel transit. In the Great Lakes, transit ports are associated with grain movement. For example, Duluth, Milwaukee, and Toledo are transit ports that transfer grain from trains from the heartland to waterborne vessels for transportation abroad. These ports are identifiable by their numerous grain elevators and railway connections to move cargoes to these facilities.

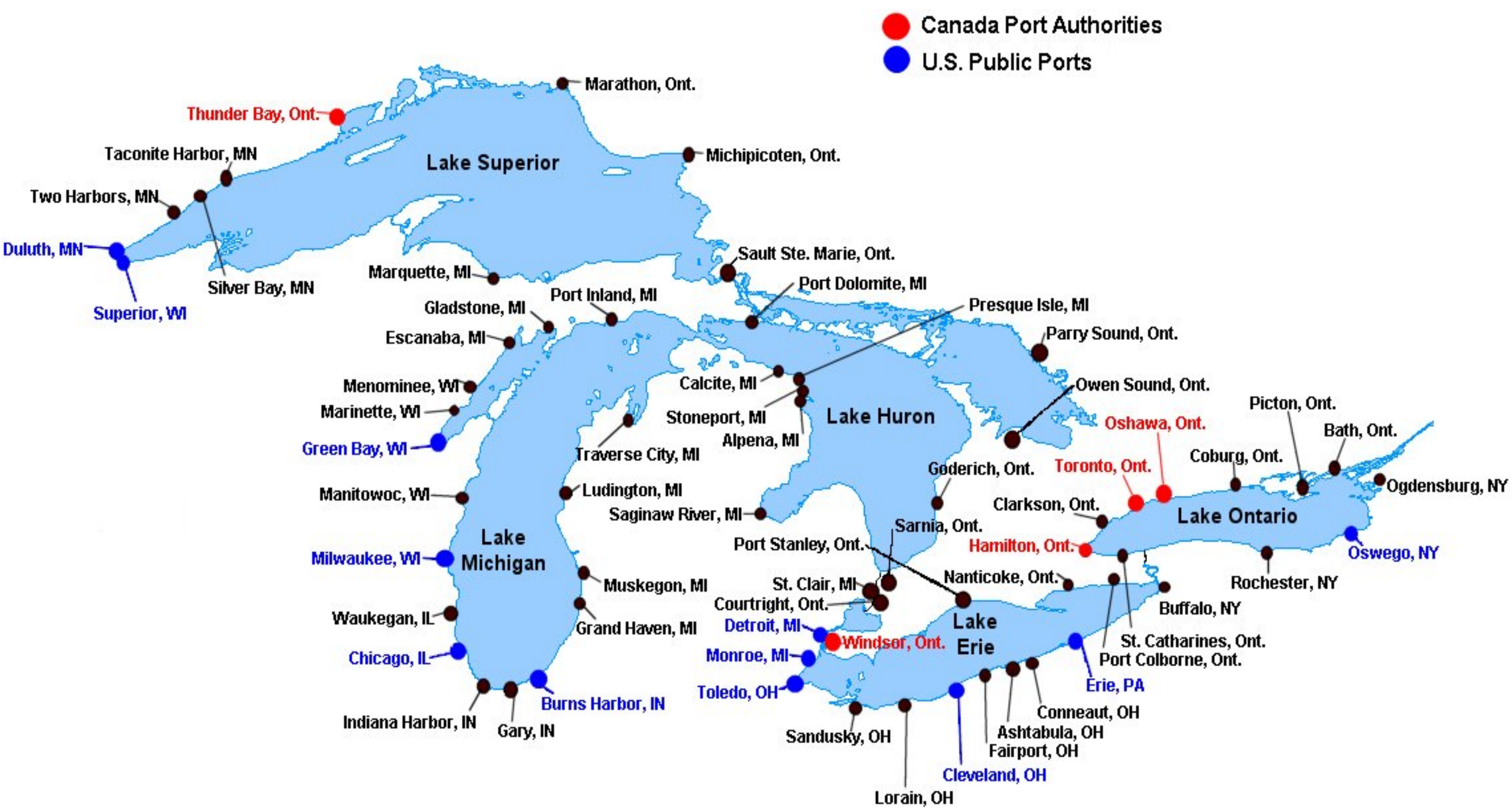


Fig. 6. Map of commercial ports in the Great Lakes, including Canada Port Authorities and U.S. public ports

Box 1: The Great Lakes-St. Lawrence Seaway

Since 1959, the Great Lakes-St. Lawrence Seaway (GLSLS) system has enabled ocean-going vessels access to ports in the Great Lakes—some over 2,163 kilometers from the system's Atlantic Ocean entrance. Though the GLSLS opened in an era dominated by smaller "break bulk" freighters, the design limitations of the system (it can accommodate vessels up to 225 meters long and 24 meters wide) restrict many vessels from using the system. Classes of ships unable to use the system include the larger container ships that now dominate the shipping industry.

Citing the age, size limitations, and cost of maintaining the GLSLS system, maritime interests have periodically proposed further improvement of the system infrastructure or maintenance to allow larger vessels, including container ships, and/or a longer navigation season. For example, in May 2003 the U.S. and Canadian governments announced the joint Great Lakes-St. Lawrence Seaway Study to assess the ongoing maintenance and capital requirements to sustain and optimize the GLSLS system and the marine transportation infrastructure on which it depends.

The memorandum of cooperation signed by the two countries listed the following study objectives:

- Identify factors and trends affecting the domestic and international marine transportation industries.
- Assess current and future transportation requirements for the waterway.
- Evaluate the reliability and condition of the waterway, including the costs and benefits of maintaining the existing infrastructure.
- Assess the environmental, engineering, and economic factors associated with the current and future needs of the GLSLS system and its transportation infrastructure.

Transport Canada and the U.S. Department of Transportation are leading the study, which is examining maintenance rather than major infrastructure modifications, including the expansion of the system. The study steering committee includes the U.S. Army Corps of Engineers, St. Lawrence Seaway Management Corporation, Saint Lawrence Seaway Development Corporation, Environment Canada, and U.S. Fish and Wildlife Service. According to Wayne Schloop, the former project manager for the study on the U.S. side (U.S. Army Corps of Engineers), the project schedule calls for a report to be completed by the fall of 2006. He expects a public review period to follow.

The GLSLS study follows an 18-month U.S. Army Corps of Engineers effort called the Great Lakes Navigation System Review. This analysis considered the economic cost and environmental impacts of modifications to the system, with a focus on increasing the depths of the locks and channels. Much of this work was completed and made public in June 2002. A final report was not completed, however, and so there were only overall findings or recommendations. It was decided that the binational GLSLS study was the appropriate next step.

In addition, some transit ports in the GLSLSS specialize in transshipment, i.e., the transfer of goods from one waterborne carrier to another, or to another mode of transportation. Transshipment ports are equipped with specialized, large storage facilities that are designed to receive goods from one size or type of vessel and load another. All of the GLSLSS transshipment ports are located along the St. Lawrence River, including Quebec City and Montreal. Cargoes from the U.S. and Canadian agricultural and industrial heartland arrive from western GLSLSS ports to these transit ports in Seaway-sized vessels, where they are off-loaded, combined with other shipments, and then loaded into much larger ocean-going bulk cargo and container ships for overseas shipment. Typically, the Seaway-sized vessels then load iron ore for transport back to Great Lakes ports. From overseas, larger vessels carry containerized and general cargo to ports along the St. Lawrence, which is subsequently transshipped to road and rail. The Port of Montreal is a major center for transshipment of containerized cargo to rail, as the port has excellent rail links to central Canada and the American Midwest. The Port of Quebec transshipped 5 million–6 million metric tons of cargo per year in 2001 and 2002. Smaller St. Lawrence ports, such as Baie-Comeau, Sept-Isles, and Trois-Rivieres, transship grain from Seaway-sized ships to larger ocean-going bulk carriers.

Compared with other major freshwater port systems worldwide, the ports of the GLSLSS are situated far from open water (box 2). For example, the Port of Duluth, Minnesota, in Lake Superior is 2,163 kilometers from the Atlantic Ocean; the Port of Chicago, Illinois, in Lake Michigan is 2,013 kilometers from the Atlantic Ocean; and the Port of Toronto, Ontario in Lake Ontario is 563 kilometers from the Atlantic Ocean. In contrast, the world's busiest freshwater port, the Port of Philadelphia in Pennsylvania, is situated a mere 164 kilometers from open water.

Box 2: Comparison of Major Freshwater Port Systems with Transoceanic Shipping

Country	State/Province	Port	Distance from Coast/Sea
United States	Minnesota	Duluth	2,163 km
United States	Illinois	Chicago	2,013 km
United States	Michigan	Detroit	995 km
United States	Ohio	Cleveland	859 km
Canada	Ontario	Toronto	562 km
United States	Pennsylvania	Philadelphia	164 km
United States	Oregon	Portland	126 km
China	Jiangsu	Nanjing	270 km
Spain	Andalusia	Seville	80 km
Belgium	Flanders	Belgium	60 km
Germany	Bremen	Bremen	60 km

Vessels

There are four types of vessel fleets involved in the movement of cargo throughout the GLSLSS, which vary significantly in appearance, specialization, and trade pattern (table 1). Briefly summarized, they include the following:

U.S.-flagged domestic vessels ("Lakers") comprise approximately 60 vessels, the vast majority of which are bulk freighters. Lakers are by far the largest vessels on the Great Lakes, with some vessels over 300 meters in length. Their size prevents them from transiting the Welland Canal, and so they trade exclusively in the upper four Great Lakes. Lakers move cargo to serve three primary markets: iron ore and coal for domestic steel production, coal for electric utilities and power companies, and limestone for cement manufacturers. The primary trade pattern for laker vessels is to carry iron ore and coal from northern Michigan and Minnesota south to the major industrial cities. Vessels tend to return north in ballast, although some backhaul of stone does occur.

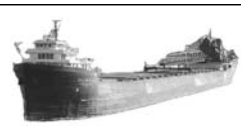
U.S.-flagged domestic barges comprise over 27,000 vessels nationally; but the number of barges that travel routes relevant to the Great Lakes total approximately 6,000 vessels due to U.S. Coast Guard regulations restricting the geographic scope of inland barge traffic. These vessels, which enter the GLSLSS from the Illinois River at Chicago are prohibited from traveling northward beyond Milwaukee, WI and east beyond Muskegon, MI. A typical barge operating on the Mississippi and Illinois River systems measures 59 meters long and can carry just over 1,300 metric tons of cargo. The barges transport many of the same bulk commodities carried by the larger laker and Salty fleets, including grain, petroleum products, chemicals, and coal. In general, grain is shipped from ports along the Upper Mississippi River and Illinois Waterway south to Gulf of Mexico ports for shipment overseas. Other commodities such as chemicals and iron and steel products tend to be transported upriver on the Mississippi and Illinois Waterway.

Canadian-flagged domestic vessels ("Canadian lakers") comprise approximately 80 vessels, most of which are self-unloading bulk carriers. Because the vessels are much smaller than U.S-flagged lakers, they are able to visit ports throughout each of the five Great Lakes, and in some cases, Canadian ports outside the GLSLSS. In general, cargoes the Canadian lakers carry are similar to those carried by the U.S. domestic fleet, with coal, iron ore, and limestone, accounting for nearly two-thirds of the cargo carried. Other cargoes carried include tanker products, grain, salt, miscellaneous bulk, and cement. The primary pattern for Canadian lakers is to transport grain from Thunder Bay and Duluth-Superior to ports along the St. Lawrence River.

Seaway-sized transoceanic vessels ("Salties") comprise approximately 220 vessels flagged in more than 30 countries. The vast majority of vessels are bulk carriers, though there are also a small number of general cargo carriers, heavy lift ships and tankers in service. With the exception of barges, Salties are by far the smallest vessels operating on the lakes, with most vessels approximately 180 meters long. This smaller size enables them to enter the lakes from overseas, transit the St. Lawrence Seaway, Welland Canal, and all five Great Lakes. Salties generally follow a "steel in - grain out" trade pattern, whereby iron and steel, and other high value cargoes generally arrive from Europe, and are discharged in a series of lower lake ports.

Vessels then travel in full ballast to pick up grain for their outgoing voyage, primarily from Duluth-Superior and Thunder Bay.

Table 1. Comparison of the U.S.-, Canadian-, and overseas-flagged fleets currently operating on the Great Lakes-St. Lawrence Seaway system

	U.S.-flagged lakers	U.S.-flagged barges	Canadian-flagged lakers	Overseas-flagged Salties
Number of vessels In fleet	60	~6,000	80	220
Length (average)	230 m	59 m	190 m	160 m
Beam (average)	24 m	10 m	21 m	21 m
Gross registered tonnage (average)	18,000 MT	1,360 MT	15,000 MT	14,000 MT
Ballast capacity (average)	30,000 m^3	--	15,000 m^3	10,000 m^3
Ballast pump rate	4,500 m^3/hour	--	1,000–2,000 m^3/hour	1,000–2,000 m^3/hour
Primary cargos	Iron ore, coal, limestone	Grain, oilseeds, petroleum products, chemicals	Iron ore, coal, limestone	Steel products, grain
Trade pattern	Upper four Great Lakes	Mississippi River, Illinois Waterway, Intracoastal waterway	Great Lakes, St. Lawrence River, eastern coast of Canada	Great Lakes, St. Lawrence Seaway, overseas
Representative vessel				

The GLSLSS's transoceanic trade is the primary vector for non-native species introductions into the Great Lakes, and is therefore the primary focus of this report. Canadian and U.S. domestic fleets that operate exclusively within waters of the GLSLSS are considered insular and therefore a ready secondary vector for species spread about the GLSLSS. These fleets are described in Appendix A of this report.

Size and Types

The dimensions of the St. Lawrence Seaway locks are 225 meters in length and just over 24 meters in breadth. Seaway-sized transoceanic ships are therefore small in comparison with other ocean-going vessels (table 2). On average, Seaway-sized bulk carriers are 180 meters long and 23 meters wide, and are classed within the Handymax class of bulk carriers. In contrast, a Panamax bulk carrier measures 225 meters long and 32 meters wide, while a Capesize bulk carrier measures 288 meters long and 45 meters wide. Typical container ships measure over 240 meters in length and 32 meters in width. Car and container vessels, though smaller in length than most bulk carriers and tankers, are disproportionately wider compared to both these vessel types.

Seaway-sized transoceanic vessels are also small in comparison with the Canadian and U.S. laker fleets (fig. 7). Of the three fleets, U.S. lakers are by far the largest vessels on the Great Lakes, with some vessels over 300 meters in length. Their size prevents them from transiting the Welland Canal, such that they trade exclusively in the upper four Great Lakes. Canadian lakers, though smaller than U.S-flagged lakers, are still larger than the transoceanic vessels, and therefore are able to visit ports throughout each of the five Great Lakes, and in some cases, Canadian ports outside the Great Lakes system.

Table 2. Ocean-going vessels types relative to representative length, beam, and depth

Type of ocean-going vessel	Length (m)	Beam (m)	Depth (m)
Aframax tanker	246	43	20
Panamax tanker	228	32	19
Handymax tanker	165	25	13
Very large crude carrier	327	56	30
Container (1500 – 2000 TEU)	174	27	16
Container (2000 – 3000 TEU)	226	32	19
Container (3000 – 3500 TEU)	241	32	19
Container (3500 – 4000 TEU)	246	32	19
Container (4000 – 4500 TEU)	263	37	22
Capesize bulk carrier	288	45	24
Panamax bulk carrier	225	32	19
Handymax bulk carrier	182	32	16
Chemical tanker	149	23	13
Car/container carrier	180	32	23
LNG carrier	276	46	25

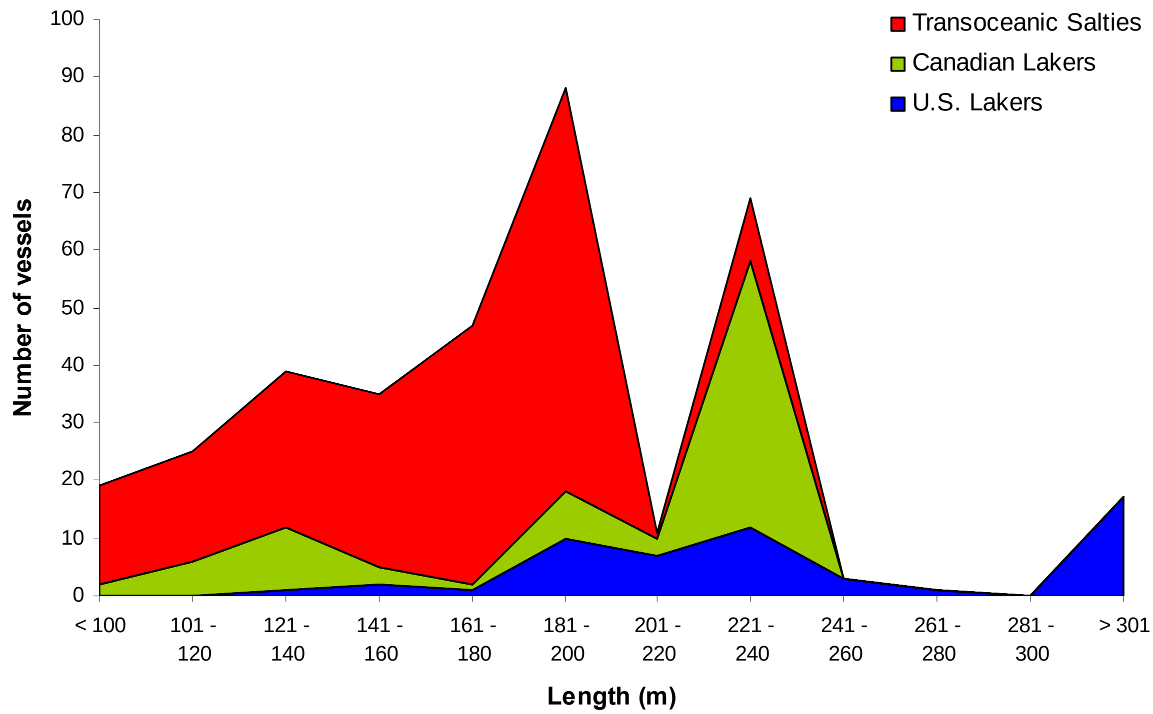


Fig. 7. Comparative vessel length of transoceanic Salty, Canadian laker, and U.S. laker fleets that operated on the Great Lakes-St. Lawrence Seaway System in 2002[2]

Numbers

Each year an average of 220 distinct transoceanic vessels visit the lakes. The vast majority of these vessels are bulk carriers, although there are a small number of general cargo carriers, heavy lift ships, and tankers in service (fig. 8). About 60 percent of these ships belong to a stable, core group of vessels that make regular runs into the lakes every shipping season. The rest are ships that visit the lakes in so-called tramp service, available to move cargo as the need arises, but not in dedicated service to the lakes. In fact, Seaway-sized vessels that visit the GLSLSS in a given year represent only a small percentage of the total pool of available vessels in service globally. A 2001 vessel fleet analysis conducted by Lloyd's Maritime Information Services of London for the St. Lawrence Seaway Development Corporation determined that 41,909 vessels, representing 69.7 percent of the world's fleet, are small enough to enter the St. Lawrence Seaway (ACOE, 2002a; table 3).

The smaller size and shallower draft of Seaway-sized vessels not only enables them to transit the St. Lawrence Seaway, Welland Canal, and all five Great Lakes, but also to access more port systems globally, especially those of developing countries. Examples of nondeep-

[2] Figure is based on an original analysis of vessels that transited the GLSLSS in 2002. Information was gathered from many sources including databases compiled by the U.S. Army Corps of Engineers Navigation Data Center (http://www.iwr.usace.army.mil/NDC/data/data1.htm), and classification society and individual ship owner/operator websites.

water and/or less developed ports that are open only to Seaway-sized ships elsewhere include certain ports in China and central and west Africa.

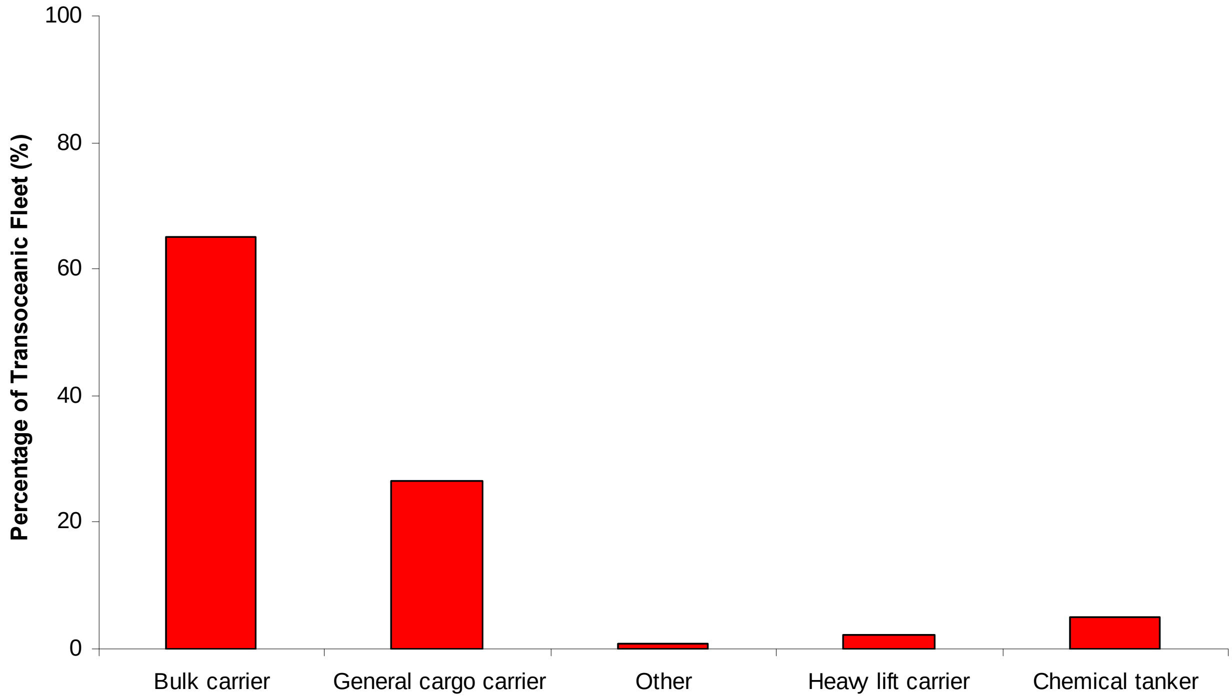


Fig. 8. Major types of transoceanic vessels that entered the Great Lakes-St. Lawrence Seaway system in 2002[2]

Table 3. World fleet currently capable of entering the Great Lakes-St. Lawrence Seaway system (source: ACOE, 2002a)

	No. of Vessels	% of World Fleet (no. of vessels)	Gross Tons	% of World Fleet (gross tons)
Bulk carrier	1,028	15.4	2,778,325	1.6
Container	663	21.8	3,596,327	4.7
Gas	722	60.7	1,793,053	7.6
General Cargo	12,048	81.2	26,506,134	44.6
Misc.	16,496	92.8	18,346,314	60.8
Passenger	3,405	83.5	9,762,675	32.8
Reefer	959	71.5	3,153,159	44.9
RoRo	1,093	60.5	5,796,004	19.4
Tanker	5,495	58.7	10,821,003	5.3
TOTAL	**41,909**	**69.7**	**82,549,994**	**12.9**

Useful Life

Because these Seaway-sized transoceanic vessels operate mostly in a saltwater environment, their useful service life is approximately 25 years—significantly shorter than U.S.- and Canadian-flagged lakers, which ply primarily within the freshwater system. Most of the transoceanic vessels currently entering the GLSLSS are at the end of their service life, though a recent spate of new builds have or will soon come on-line (fig. 9).

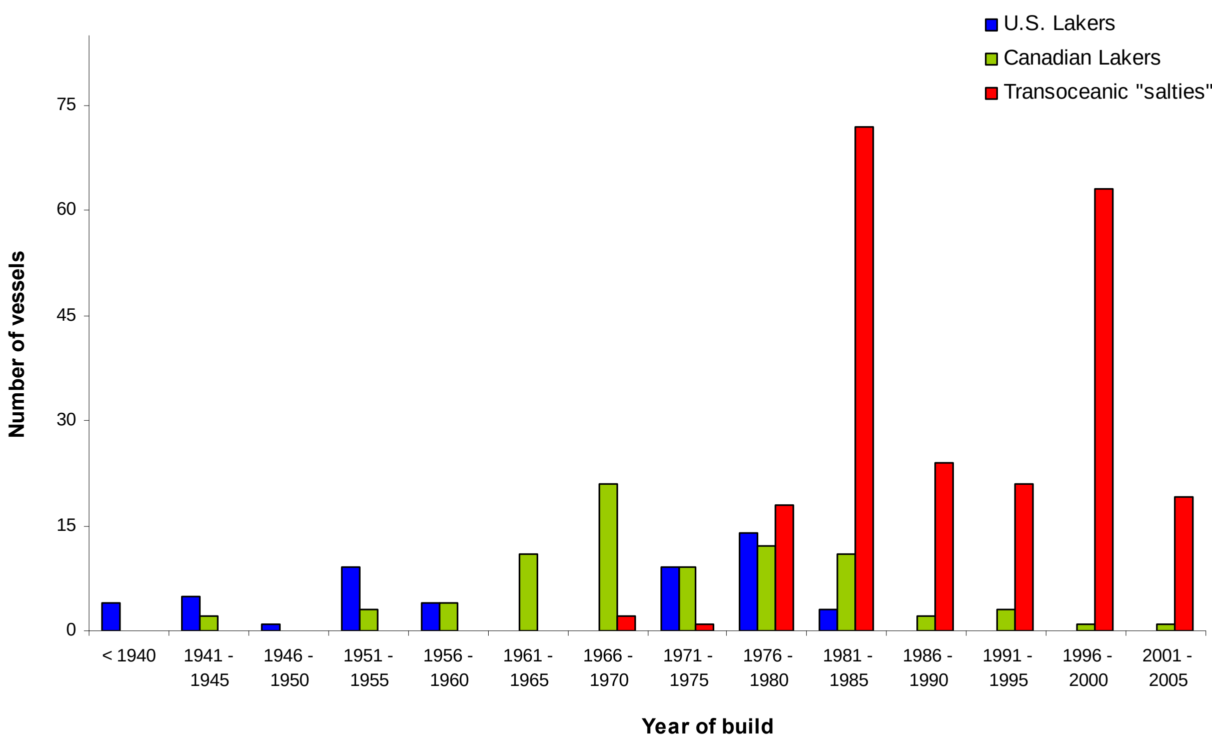


Fig. 9. Comparative year of build of transoceanic Salty, Canadian laker, and U.S. laker vessel fleets that operated on the Great Lakes-St. Lawrence Seaway system in 2002[2]

Cargoes

Cargoes are quantified in terms of tonnage and value. More than 220 million metric tons of cargo move into, out of, and around the Great Lakes each year. Much of this tonnage—approximately 95 percent—is carried in bulk freighters and tankers of the U.S. and Canadian laker fleets. These laker cargoes include coal, iron ore, limestone, and grain (see appendix A). In contrast, cargoes transported by transoceanic ships tend to have lower tonnage but higher value. Generally, the incoming cargoes include iron and steel products discharged in lower-lake ports, and the outgoing cargo is grain taken on board in upper-lakes ports for delivery overseas (fig. 10). A significant portion of grain cargo, however, departs from the Port of Toledo in the lower lakes.

The iron and steel products carried by Salties generally arrive from European ports in Belgium, the Netherlands, Brazil, France, Germany, Russia, Poland, Spain, Turkey, and the United Kingdom. Lower-lake ports receiving these high-value cargoes include Toronto, Hamilton, Oshawa, Ashtabula, Cleveland, Toledo, Detroit, Burns Harbor, and Milwaukee (table 4). Not all of the cargo arrives to a single port, however. Instead it is common for vessels to discharge part of their cargo at several lower-lakes ports as they travel farther west in the basin, taking on more and more ballast water each time they unload (fig. 10). From their final discharge port, the Salties then travel in full ballast to pick up grain for their outgoing voyage, primarily from Duluth-Superior and Thunder Bay (table 4). The grain usually is then transported to ports in Belgium, the Netherlands, Algeria, Italy, Spain, Venezuela, and the United Kingdom.

Besides iron, steel and grain, Salty vessels also carry specialty cargoes in and out of the Great Lakes. Generally, these cargoes are carried on smaller vessels, which are able to visit a wider variety of port and dock facilities. For example, FedNav recently moved a shipment of windmills to Milwaukee, Wisconsin, to be used in wind-power generation. Other examples include heavy machinery, such as imported machine presses used by General Motors in auto manufacturing, and outgoing tunnel boring equipment manufactured by Robbins Co. for use in European construction projects (G. Failor, pers. comm.). A regular transit route has also recently opened up between ports in Germany and Finland and Menominee, Wisconsin, and Duluth, Minnesota, for the importation of wood and paper products. The Port of Toledo has also recently begun receiving shipments of sugar and aluminum.

In 2002, more than 12 million metric tons of overseas cargo passed through GLSLSS ports, including nearly 6.8 million metric tons arriving at GLSLSS ports, and more than 5.5 million metric tons leaving GLSLSS ports (St. Lawrence Seaway Development Corp, 2003). This figure is on par with the annual tonnage carried by transoceanic vessels over the last four years (fig. 11). As in previous years, the major commodities were iron, steel, and agricultural products. The iron and steel float of nearly 3 million metric tons, almost all of it imported, represented an increase from 2001, though tonnage has generally been declining compared with past years (St. Lawrence Seaway Development Corp, 2003; fig. 12). The agricultural products float of almost 4.7 million metric tons also represented a decline compared to previous years (St. Lawrence Seaway Development Corp, 2003; fig. 12). Overall, more than 20 ports in the GLSLSS, including those in Canada, received cargoes from nearly 40 countries in 2002, while cargoes for export were shipped from only 14 ports in the system to 30 countries during that same period (ACOE, 2004; figs. 13 a–e).

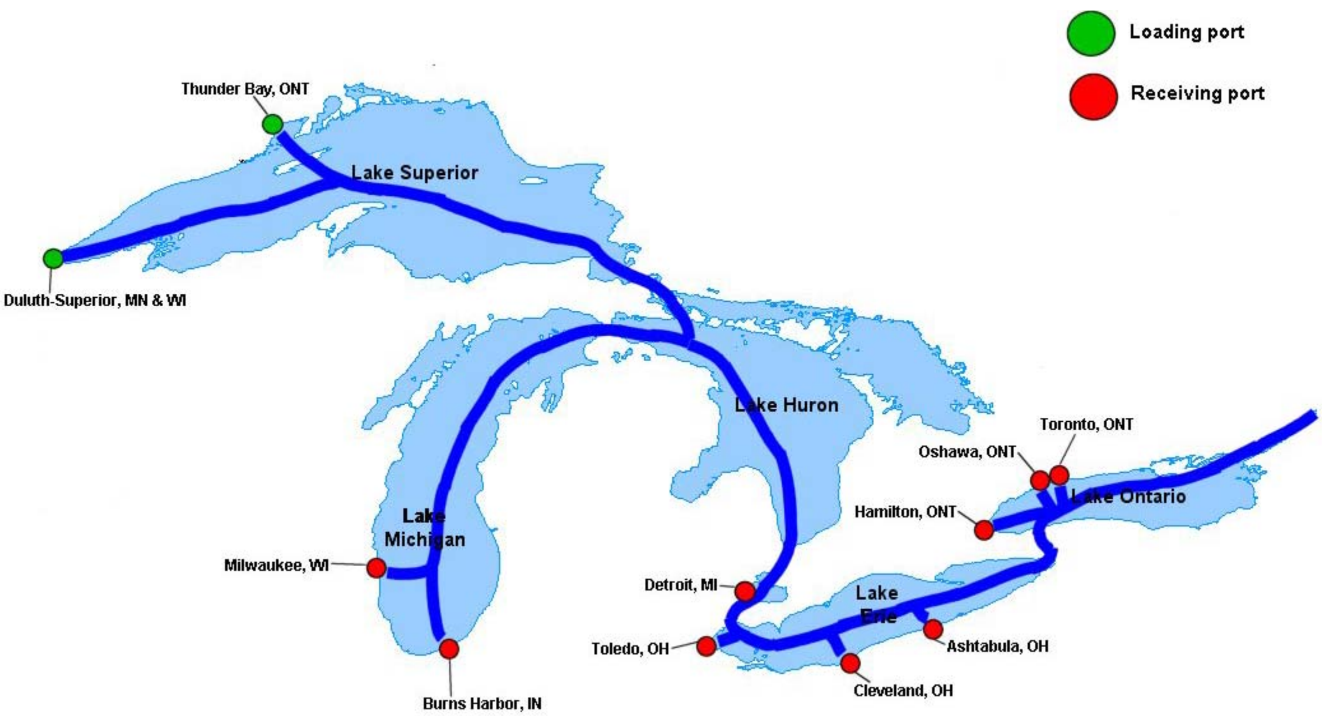


Fig. 10. Generalized trade pattern of overseas-flagged transoceanic vessels transporting steel in and grain out of the Great Lakes-St. Lawrence Seaway system

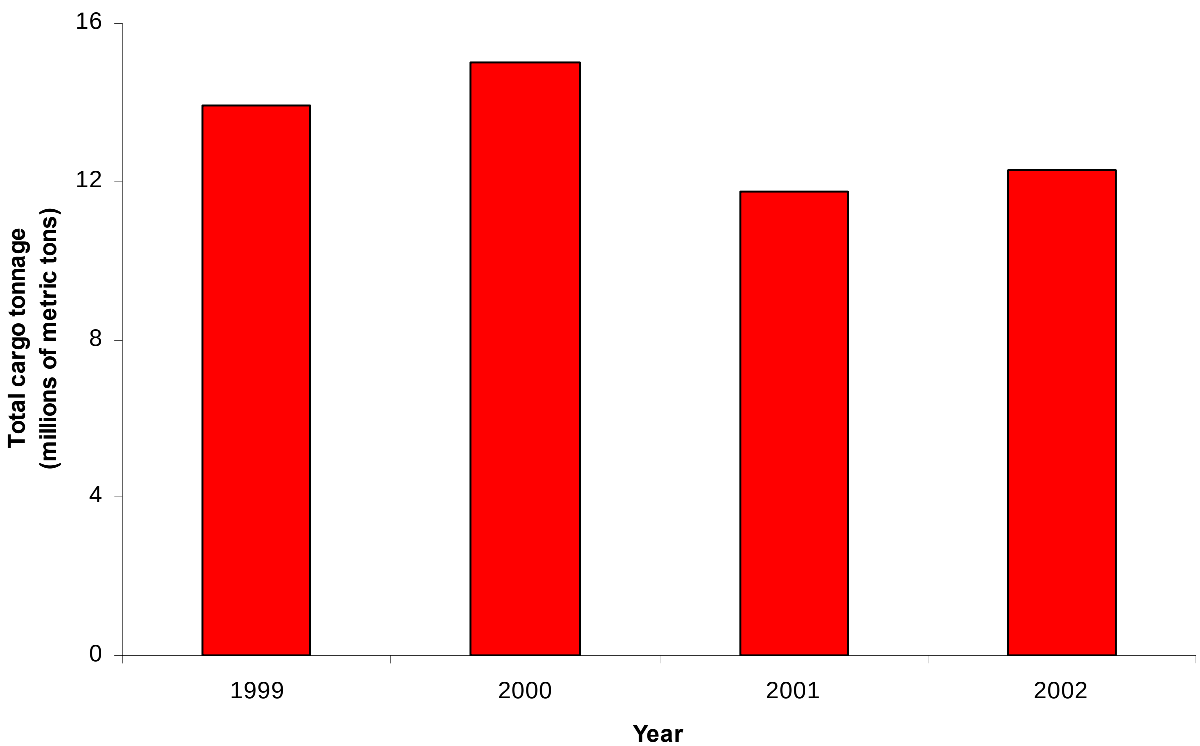


Fig. 11. Total tonnage of cargo (in millions of metric tons) carried by the overseas-flagged transoceanic fleet, 1999–2002 (source: St. Lawrence Seaway Development Corp, 2003)

Table. 4. Cargoes transported by transoceanic vessels to and from major ports in the Great Lakes in 2002 (source: ACOE, 2004)

	Primary Iron and Steel Products (Ingots, Bars, Rods, etc.)	Primary Non-Ferrous Metal Products; Fabricated Metal Prods.	Non-Ferrous Ores and Scrap	Iron Ore and Iron & Steel Waste & Scrap	Sulphur (Dry), Clay & Salt; other Non-metal Minerals	All Manufactured Equipment, Machinery and Products	Forest Products, Lumber, Logs, Woodchips	Primary Wood Products; Veneer; Plywood	Pulp and Waste Paper	Barley, Rye, Oats, Rice, Wheat and Grains; Other Agricultural Products	Building Cement & Concrete; Lime; Glass	Chemicals and Related Products; Coke, Coal, Petroleum and Oil Products
Ashtabula, OH	I	I	I		I							
Buffalo, NY	I											
Burns Waterway Harbor, IN	I	I				I	I			E	I	E
Chicago, IL	I	I				I				E		I - E
Clarkson, Ont.												I
Cleveland, OH	I	I				I						
Conneaut, OH		I	I		I							
Detroit, MI	I	I				I - E						I - E
Duluth-Superior, MN & WI	I	I			I - E	I	I	I		I - E		
Erie, PA						I						
Gary, IN												E
Goderich, Ont.										E		
Hamilton, Ont.	I	I	I							I	I	I - E
Indiana Harbor, IN	I		I									
Ludington, MI				I	I							E
Marathon, Ont.							E		E			
Menominee, MI	I							I	I			
Milwaukee, Wi	I	I				I	I			I - E	I	
Ogdensburg, NY					E					E		
Oshawa, Ont.	I											
Sarnia, Ont.												I - E
Sault Ste. Marie, Ont.	I											
Thunder Bay, Ont.					I - E				E	E		E
Toledo, OH	I	I			I	I	I			I - E		I
Toronto, Ont.	I				I	I		I	I	I		
Windsor, Ont.	I											

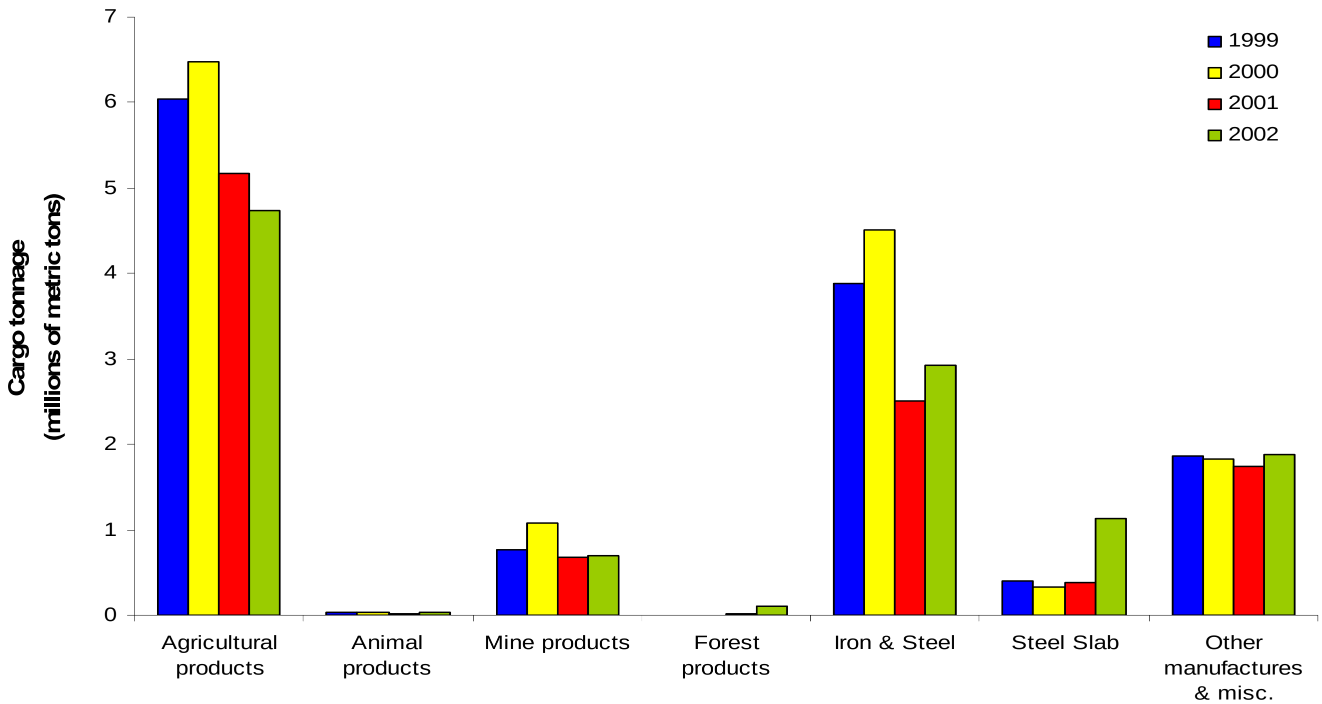


Fig. 12. **Tonnage of cargo (in millions of metric tons) carried by the overseas-flagged transoceanic fleet by major cargo category, 1998–2002 (source: St. Lawrence Seaway Development Corp, 2003)**

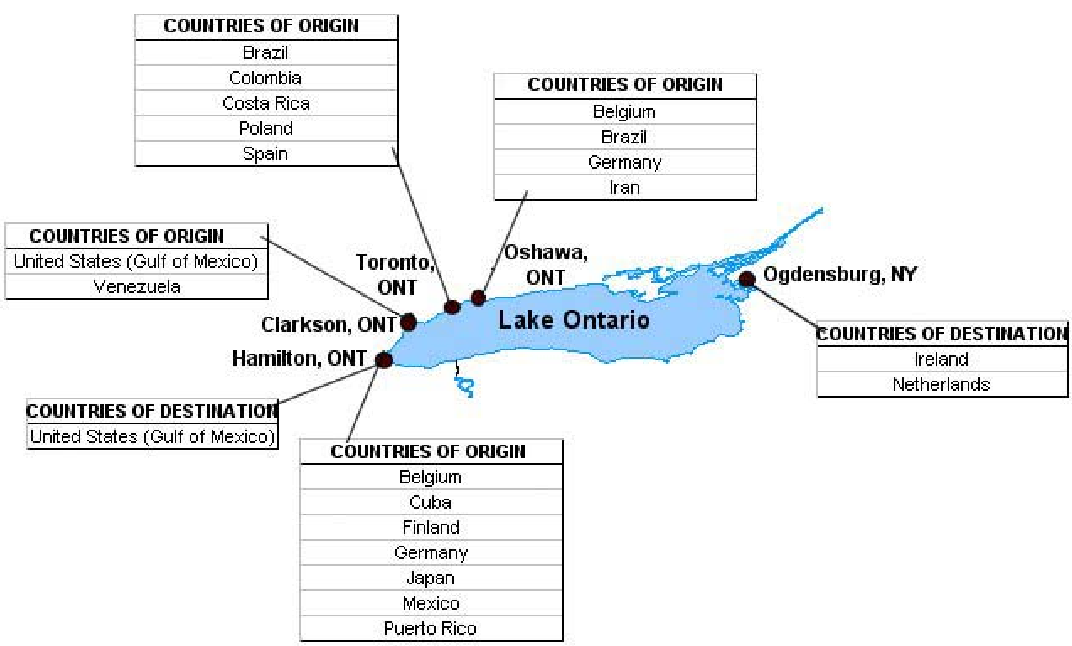


Fig. 13a. **Countries of origin and destination for cargoes transported to and from ports in Lake Ontario in 2002**[2]

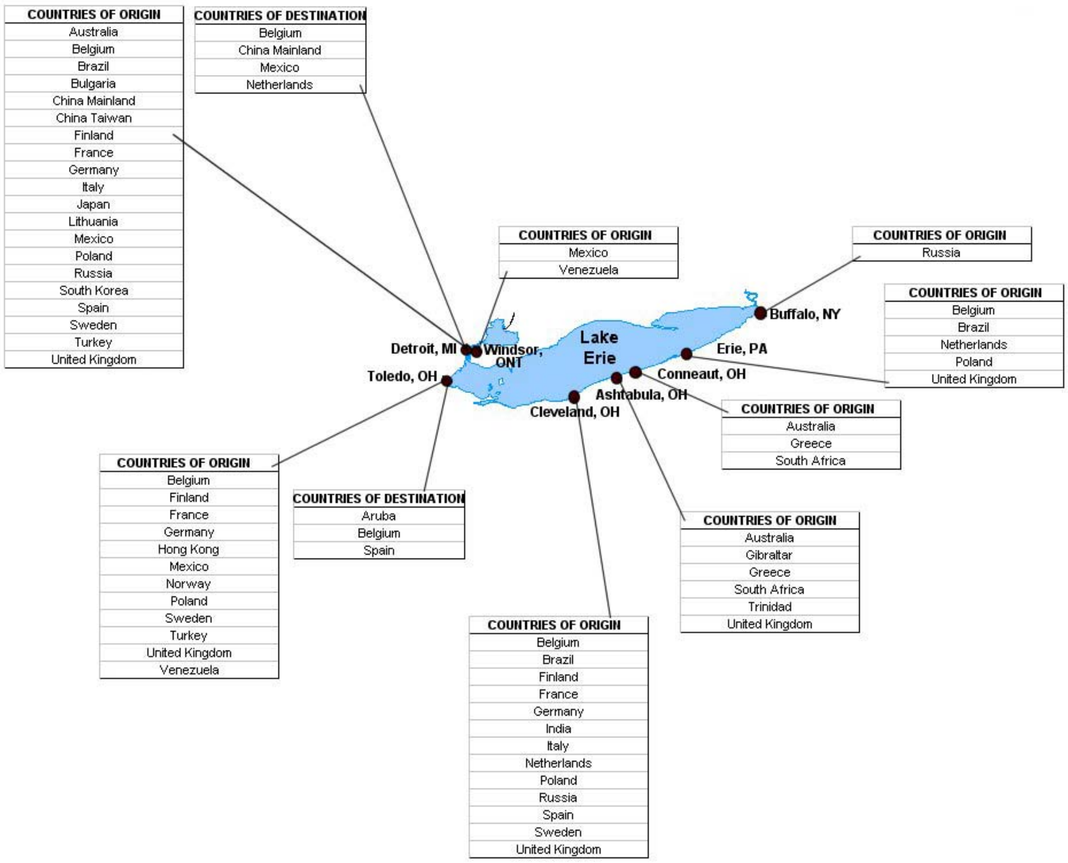


Fig. 13b. Countries of origin and destination for cargoes transported to and from ports in Lake Erie in 2002[2]

Fig. 13c. Countries of origin and destination for cargoes transported to and from ports in Lake Huron in 2002[2]

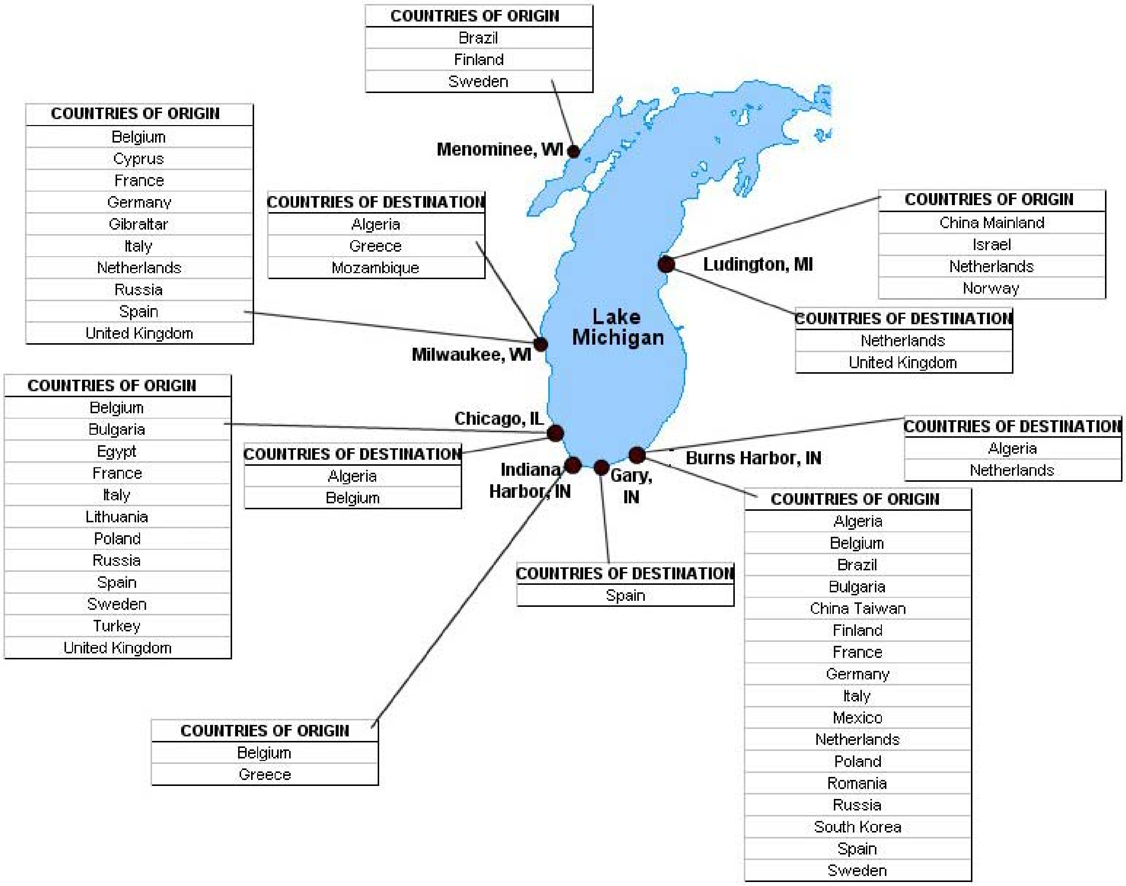


Fig. 13d. Countries of origin and destination for cargoes transported to and from ports in Lake Michigan in 2002[2]

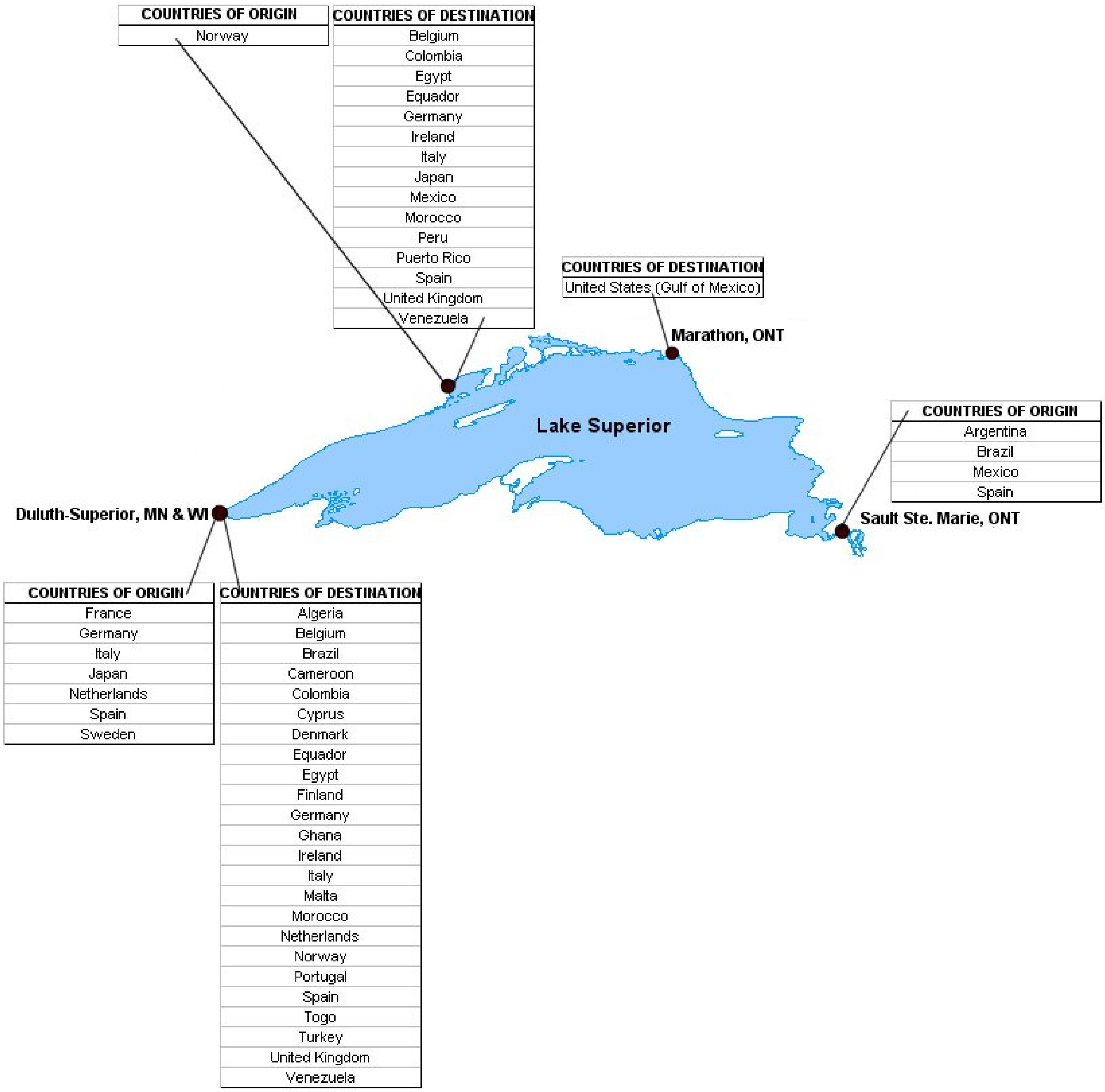


Fig. 13e. Countries of origin and destination for cargoes transported to and from ports in Lake Superior in 2002[2]

Fiduciary Pieces

The financial network through which money flows to nourish Great Lakes maritime trade is even more complex than the system's physical infrastructure. Fiduciary moving pieces populate the supply chain and the transportation services chain that enable waterborne transportation on the GLSLSS. This section describes the primary fiduciary players and their relationships to one another. It then outlines the flow of funds associated with typical transactions resulting in visits by transoceanic vessels to Great Lakes ports.

The Supply Chain

The supply chain comprises entities that extract, alter, or otherwise own material from extraction/production of its raw form through manufacturing processes to its consumption as a finished product. Supply chain entities interact with transportation services to move materials from one production stage to the next. The financial decisions, implicit or explicit, made by members of a supply chain influence whether and how transportation will occur.

Supply chains involving waterborne transportation can be simple or complex depending upon the degree of refinement of the cargo prior to and following transport. In the case of the GLSLSS, the supply chains for imports and exports derive from distinct industries—steel and grain, respectively—but the two industries share responsibility for transportation conditions associated with their cargoes; for reasons of economic efficiency, the same ships and the same voyages (albeit different legs) are used for their respective waterborne shipment. It is doubtful that either industry would be sufficient to support waterborne trade on the GLSLSS in the absence of the other for any extended period.

The supply chain associated with the most significant cargo *imported* to the GLSLSS from overseas, i.e., steel, reflects both pre-shipping and post-import (within the Great Lakes region) processing. The story begins with the overseas entities exporting finished and semi-finished steel to the GLSLSS port range. Imported semi-finished steel may then be further processed to meet specifications of U.S. manufacturers. Between 1997 and 2002, shippers in Europe were responsible for 74 percent of the steel imported to U.S. ports in the Great Lakes (ACOE, 2004). These European steel cargoes departed from Belgium, the Netherlands, Lithuania, France, and Latvia. Though the steel manufacturers directly responsible for shipments like these are diverse and numerous, they are often owned by or organized into larger international steel groups. Among the larger of these groups are Arcelor, Duferco, THEIS, and ThyssenKrupp. Non-European steel imports during the 1997-2002 timeframe originated in Asia (Russia, Taiwan, Turkey, Japan, and South Korea) and South America (predominantly Brazil, with some from Venezuela and Argentina) at 15 percent and 8 percent, respectively (ACOE, 2004). Major steel producers in South America include Arcelor and Gerdau SA.

The specific names of and volumes shipped to specific receiving companies through GLSLSS ports are considered proprietary information and carefully guarded by the ports, and for the same reason are not available under the Freedom of Information Act. However, given the ports through which the material passes, International Steel Group, Inland Steel, and USX, Steel are likely receivers of these goods. Upon arrival in the lakes (usually Burns Harbor, Detroit, Cleveland, Chicago, and Hamilton), imported steel may pass through a series of intermediary refinement processes at steel service centers (box 3). The number of these intermediaries varies, and so the steel may make several stops along the supply chain to be cut, pickled, stamped, etc., before finally being used to assemble finished manufactured goods. The most significant end user of steel in the Great Lakes region is the auto manufacturing industry; others include appliance manufacturers and the construction industry (S. Fisher, pers. comm.). Consumers of the finished products from steel imported from abroad to the GLSLSS are largely (though not entirely) domestic to the United States and Canada.

The supply chain associated with the *exports* from the Great Lakes is simpler, at least on the Great Lakes-based side, which in this case is the pre-shipping side (box 4). Agricultural products such as grain and oilseeds are purchased from Midwestern farmers by corporations like Cargill, Archer-Daniels Midland, CHS, General Mills, AGP, and Louis-Dreyfuss, and moved via rail to grain elevators at Duluth-Superior and Thunder Bay, or, to a lesser extent, Milwaukee and Toledo. The grain shippers then hire Salty vessels (empty of cargo having unloaded steel from their in-bound voyage) to move these grain cargoes abroad. In some cases, shippers use Canadian laker vessels to transport grain first through the St. Lawrence Seaway to Quebec and other ports along the St. Lawrence River for transshipment. Several Canadian laker loads can be consolidated at these outer deep water ports and loaded into ocean-going vessels too large for the Seaway. At the other end of the journey, processing may or may not occur prior to consumption. Between 1997 and 2002, 61 percent of the grain exported from U.S. ports in the Great Lakes was sent to Europe, with Africa accounting for another 27 percent of grain exports (ACOE, 2004). Countries within Europe receiving the goods included Italy, Belgium, Spain, the Netherlands, and the United Kingdom, while Algeria, Morocco and Tunisia were the largest African consumers of the Great Lakes grain (ACOE, 2004). The majority of this processed grain is consumed within these overseas markets.

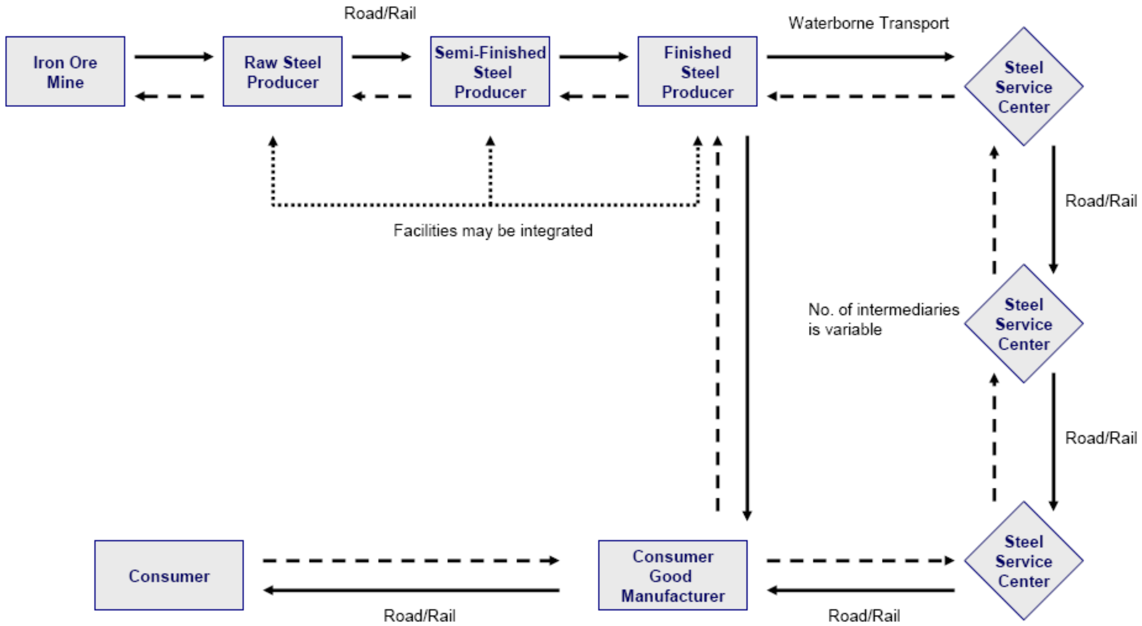
Box 3: Steel Import Example

The supply chain associated with imports of steel products to Great Lakes can vary considerably in complexity. Steel may be imported in raw, semi-finished, or finished form, and may pass through a number of service centers or "middle men" before ultimately being consumed by a manufacturer.

A good example would be a shipment of European-produced steel destined for a North American automobile manufacturer. Consider a shipment of steel produced by ThyssenKrupp Steel AG, one of the major multinational steel groups. ThyssenKrupp produces highly finished, cold-rolled steel and supplies the auto industry and other consumer goods manufacturers. This steel goes through a number of finishing processes prior to export, which may occur at one integrated facility or at a number of facilities throughout Europe.

When the steel is finished and ready for export, ThyssenKrupp arranges for the shipment to be transported to the Great Lakes via an ocean-going carrier. The carrier then transports the steel shipment to one of the major steel ports in the Great Lakes, such as Burns Harbor, Detroit, Cleveland, Chicago, or Hamilton. The steel may undergo further processing, such as slicing, sizing, stamping, etc., at service centers in and around the port before being delivered to the final manufacturer.

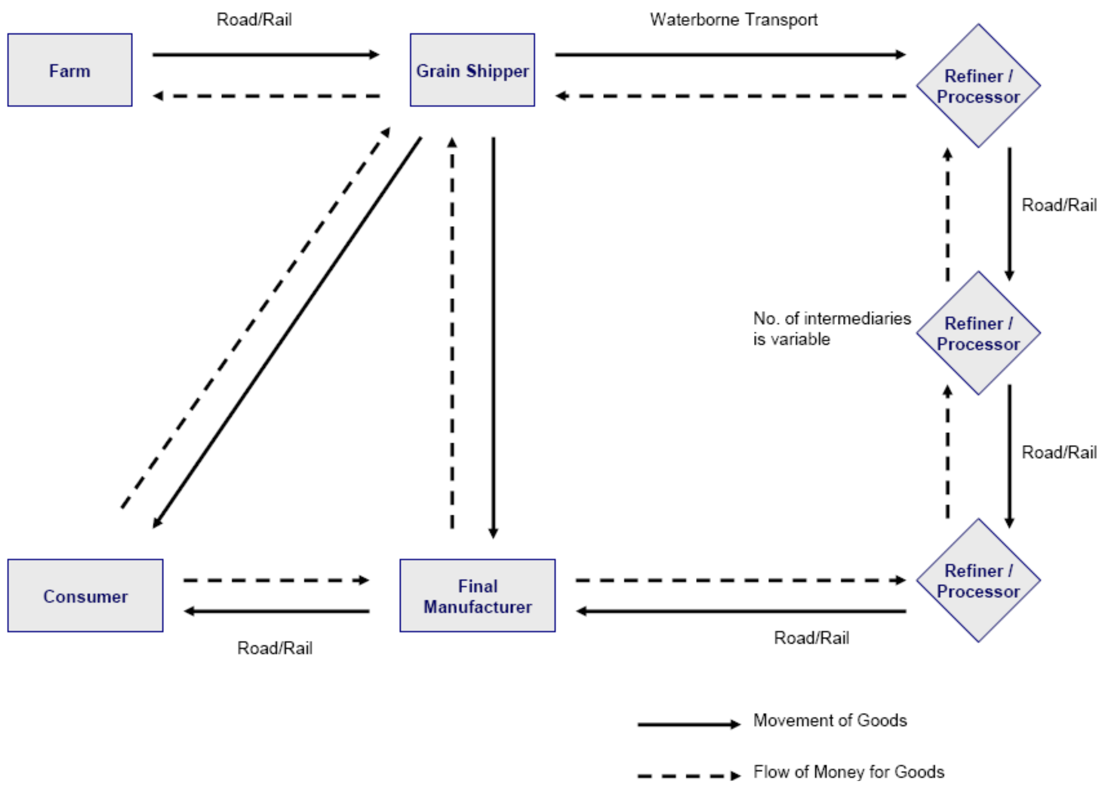
This is just one example of a supply chain for steel imported to the Great Lakes. Steel may be imported raw or semi-finished as well, and undergo processing and finishing at integrated steel mills in the Great Lakes region.



Box 4: Grain Export Example

Before export, the supply chain associated with exports of grain and agricultural products from the Great Lakes is relatively simple. Grain is grown and harvested on farms in Midwestern North America and transported via rail to grain silos at ports such as Duluth, Thunder Bay, Toledo, and Milwaukee. These silos are owned and operated by the large companies that ship and export grain (i.e., Cargill, ADM, General Mills, and Louis Dreyfuss). Here, grain is loaded onto ocean-going vessels bound for overseas destinations.

However, the supply chain varies in complexity once the grain has left the exporting port. For example, grain from Duluth or Thunder Bay may be shipped to ports along the St. Lawrence River for consolidation with other grain and transshipment to larger ocean-going vessels. Some grain may be processed and refined in the importing nation for use in consumer food products. An example of this type of processing is in the export of barley from Duluth to Ireland and Great Britain for use in a brewery owned by Budweiser. A simpler supply chain also exists in the form of direct exports of grain and agricultural products as food aid for nations such as Egypt and Algeria.



The Transportation Services Chain

Members of the supply chain contract with transportation service providers to move their goods. Transportation services relevant to the GLSLSS include vessel ownership, operation and maintenance, Seaway operation and maintenance, vessel pilotage, cargo loading and unloading, and maintenance of dock space and intermodal links.

Shipowners, Operators and Charterers

The chain of unique entities delivering ship operation to a shipper of cargo, like the supply chain itself, may be simple or complex, involving separate shipowners, charterers, and/or operators. A shipowner is the company legally recorded as the vessel's owner on the ship's certificate of registration. A ship operator is the company responsible for the actual management of the vessel and its crew. A ship charterer is the company responsible for the transportation of cargo to and from a specified series of ports on a time-limited basis.

The transportation services chain is most simple when the cargo to be shipped is highly reliable and frequent. Ships in dedicated trade may be owned and operated by separate subsidiaries of the same company. Indeed, at times, the cargo shippers, carriers, and even receivers of goods are components of the same corporate entity. For example, Cargill formerly owned its own fleet of carriers for service on the GLSLSS.

However, the trend in transportation service chains, in both waterborne transportation on the GLSLSS and globally, is toward complexity. Fewer than 10 percent of the 220 Salty vessels that entered the GLSLSS in 2002 were owned and operated by the same company. This low rate is in part an artifact of shipowners setting up "dummy" companies in order to switch vessel registrations from traditional shipping nations to offshore registers (see discussion of "Flag States" below) to enjoy lower taxes, fees, wage scales, and regulations for vessels. However, it also reflects a global trend toward vessel chartering as shippers/receivers look to reduce overhead and liability, and maintain flexibility in constantly changing global trade markets.

Shipowners offer their vessels to cargo owners for charter. There are three basic types of charters available:

Voyage charter, in which the shipper contracts with the vessel owner to move a cargo from point A to point B on specified dates, and for a certain sum—either as so much per ton or a lump sum. The vessel owner remains responsible for the cost of running the ship during this period, and for paying for the fuel and port expenses.

Time charter, in which a charterer hires the ship for a period of time, which may be months or even years, for an agreed rate paid in advance and at regular intervals. In this capacity, a ship charterer is considered a customer of the shipowner, with the two parties entering into a contractual arrangement. The charterer pays for the fuel and operational and port expenses, although capital and running expenses, for keeping the ship in good condition, remain the responsibility of the owner.

Bareboat charter, in which the vessel owner virtually hands over his ship to the charterer, who will treat it as his own, possibly painting it his colors, placing his own crew aboard, and taking full responsibility for its trading, in return for regular agreed payments.

Both voyage chartering and time chartering involve vessels and cargo being matched on the charter market. Shipowners or operators contact brokers—middle men who specialize in setting up work for a given vessel—when they have a ship available, free of cargo. The broker then contacts the shipper/receiver who has a particular volume of cargo to transport from one location to another, or for a specific period of time. The deal is completed when the charter party is drawn up. The charter market is complex and often volatile, where large sums of money can sometimes be gained—or lost—depending on supply and demand. However, this service chain is ideal for shippers with unreliable or infrequent consignments of cargo. These vessels operate in so-called "tramp trade," analogous to taxi services that hire drivers and a centralized dispatcher (agent) to inform the cabs of their next human consignment. The shippers of cargo also have agents to procure the most cost-effective carriers for a particular shipment.

In contrast, bareboat charters are particularly useful if the shipper/receiver has a long-term requirement for bulk transport, but does not wish to become a shipowner due to the large capital investment. The duration of these charters range from 10 to 15 years, providing a base load of shipping capacity to cover long-term material supply contracts. Charters of this type are generally agreed upon before the vessel is built. FedNav Ltd. is an example of a company involved in the long-term charter of a large proportion of its fleet operating on the Great Lakes.

Despite these dynamic owner-charterer-operator relationships, a stable core group of companies operates vessels making one or more runs into the GLSLSS each shipping season. Table 5 lists the top 12 companies that operated transoceanic vessels that entered the GLSLSS in 2002.

Port Administrations

As noted above, ports comprise one or more docks. The vast majority of port and dock space in the Great Lakes is private. In particular, the smaller ports around the Great Lakes are often owned and operated by the private entities shipping cargo. For example, a steel mill or mining operation might have its own port. These private ports process shipments almost exclusively involving U.S. and Canadian domestic vessels (fig. 14). The region's major commercial ports, comprising many docks, are far larger than these private ports, and are the destinations for most transoceanic vessels (fig. 15). At these locations there is typically some public ownership of docks. These facilities, fewer in number than private ports, are owned and managed by public agencies.

Table 5. Top 12 companies that operated overseas-flagged transoceanic vessels that entered the Great Lakes-St. Lawrence Seaway system in 2002[2]

Ship operator	Type of vessel	No. of vessels	Average gross registered tonnage
FedNav Ltd.	Bulk carrier	40	20,895
	General cargo carrier	1	
Wagenborg Shipping	General cargo carrier	19	6,253
Canfornav Ltd	Bulk carrier	15	17,479
	General cargo carrier	1	
Polish Steamship Company	Bulk carrier	14	16,262
	General cargo carrier	2	
Flinter Groningen BV	General cargo carrier	7	5,096
Oldendorff Carriers	Bulk carrier	6	17,245
BBC Chartering & Logistics	General cargo carrier	5	5,356
B&N Rederi	Bulk carrier	3	5,620
	General cargo carrier	2	
Lithuanian Shipping Corporation	Bulk carrier	5	9,965
Jumbo Shipping	General cargo carrier	1	6,412
	Heavy load carrier	3	
Knutsen O A S	Tanker	4	13,590

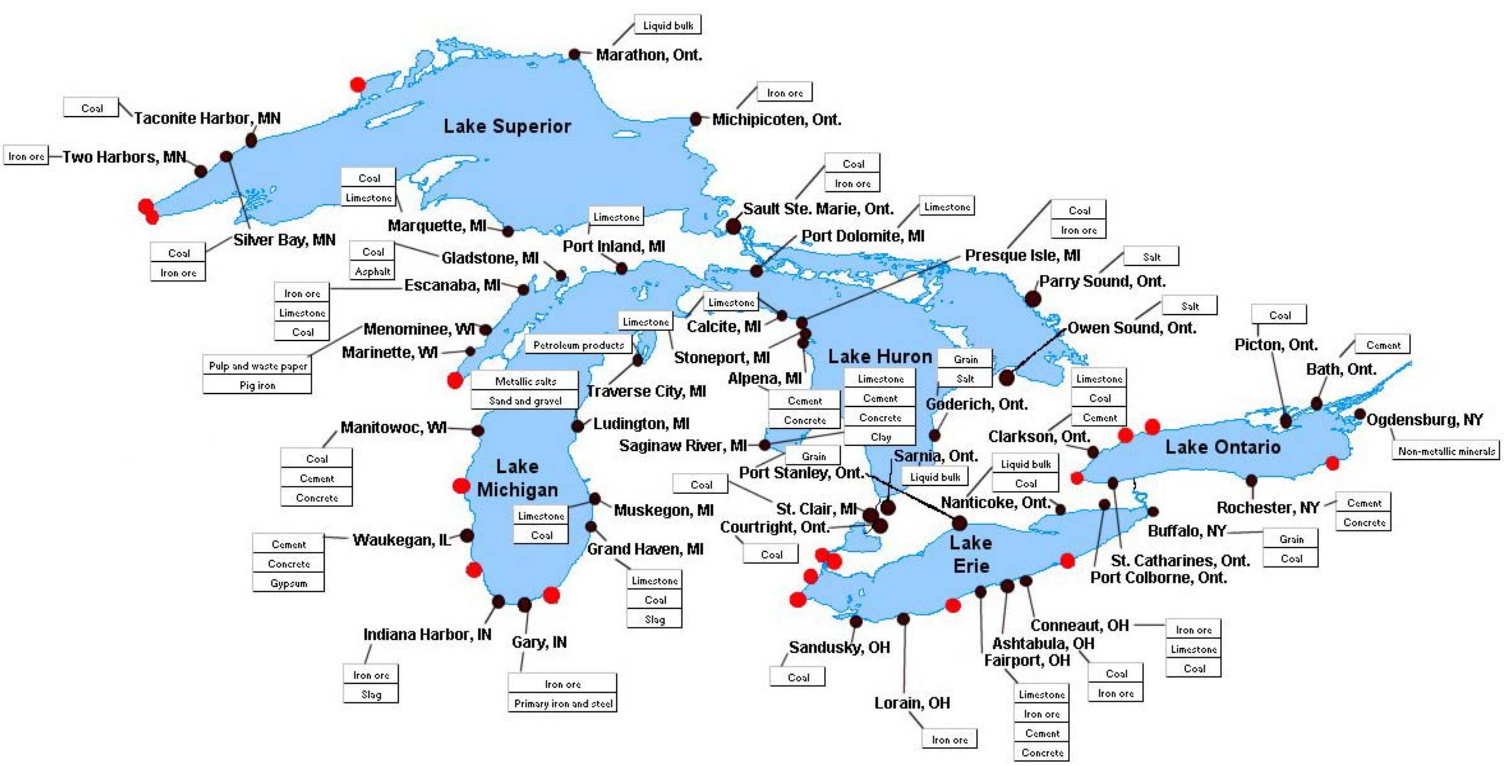


Fig. 14. Map of private ports in the Great Lakes-St. Lawrence Seaway system and types of cargoes processed[2]

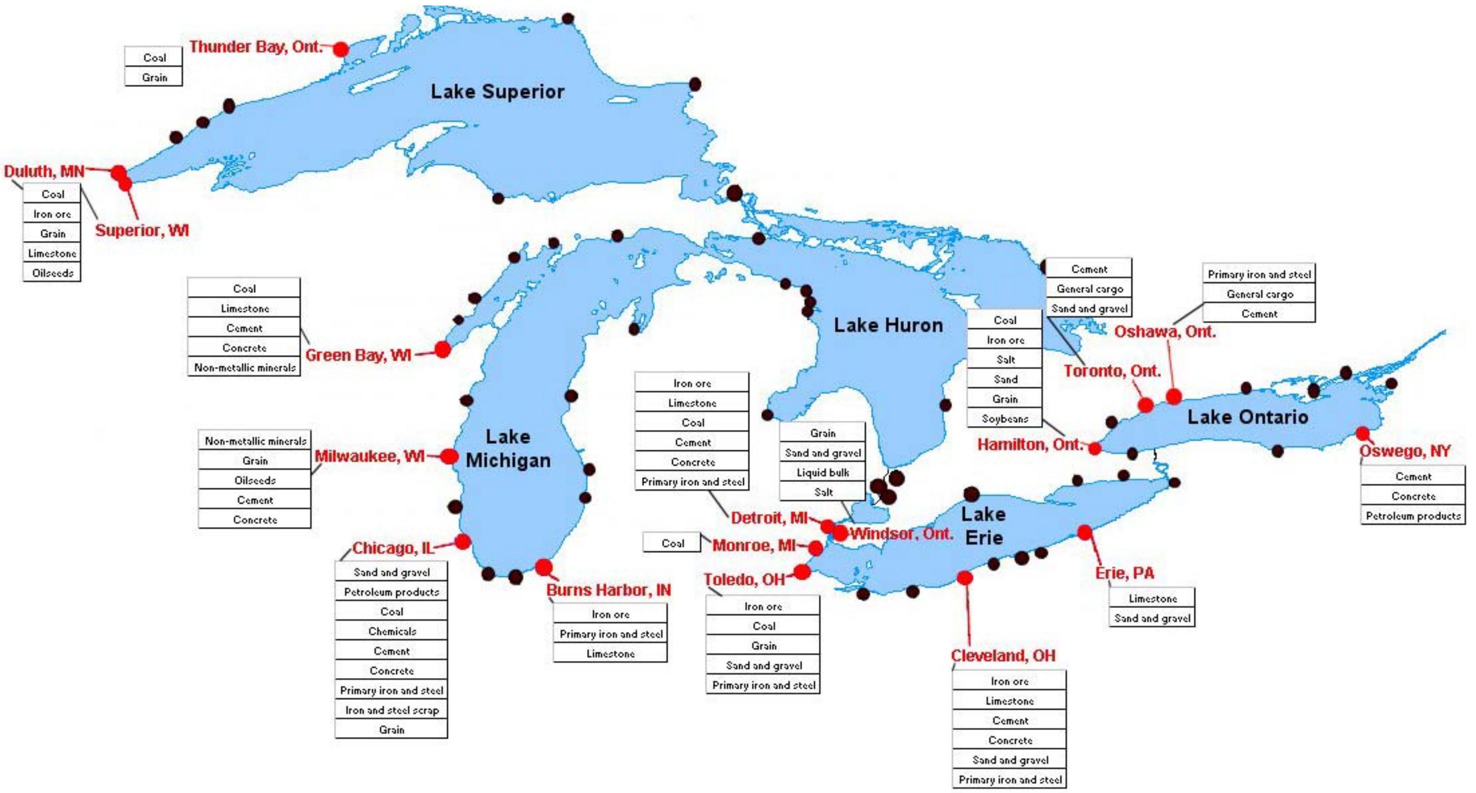


Fig. 15. Map of public ports in the Great Lakes-St. Lawrence Seaway system and types of cargoes processed[2]

Public Port Authority Organizations Models

There are a number of models for the organization and operation of public port authorities in the Great Lakes, and these tend to mirror the models throughout the rest of North America.[3] Some ports in the Great Lakes are owned and operated by government entities, including state, county, and municipal governments. For example, the port of Milwaukee is municipally run, the port of Green Bay is owned and operated at the county level, and Burns Harbor (as well as Indiana's non-Great Lakes ports) is state owned and operated.

The more common model, however, is for a public port authority to be established by state legislation. Most of the major Great Lakes ports, such as Cleveland, Toledo, Duluth, Chicago, and Detroit, operate under this model. State legislation authorizes the port authority to engage in maritime commerce activities and, in some cases, other activities such as bonding and financing. Typically, these port authorities are governed by a board of directors, with state, county, and municipal governments appointing a predetermined number of the board members.

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[2] Three Great Lakes ports operate under State control (Indiana Ports, Ogdensburg, and Oswego); five under City control (Monroe, Ashtabula, Lorain, Milwaukee, and Superior); and one under County control (Green Bay). The remaining ports operate under Port Authorities or Port Districts that are partnerships between some combination of State, County, and City Government: three by State/City authority (Chicago, Waukegan, and Erie), two by State/City/County authority (Detroit-Wayne and Duluth), and two by City/County authority (Cleveland-Cuyahoga and Toledo-Lucas).

Box 5 provides an example, detailing the organization, authority, and governance of the Port of Cleveland.

Canada's major public ports were commercialized in 1998 under the Canada Marine Act. This law designated the 14 most significant Canadian ports as Canada Port Authorities (CPAs). These self-sufficient port authorities receive no federal appropriations, deriving all revenue from maritime operations. In addition, they are no longer controlled and operated directly by the federal government. Despite these recent changes, Canadian ports remain public institutions. The major CPAs are governed by boards of directors similar to those of their U.S. counterparts, appointed by and representing federal, provincial, local, and municipal governments. Smaller ports in Canada that are not eligible for CPA status have also been defederalized, with the Transport Ministry selling or transferring these ports to municipal, provincial, or private interests.

Port Financing Authorities

Many port authorities throughout the United States provide financing mechanisms for developments and projects to promote economic development, generally. These authorities are ready entities that can support countywide or regional economic development efforts because they usually have broad-based representation in their boards and the ability to supply funding. The funding revenues may vary by port authority, but they generally are provided by tax revenues, bonds, and income from industry-related activities. For example, one of the Cleveland Port Authority's revenue sources is a bed tax from hotels in Cuyahoga County. This revenue is shared and agreed on by the Port, the Cleveland Visitors Bureau, and 12 participating municipalities. The success of these financing mechanisms outside of maritime and shipping operations has been developed over the past 10 years.

The concept of using the port for development finance was created at the St. Paul Port Authority, Minnesota. It demonstrated the need for a regional venue to improve and retain development opportunities in the region and highlight their competitive advantage. Toledo and Cleveland Ports recognized St. Paul's success and sought similar financing mechanisms for nontraditional developments outside of their role of shipping operations. Today, ports throughout Ohio and other Great Lake states look to Cleveland and Toledo as successful operations in providing financing alternatives for communities. To better understand how the ports obtained this power, a review of the statutory authorities is required.

Types of Port Financing

Most port authorities establish their own set of financing tools through a separate division of a development office within the authority's organizational structure. The financing incentives are the low interests and fee structures these tools provide. This structure provides a competitive advantage over traditional developer/bank investments, which usually charge high fees and penalties. In addition, the Ohio Department of Development administers separate supportive bond funds established solely for port use under the Port Authority Bond Reserve Fund Program to "provide eligible Port Authorities financial assistance for economic activities."

Box 5: Port Governance Case Study

Legislative Authority and Origin – The Cleveland-Cuyahoga County Port Authority was authorized under the Ohio Port Authorities Act, which became Chapter 4582 of the Ohio Revised Code. In 1968, the City of Cleveland and Cuyahoga County created the Port Authority as an independent agency.

The powers granted to the Port Authority include to:

- Acquire, construct, furnish, equip, maintain, repair, sell, exchange, lease, convey other interests in, or operate real or personal property related to, useful for, or in furtherance of any authorized purpose, and make charges for the use of any port authority facility
- Straighten, deepen, and improve any canal, channel, river, stream, or other water course or way necessary or proper in the development of the facilities of the port authority
- Issue bonds or notes for the acquisition, construction, furnishing, or equipping of any real or personal property
- Issue revenue bonds beyond the limit of bonded indebtedness provided by law
- Operate any property in connection with transportation, recreational, governmental operations, or cultural activities
- Apply to the proper authorities of the United States for the right to establish, operate, and maintain foreign trade zones and to establish, operate, and maintain foreign trade zones

Mission – The strategic mission of the Cleveland-Cuyahoga County Port Authority is to assist private industry in retaining and creating jobs by providing waterborne cargo transportation/services and by providing economic development facilitation through financing services and other development tools in partnership with local and state development agencies.

To serve this mission, the Port Authority is divided into two groups: a Maritime Group and a Development Finance Group. The Maritime Group provides support to the manufacturing base of the region by supplying transportation services that positively impact the area's competitiveness. The Development Finance Group provides support to the community's private industry through financing vehicles that enhance the competitiveness of the area.

Governance – The Port Authority is governed by a nine-member Board of Directors. Three of these directors are appointed by the Cuyahoga County Commissioners. The remaining six directors are appointed by the Mayor of Cleveland, with the approval of the Cleveland City Council. Directors serve for a minimum four-year term. Board members earn a salary as compensation, with the Chairman earning $15,000, the Vice Chairman earning $8,000, and remaining members earning $4,800 annually.

Port Bonding Authorities

Some of the major public port authorities have bonding authority and have made significant investments in waterfront redevelopment. Some of the profits from these investments may support maritime activity indirectly. As a result of Toledo and Cleveland's interest in opening new venues, resolutions adopted in 1988 under the Ohio Revised Code allow the port authority to finance development projects that are approved by its board:

(A) A port authority created in accordance with section 4582.02 of the Revised Code may:

(1) Acquire, construct, furnish, equip, maintain, repair, sell, exchange, lease to or from, lease with an option to purchase, convey other interests in, or operate real or personal property, or any combination thereof, related to, useful for, or in furtherance of any authorized purpose, and make charges for the use of any port authority facility, which shall be not less than the charges established for the same services furnished by a public utility or common carrier in the jurisdiction of the particular port authority;

(2) Issue bonds or notes for the acquisition, construction, furnishing, or equipping of any real or personal property, or any combination thereof, related to, useful for, or in furtherance of any authorized purpose, in compliance with Chapter 133 of the Revised Code, except that the bonds or notes only may be issued pursuant to a vote of the electors residing within the territory of the port authority. The net indebtedness incurred by a port authority shall never exceed two per cent of the total value of all property within the territory comprising the authority as listed and which (9) Enjoy and possess the same rights, privileges, and powers granted municipal corporations under sections 721.04 to 721.11 of the Revised Code;

Types of Port Development Projects

The Cleveland Port and Toledo Ports have financed a variety of development projects throughout and outside of their jurisdictions. These include such large projects as the world headquarters for Owens-Corning Fiberglass in Toledo and Applied Industrial Technologies in Cleveland. In addition to these industrial investments, recently the ports have financed retail development investments—even though they are considered riskier. Examples include financing $230 million for a mixed-use development in suburban Westlake, Cuyahoga County, Ohio; $14 million for a retail parking garage in University Heights (a Cleveland suburb); and $39 million for the Rock and Roll Hall of Fame and Museum, a cultural/entertainment facility.

Marine Terminals

The ports in the Great Lakes are considered “landlord” or nonoperating ports, which means they do not directly employ labor to load and unload vessels. Rather, the ports contract with marine terminals to handle cargo loading and unloading. In addition, marine terminals can be responsible for locating a vessel to carry cargo for a customer.

Marine terminals lease space from and pay wharfage fees to port authorities per ton of cargo loaded or unloaded. They also charge vessel operators a fee for cargo loading and unloading operations, which incorporates the terminal’s operating costs, such as rent and wharfage.

Labor

The Great Lakes region relies heavily on the maritime industry for employment. Shipping activity at 16 major U.S. Great Lakes ports in 2000 created almost 44,000 jobs directly, and 54,000 jobs indirectly (Martin Associates, 2001). Of the direct jobs created, 5,422 (12.3 percent) were associated with the movement of steel and 1,467 (3.3 percent) were associated with the movement of grain (Martin Associates, 2001). Though some of the grain-related jobs were likely associated with Mississippi-bound trade, and other commodities were associated with transoceanic trade, a reasonable estimate of the number of jobs directly generated by transoceanic cargo movement in the GLSLSS is 10,000—equivalent to nearly one-quarter of the total number of direct jobs. Martin Associates (2001) also reports that GLSLSS shipping provided $1.6 billion in direct income, and $2.7 billion in indirect income. Compared with 1991, direct and indirect jobs and personal income had more than doubled by 2000.[4]

Waterborne shipments in the GLSLSS directly provide employment in the maritime services sector, comprising cargo handling and transportation, vessel operations, and government agencies (39 percent of direct jobs); the shipping/consignee sector, comprising the manufacturing plants that depend on the cargoes shipped using the GLSLSS (32 percent of direct jobs); the transportation sector, including railroad and trucking industries (28 percent of direct jobs); and the port sector, including port authorities and associated organizations (1 percent of direct jobs) (Martin Associates, 2001).

Virtually all of this labor is unionized. Primary labor organizations representing workers from these sectors in the Great Lakes for the U.S. flag lakers are the American Maritime Officers; International Organization of Masters, Mates and Pilots; and Seafarers International Union. For the salty ships, the only Unites States labor involved are the dock workers represented by the International Longshoremen’s Association;

Seaway Development Authorities

The U.S. and Canadian federal governments have authorized organizations to help manage GLSLSS maritime activity on their respective sides of the national frontier. The Canadian government established the St. Lawrence Seaway Management Corporation (SLSMC)

[3] All monetary comparisons are in nominal dollars.

as a nonprofit organization in 1998 to bring commercial management concepts to St. Lawrence Seaway operations. Seaway users and other stakeholders finance and run the organization under contract to the Canadian government, which retains ownership. The SLSMC requires every ship entering, passing through, or leaving the Seaway to pay a toll assessed against the ship, its cargo, and its passengers for a complete or partial transit of the Seaway, covering a single trip in one direction. The cargo-related toll varies by commodity, and is assessed per metric ton. A vessel charge increases with gross registered ton of the vessel. Finally, lockage charges to SLSMC increase per lock, and vary depending on the ballast condition of the vessel. Lockage charges apply only to the Welland Canal. Table 6 provides an overview of the cargo tolls, vessel charges, and lockage fees applicable to vessels transiting the GLSLSS. It should be noted that these tolls and charges are assessed in Canadian dollars; the values in table 6 and the following tables have been converted to U.S. dollars.

The St. Lawrence Seaway Development Corporation (SLSDC), a wholly owned government corporation and an operating administration of the U.S. Department of Transportation, is responsible for the operation and maintenance of the U.S. portion of the Seaway between Montreal and Lake Erie. This responsibility includes managing vessel traffic control in areas of the St. Lawrence River and Lake Ontario, as well as maintaining and operating the two U.S. Seaway locks in Massena, N.Y. The SLSDC coordinates its activities with its Canadian counterpart, the SLSMC, to ensure that the U.S. portion of the St. Lawrence Seaway—including the two U.S. locks—are available for commercial transit. The SLSDC and SLSMC, under international agreement, jointly publish and administer the St. Lawrence Seaway Regulations and Rules (Practices and Procedures in Canada) in their respective jurisdictions. The United States does not charge tolls.

Table 6. Cargo tolls, vessel charges, and lockage charges assessed for vessels transiting the Montreal-Lake Ontario and Welland Canal sections of the Great Lakes-St. Lawrence Seaway system

	Montreal-Lake Ontario	Welland Canal
Cargo Tolls ($US per metric ton)		
Bulk Cargo	0.768	0.5088
Grain	0.472	0.5088
Coal	0.4533	0.5088
General Cargo	1.85	0.8143
Steel Slab	1.675	0.5829
Contanerized Cargo	0.768	0.5088
Vessel Charges (per GRT)	0.0741	0.1203
Minimum charge per vessel per lock	15.96	15.96
Lockage charges (per lock)		
Loaded Vessels	0	406.36
Ballasted Vessels	0	300.23

The Cost of Shipping

Shipping costs can be divided intro three categories: *capital costs*, *operating costs*, and *voyage costs*.

Capital costs include interest on the money used to purchase the vessel and the amortization and depreciation thereof. A typical recently built Handimax-sized, bulk cargo carrier can be purchased for $30 million Interest on this purchase could average between $2 million and $4 million per year.

Operating costs are the ongoing expenses related to the day to day running of the vessel. These include crew and manning; insurance and classification; repairs and maintenance; stores and lubes; and administration. Crew and manning is by far the largest component of operating costs, generally accounting for 40 percent to 45 percent of the aggregate. Typical annual crew and manning costs for bulk carriers range from $600,000 to $900,000. Repairs and maintenance is generally the second-largest cost category, typically accounting for 15 percent – 20 percent of total operating costs. The third-biggest cost factor is insurance and classification. However, as with crew and manning, and repairs and maintenance, these costs are highly influenced by the nationality of the shipowning company. In total, operating costs for a bulk carrier range from $1 million to $3 million.

Voyage costs are those costs directly attributed to a voyage, including the cost of fuel, port charges, pilotage fees, cargo handling expenses, canal and lock tolls, hold cleaning, and other miscellaneous costs such as representation at the ports of call. Fuel is the single most-important item in voyage costs, accounting for approximately 50 percent of the total. Port-related charges represent another major component and include various fees levied against the vessel and/or its cargo for the use of the facilities and services provided by the port. Generally, port-related charges, including port dues and service charges, account for approximately 30 percent – 40 percent of the total voyage cost (see box 6). These costs range from $100,000 to $600,000, depending on length of voyage and type of cargo carried.

If the vessel is chartered, port dues and charges are generally charged to the shipowner. The charterer, in turn, usually pays all charges specific to the cargo, as well as canal and toll dues, though in some situations the shipper/receiver pays for cargo loading/unloading. If this is the case, the shipper/receiver may contract with a stevedore to load or unload cargo.

Regardless of the terms of the voyage charter, most of the fees, tolls, and other shipping costs incurred by the associated parties are passed on to the shipper/receiver. In turn, the shipper incorporates the costs into the price of its goods, ultimately passing those costs on to purchasers and consumers. Figure 16 represents the flow of funds associated with maritime transportation in the Great Lakes. Box 6 details an example of the various fees and tolls a Salty vessel carrying cargo to a Great Lakes port would be subject to.

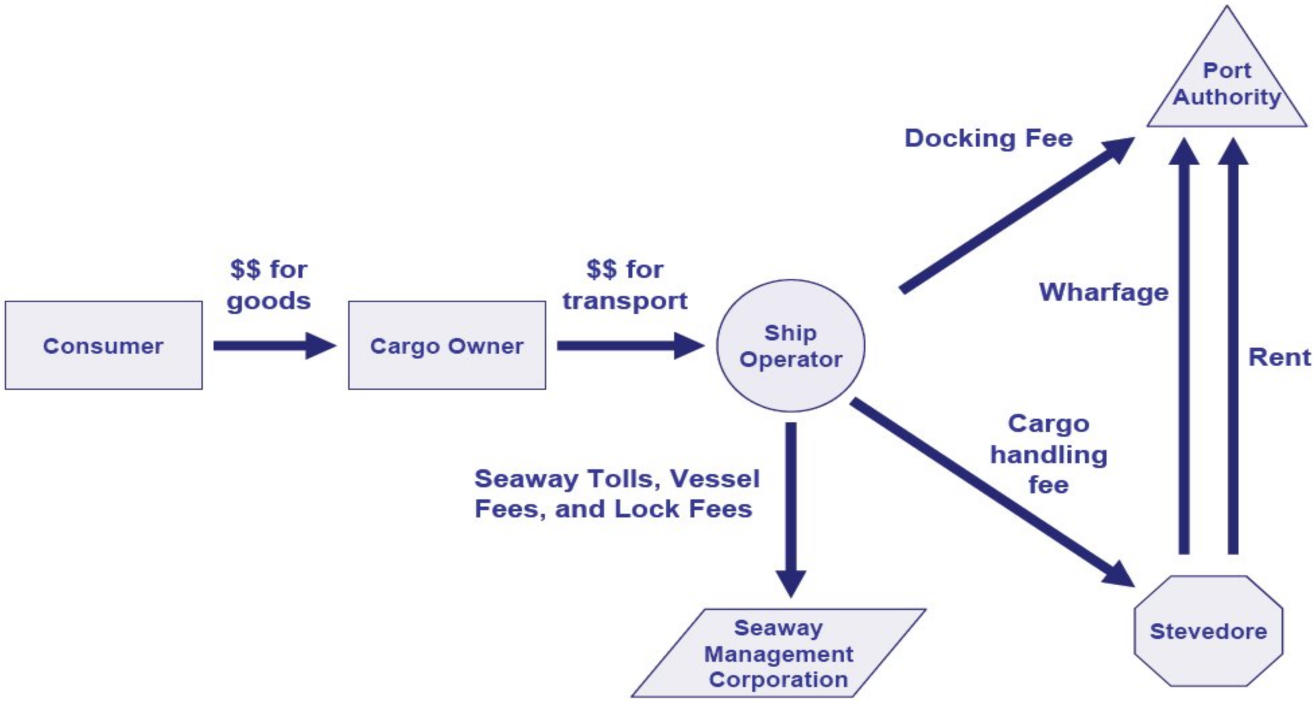

Fig. 16. General representation of the flow of funds associated with maritime transportation in the Great Lakes.

Box 6. Example of Fees and Tolls Charged to Typical Salty Vessel

The following table presents a hypothetical example of the various fees and tolls a Salty vessel carrying cargo to a Great Lakes port would be subject to. In this example, a typically sized Salty vessel (14,000 metric tonnes) is fully loaded with steel bound for the Port of Cleveland, Ohio.

During the course of its voyage, the vessel would be required to pay a cargo toll and a vessel charge to transit the Montreal-Lake Ontario section of the GLSLSS. At the Welland Canal, a lock charge is assessed, as well as additional cargo tolls and vessel charges. At the Port of Cleveland, the vessel must pay a docking/berthing fee for space at the port, and a wharfage fee to unload its cargo. While the total of these tolls and charges will vary with the size of the vessel and the amount and value of cargo carried, they can become substantial.

An overview of the fees and tolls a hypothetical salty vessel carrying cargo to Cleveland, OH would be required to pay

Seaway and Port Fees Example

14,000 MT Salty fully loaded with steel entering the Great Lakes and bound for Cleveland, OH

Montreal-Lake Ontario Fees	
Cargo Toll	$23,450
Vessel Charge	$1,037.40
Lock Charges	N/A
Welland Canal Fees	
Cargo Toll	$8,160.60
Vessel Charge	$1,684.20
Lock Charges	$3,250.88
Port of Cleveland Fees	
Dock/Berth	$1,120
Wharfage	$9,800
TOTAL	**$48,503.08**

Regulatory Pieces

Vessel operators must deliver transportation services in compliance with a constellation of regulations from disparate government and maritime industry regulating authorities. Some of the regulating authorities have overlapping geographic jurisdictions, in which operators must comply with several sets of standards at once. In addition, various sets of regulations phase in and out as the ship plies from jurisdiction to jurisdiction. The potential for inefficiency related to overlap and conflict inspires energetic industry efforts, through the International Maritime Organization (IMO), to coordinate regulation and standards related to aspects of waterborne transportation domestically and internationally. Government regulators, which are independent and often sovereign authorities, may not sign onto or fulfill such agreements, but internal industry regulators (known as classification societies) do for purposes of assuring safe vessel operation and complying with government regulators to safeguard investments by ships' underwriters. This section identifies and describes the jurisdictions and entities that may regulate a ship's voyage into the GLSLSS.

Flag States

To gain port entry, every commercial vessel must have a certificate of registration from a nation state and operate under the flag of that nation. The United Nations Convention of the Law of the Sea requires that flag states bear primary responsibility for governing all aspects of ocean space, including delimitation, environmental control, marine scientific research, economic and commercial activities, transfer of technology, and the settlement of disputes relating to ocean matters. While international agreements help make requirements across flag states consistent—by at least establishing a regulatory floor—each flag state can impose its own requirements on ships under its registration in keeping with those agreements. Some states have more onerous requirements than others. The U.S. flag requirements are some of the world's most stringent. Flag state requirements may govern operational, structural, and financial circumstances, such as taxation rates, fees, crew nationality, working conditions, wage scales, and environmental protectiveness.

At one time, ships flew the flag of the nation where their owner was located, but the disparity between flag requirements and the competitive nature of the global shipping market has led shipowners to choose registrations based on fiscal considerations. Due to stringent U.S. requirements, the U.S. flag is one of the most expensive to fly and the least frequently encountered, except on ships that seek access to subsidies and markets exclusively reserved by Congress for U.S. flag vessels. Flag "shopping" has resulted in large numbers of registrations with nations that offer the least stringent registration requirements. Among flag states, there is a competitive advantage to offering inexpensive approaches to meeting floor requirements and not exceeding them. The result is a wide variation in how internationally established safety and environmental standards are realized and enforced among the scores of registries worldwide. In fact, some flag states are accused of merely paying lip service to mandatory requirements, such as the International Convention for the Safety of Life at Sea, the International Convention for the Prevention of Pollution from Ships, and the 1978 Convention on Standards of Training, Certification and Watchkeeping for Seafarers. Worldwide, nearly 30 countries—including Barbados, Bermuda, Cyprus, Gibraltar, Liberia, Malta, and Panama—have been identified as “flags of convenience” by the Fair Practices Committee of the International Transport Workers’ Federation.

Salties visiting the GLSLSS fly flags of more than 30 countries (fig. 17). The most common flags are the Netherlands (14 percent of vessels), Cyprus (10 percent), the Bahamas (8 percent), and Norway (8 percent). Of the 220 Salties that entered the Great Lakes in 2002, about half were registered under a flag of convenience.

Port States

A port state has the authority to regulate, inspect, detain, or deny entry to a below-standard ship that visits its ports. Port state control is a powerful line of defense against substandard flag state enforcement of internationally agreed shipping standards, particularly in the interest of vessel safety and environmental protection. It is also a way for countries to stipulate requirements that exceed the international conventions. However, to comply with global trade law, any imposition or enforcement of this authority must be “flag neutral” and otherwise unbiased with respect to national origin. The United States, for example, unilaterally enacted regulations to address ballast water introductions of invasive species. The Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 (NANPCA) required vessels entering the Great Lakes to conduct ballast water management, and the National Invasive Species Act of 1996 (NISA) reauthorized these requirements and also established a regulatory national ballast water management program.

Seaway Development Authorities

The St. Lawrence Seaway Management Corporation’s Seaway Practices and Procedures, established under Section 99 of the Canada Marine Act, and the St. Lawrence Seaway Development Corporation’s Seaway Regulations, established pursuant to the St. Lawrence Seaway Act of 1954, jointly regulate the transit of ships in a subsection of the Great Lakes St. Lawrence Seaway System, from Montreal to Lake Erie. Every ship entering the GLSLSS after operating beyond the exclusive economic zone (EEZ) must agree to comply with these regulations.

Ports

Ports can issue port-specific regulations that cover a broad range of topics. Operational matters such as mooring of vessels, vessel speed while navigating around the port, and required safety procedures and safety equipment are typically included. Port regulations also establish the fees for berth space, wharfage, and support services that vessels must pay. Ports also have authority over environmental regulation, such as provisions regulating or prohibiting the discharge of oil into port waters.

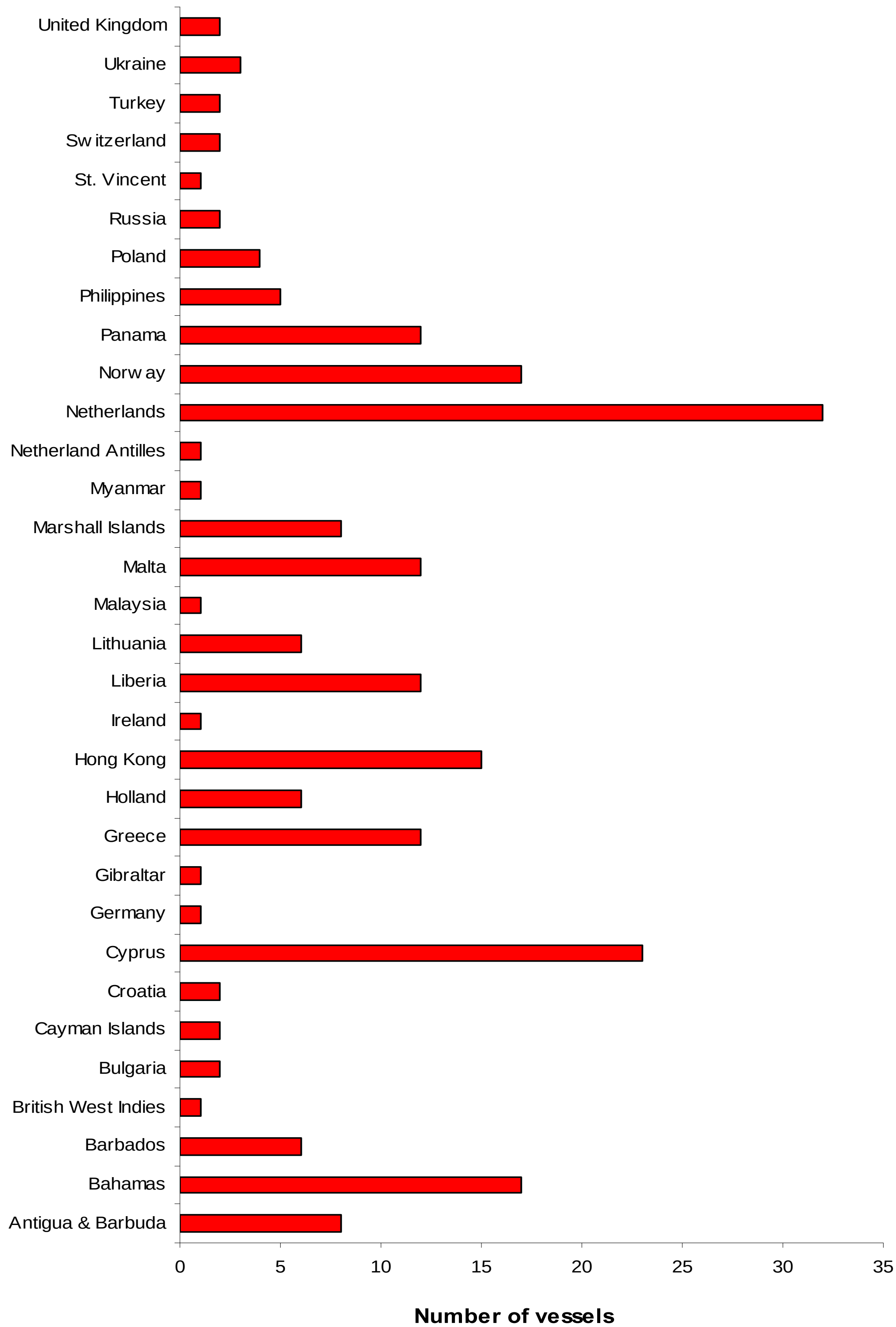

Fig. 17. Flag country of transoceanic vessels that entered the Great Lakes-St. Lawrence Seaway system in 2002[2]

States/Provinces

States and provinces have authority to regulate vessel operations in their waters, provided that those regulations do not conflict with constitutional powers of the federal government, federal laws, and regulations. States may enact regulations that address both operational and environmental concerns. Typically, state environmental regulation derives from the power to preserve and protect the state's natural resources (O'Shea and Cangelosi, 1996). From this authority, states have enacted regulations over various pollutant discharges, establishing No Discharge Zones for marine sanitation devices (in 15 coastal and Great Lakes states) and regulating ballast water discharges (in California, Oregon, Michigan, and Washington). A Washington law requiring oil spill prevention and response measures illustrates a conflict with federal authority; these regulations were challenged by an international tanker trade organization in 1995, and in 2000 the U.S. Supreme Court invalidated much of Washington's law on the grounds that it was preempted by the federal Oil Pollution Act of 1990 (Washington Attorney General's Office, 2000). However, this ruling affirmed a state's right to regulate discharge quality and, indirectly, the management practices of vessels in their waters.

Classification Societies

Regardless of cargo type, commercial operation, and flag country, marine underwriters will insure only classed ships. Therefore, all commercially operating vessels must be certified by a classification society—an independent, self-regulating organization that establishes and applies technical standards for the design, construction, and survey of ships. Societies issue these standards as published rules. A vessel that has been designed and built to the appropriate rules of a society may apply for and receive its certification upon completion of the relevant classification surveys. For ships in service, societies carry out regular surveys to be sure the ship remains in compliance with their rules. Should any defects that may affect class become apparent, or damage be sustained between the relevant surveys, the shipowner and/or operator must inform the society concerned without delay.

The role of classification and classification societies has been recognized in the International Convention for the Safety of Life at Sea and the 1988 Protocol to the International Convention on Load Lines. Classification is one element within a network of maritime safety partners, including the shipowner, shipbuilder, flag state, port state, underwriter, shipping financier, and charterer.

Classification rules are developed to contribute to the structural strength and integrity of essential parts of the ship's hull and its appendages, and the reliability and function of the propulsion and steering systems, power generation, and other features and auxiliary systems built into the ship to maintain essential services on board. Classification societies also maintain significant research departments that contribute to the ongoing development of appropriate, advanced technical standards.

More than 50 organizations worldwide define their activities as providing marine classification. Ten of those organizations form the International Association of Classification Societies (IACS): the American Bureau of Shipping, Bureau Veritas, China Classification

Society, Det Norske Veritas, Germanischer Lloyd, Korean Register of Shipping, Lloyd's Register, Nippon Kaiji Kyokai, Registro Italiana Navale, and Russian Maritime Register of Shipping. These 10 societies, together with the Croatian Register of Shipping and the Indian Register of Shipping—which have been accorded associate status by IACS—collectively class about 94 percent of all commercial tonnage involved in international trade worldwide, and about 95 percent of commercial tonnage involved in international trade in the Great Lakes (fig. 18).

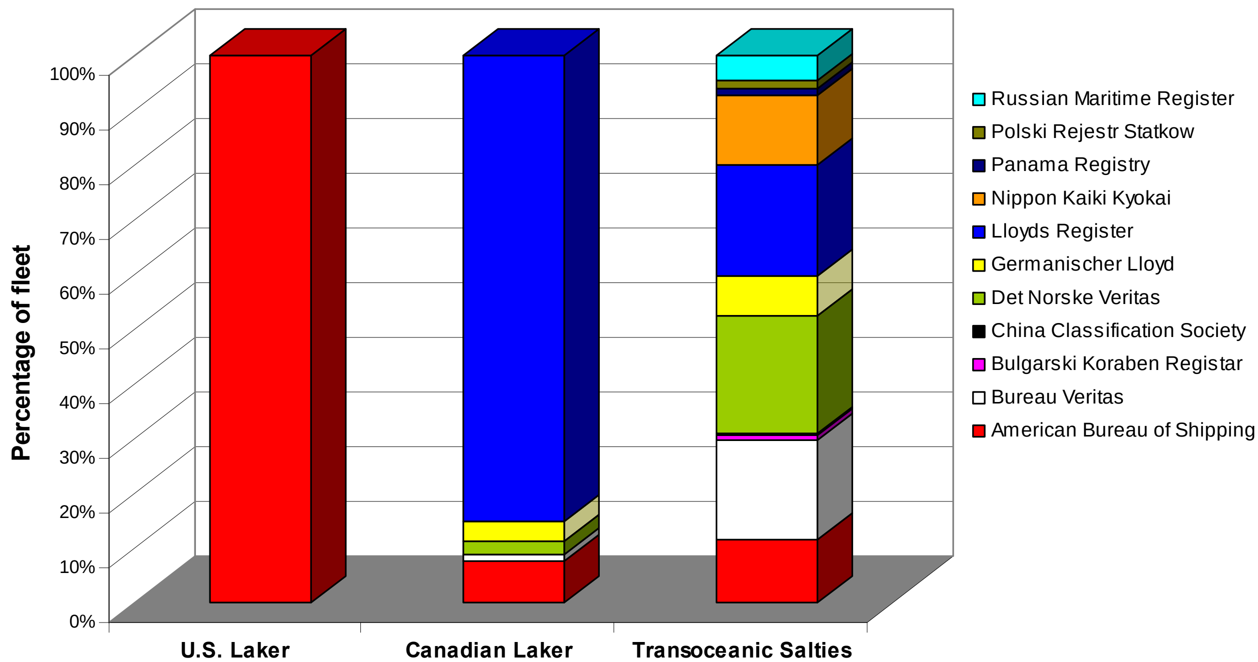

Fig. 18. Comparative vessel classification for U.S.-flagged lakers, Canadian-flagged lakers, and overseas-flagged Salty vessels operating on the Great Lakes-St. Lawrence Seaway system[2]

Drivers and Influences

Key drivers and influences for transoceanic waterborne trade activity in the GLSLSS include global events (such as catastrophic events, political conflict, global trade trends, and conglomeration); regional economic trends; competition with alternate modes of transportation/port ranges; and inertia.

Global Change

The globalization of the world economic and financial system means major economic trends and events anywhere in the world could influence commercial transportation activity on the GLSLSS.

Catastrophic Events and Political Conflict

Catastrophic weather or political events anywhere in the world could influence waterborne trade to and from the GLSLSS. In 2005, Hurricane Katrina devastated the Gulf Coast, disrupting operations and traffic in New Orleans and the Port of Louisiana, among America's busiest ports. It is clear that the closure of Gulf ports could have resulted in significant cargo diversion, either to other ports or other modes of transportation. A possible outcome could have been increased movement and/or storage of grain at Great Lakes ports, such as Duluth-Superior (Passi, 2005). However, Cargill, the nation's largest grain exporter, has indicated that their best option may be to accept decreased exports for a short while and remain unchanged until the Gulf Ports reopen (Knight Ridder News, 2005). For imported cargo, vessels originally destined for New Orleans could be diverted through the St. Lawrence Seaway to Great Lakes ports such as Burns Harbor (Associated Press, 2005). Given the combination of circumstances—such as a shortage of railcars for grain due to the rail system running at capacity, high fuel costs that make road transport unattractive, and limited capacity at the nation's other ports—it is difficult to predict Katrina's impact on patterns, costs, and efficiency of maritime transport.

Similarly, the September 11, 2001, terrorist attacks highlighted a need for vastly increased security at America's port facilities. New federal security requirements will require new expenditures. The American Association of Port Authorities estimates that port facilities will have to spend $5.4 billion on enhanced security measures over the next decade in order to comply with regulations mandated by the Maritime Transportation Security Act (AAPA, 2004). Some federal assistance is available through port security grants, but the ports will bear most of this cost and likely seek to recoup these expenses from their customers.

Economic Trends

Currently, intense development activity in China is consuming raw material and waterborne transportation capacity globally, creating a vessel shortage and higher freight rates for vessels that could be deployed to China. Because these higher rates do not apply to landlocked modes of transportation that cannot service China, such as rail, the cost advantage of using waterborne transportation versus rail transportation to move goods inland has diminished.

Increased oil prices are driving energy development trends that favor GLSLSS waterborne trade. For example, wind farm components destined for the Midwest and refinery components destined for tar sand plants in Canada, are in increasing demand, and can only be transported by ships due to their size.

Trade Barriers

Trade barriers are political actions that alter the distribution of markets for traded goods. In the global economy, such barriers can alter trade patterns, whether they are raised by the United States or abroad. Affected parties consider some barriers fair and others discriminatory. The World Trade Organization crafts agreements and houses mechanisms to thwart arbitrary or unfair barriers. Trade barriers that have affected maritime commerce into or out of the Great

Lakes include U.S. steel tariffs and European Union stipulations regarding genetically modified crops.

One trade barrier that affects maritime commerce into or out of the Great Lakes is the onset and removal U.S. steel tariffs. In 2002, President Bush imposed a tax on certain steel imports to help level prices of domestic products and often-cheaper foreign products, and provide relief to local steel companies. This barrier had little initial effect on Great Lakes trade, despite the importance of steel importation to that trade, because it exempted the steel moved by carriers into the lakes. However, following a 2003 World Trade Organization decision that the tariffs violate international trade rules, they were dropped. This decision put U.S. steel companies at a competitive disadvantage against heavily subsidized steel from other countries, such as Japan and Russia, and resulted in less movement of domestic steel on the GLSLSS by laker vessels. However, the decision also resulted in more steel being carried on the GLSLSS by transoceanic vessels to manufacturers such as automakers, and reduced manufacturing costs for these customers.

Another example is the barrier to shipment of genetically modified crops from the United States to countries overseas, particularly in Europe. In the late 1990s, farmers in the United States rapidly adopted genetically modified crops, resulting in the most intense diffusion of new agricultural technology ever experienced (Wisner & Wang, 2000). However, numerous governments and consumers in the United States and around the world have raised concerns about the human consumption of genetically modified crops. In September 2000, the approval process of genetically modified crops came under heavy scrutiny in the United States, with many companies and suppliers removing products from retail stores. The European Union sought to block entry of U.S. genetically modified crops. A number of countries, and most recently the European Union, have introduced mandatory labeling programs for grain and oilseeds processed directly for human consumption. This has resulted in fewer shipments of grain and grain products from the Great Lakes to these governments. Great Lakes crop producers that continue to ship to the concerned governments expend additional resources to separate nongenetically modified crops from genetically modified crops, labeling both products before shipping, and marketing and finding customers for genetically modified crops.

Conglomeration

In the shipping industry and many other industries worldwide, a major trend has emerged recently as companies merge into larger and more powerful organizations. This trend has resulted in the building and operation of more efficient ships, in terms of speed and cargo capacity, by fewer shipping lines. It has also enabled companies to play a role in more aspects of the supply chain, from port terminals operations to nonmaritime transportation of cargoes. The growing dominance of a handful of players capable of overseeing many, if not all, aspects of the transportation service chain for specific cargoes appears to have had a meaningful influence on the industry and market prices. For example, larger ships mean lower costs for the transported cargoes, and company mergers result in reduced administrative expenses—many of which have been passed on to the consumer. Beyond the issue of price, merged companies also offer a number of side benefits to shippers/receivers, including a consolidation of highly skilled management and "one-stop shopping" for global transportation services.

In addition, many companies are reducing the number of vendors and suppliers with whom they work. For example, Proctor and Gamble, a major international producer of personal and home-care products, now relies on only a handful of ocean carriers worldwide. Such decisions result in carriers calling at fewer ports, while serving others through transshipment of overland connections.

Competition with Alternative Transportation Modes/Port Ranges

Shippers of bulk steel and grain to and from the North American heartland are not entirely dependent on GLSLSS. There are road, rail, and river barge transportation alternatives to link inland producers and consumers to alternative West, North, East, and Gulf Coast port ranges. In particular, the GLSLSS competes with rail transit to West Coast ports for grain exports and Mississippi River barge shipping to Gulf ports for both grain exports and steel imports. The fact that the GLSLSS is closed for a portion of the year due to cold weather, and vessel size restrictions imposed by the Seaway channel contributes advantages to competing modes of transportation. Meanwhile, proximity to producers and markets, lower costs, and ability to move large objects (like windmill components) advantage the GLSLSS. According to a recent study, it would cost shippers and receivers of goods to and from the Great Lakes $55 million more per year to move cargo by alternate means such as truck or train, or by transferring it from overseas ships at eastern or Gulf ports for transport into or out of the Great lakes on barges or local boats (Taylor & Roach, 2005). Maritime industry advocates refute aspects of the study claiming it did not take into account the volume of cargo moved during specific times of the year. For example, nearly half the GLSLSS's grain exports move during the last three months of the years—a volume they claim would overwhelm alternate transportation options during that period.

Competition with rail to West Coast Canadian ports: Each year Canada exports approximately 25 million tons of grain (Canadian Wheat Board, 2004). At one time, the majority of Canada's grain grown in the prairies of western Canada was shipped by rail for export through Thunder Bay in the East. However, in 1995, Canada acted to deregulate rail transport of grain, and removed subsidies for the railways that carried grain (Fulton *et al*., 1998). Grain shipments from Thunder Bay have since declined steadily, from 10 million to 12 million metric tons before 1995 to 5 million to 7 million metric tons after 1995 (Thunder Bay Port Authority, 2005). In recent years, less Canadian grain has passed through the GLSLSS than the port of Vancouver alone, with a 2000-2004 average of 6.1 million metric tons traveling on the Seaway and an average of 9.0 million metric tons shipped through Vancouver (St. Lawrence Seaway Development Corp., 2004; Vancouver Port Authority, 2004). Prince Rupert, Canada's other major West Coast port, typically exports 2 million to 4 million metric tons yearly (Prince Rupert Port Authority, 2001). A significantly smaller amount, approximately 363,000 metric tons annually, is shipped through the Hudson Bay port of Churchill. Remaining exports are split between smaller ports on the Atlantic and Pacific coasts, or by direct shipment from prairie elevators.

Competition with river barge traffic to Gulf ports: In 2002, grain shipments exported from U.S. ports via the GLSLSS were only 2.2 percent of total U.S. grain exports and 6 percent of total U.S. wheat exports. By comparison, in the same year grain shipped down the Mississippi

River and exported via Gulf ports such as Baton Rouge and New Orleans accounted for 62 percent of total U.S. grain exports. Although much of this southbound cargo was corn or other commodities that are not shipped on the Great Lakes, the Mississippi River/Gulf Coast region still exported four times as much wheat as U.S. ports on the GLSLSS in 2002 (ACOE, 2004).

Competition with rail transit from East Coast ports: In the case of iron and steel products, Great Lakes shipping saves little in direct transportation costs compared with rail transit from East Coast ports, but saves up to six weeks in travel time, itself a source of significant cost savings. Shippers select the GLSLSS over rail because it can generate cost savings in three primary ways: reduced handling, reduced time of transit, and reduced freight rate. These cost savings stem in large part from the fact that rail capacity in the United States is already fully exploited (NRC, 1996). In addition, alternatives for transoceanic waterborne trade require intermodal transfers that can damage precision steel goods. It is estimated that rail rates for grain would be 15 cents to 30 cents/bushel higher in the absence of the GLSLSS alternative (Martin Associates, 2001). This observation is corroborated by the annual pattern of higher rail rates for grain in winter when the GLSLSS system is closed.

Regional Economic Trends

In the last 30 years, there has been a significant economic shift within the Great Lakes region and nationally from manufacturing toward the high-tech and service sectors, including outdoor recreation. The decline of smokestack industry in the Great Lakes region to these less "place-based" industries has meant a shift of income and employment growth away from port-based shipping-related economies. Accordingly, in some parts of the region, residents place a high value on a healthy natural environment where they can enjoy outdoor recreation and second homes. In the context of this shift in industrial culture and public values, Great Lakes port administrations are under pressure to improve the aesthetics associated with port activities, and replace working dock areas with residential and recreational assets. Annual GLSLSS traffic decreased precipitously in the 1980–1982 economic recession, and has been increasing modestly since then. The U.S. Army Corps of Engineers predicts future growth of 0.7 percent annually in the absence of GLSLSS improvements (ACOE, 2003).

Inertia

Established business relationships and trade routes moderate the timing and extent to which global events (economic or climatic) ultimately affect waterborne trade in the GLSLSS. Some shipments may be influenced more by the internal business decisions of multinational corporations than by ordinary comparative advantage. For example, patterns of steel shipments into and out of Cleveland seem to reflect this influence. Trade that is driven by the internal concerns of a particular multinational corporation may be relatively insensitive to shipping costs.

Logistical inertia is a major driver of transportation choices in the marketplace, even when it runs counter to cost effectiveness. Shippers may continue with one approach to transportation despite fluctuations in its efficiency *vis a vis* other approaches because there is considerable transaction cost associated with making changes, and the cost savings may be short lived. A recent survey that assessed the criteria shippers use to select transportation providers found that while pricing was the most important factor, other factors such as on-time performance, customer service, document quality and accuracy, and shipment tracking were also considerations. Furthermore, 62 percent of the shippers surveyed indicated they were reluctant to switch transportation providers based solely on price (Journal of Commerce, 1999). (See tables 7a and 7b for additional detail.)

Table 7a. Results from a survey assessing shippers' ranking criteria for selecting a transportation provider

Factor	Percent of shippers rating this factor as "most important" (%)
Pricing	31
On-time performance	22
Customer service	13
Document quality and accuracy	13
Shipment tracking	11
Global coverage	5

Table 7b. Results from a survey assessing shippers' ranking criteria for selecting a transportation provider

Statement	Percent of shippers who agreed with statement (%)
See inherent value of carriers	72
Reluctant to switch transport providers based solely on price	62
Would sacrifice a few days for price	50
See confidential rates as extremely important	48
Believe confidentiality as achievable	29

III. Ship-Mediated Biological Pollution in the GLSLSS and its Prevention

Biological pollution is the displacement of viable and harmful biological material from one ecosystem to another. Ship-mediated biological pollution occurs as a consequence of ship movements between disparate ecosystems. Technically, ship-mediated biological pollution can include terrestrial organisms, in particular forest and crop pests that have arrived in grain cargo and in wood pallets. However, this scoping effort focuses on aquatic organisms that hitch rides in ships' ballast water, on their hulls, and adhered to anchor chains or sea chests. This section describes ship-mediated biological pollution, and the state of the art of prevention, including prevention policy, prevention methods, and regulatory regimes.

Ship-Mediated Biological Pollution

Ballast Water

Ballast water and entrained solids in ships entering the GLSLSS from overseas are considered the primary mode by which ships transfer non-native aquatic organisms (Grigorovich *et al*., 2003a). It is also considered the primary mode of ship-mediated biological pollution globally (Carlton *et al*. 1995, Carlton & Geller 1993, Carlton 2001).

Function of Ballast Water

Ballast water is essential to present day commercial ship operations. When ships are empty or partially empty of cargo, they take on ballast water to maintain draft and stability, submerge the propeller and rudder, and uphold acceptable stress loads on the hull. Weather conditions and water depth influence a ship's ballast operations, but the amount, weight, and distribution of cargo on board ultimately determine ballast loads and distribution within the ship. The greater the load of cargo, the less ballast water and vice versa.

Ballast Operations in the GLSLSS

Ballast uptake and discharge most often occur in port during cargo operations, but may also occur while the vessel is in transit in the open lake or through connecting waterways to maintain trim. Ships generally contain two matched pumps to drive ballasting operations, but to save fuel a ship's master will employ the process of "gravitation" to load and unload water, using gravity instead of ballast pumps, to the extent possible.

For ships that enter the GLSLSS loaded with cargo and make their first stops in the southern lakes to off-load cargo, most ballast uptake occurs in those lower lake harbors. This ballasting process prepares the ships to travel empty of cargo to upper lakes ports to load grain. Subsequent ballast discharge occurs in the upper lake ports where grain cargoes are loaded (fig. 10).

Ballast water storage capacities and flow rates differ among various types of vessel. Seaway-sized bulk carriers have a ballast capacity of around 10,000 cubic meters and pump rate of 600 cubic meters per hour; Seaway-sized tankers have a ballast capacity of 5,000 cubic meters and pump rate of 300 cubic meters per hour; and Seaway-sized general cargo carriers have a ballast capacity of around 8,000 cubic meters and pump rate of 900 cubic meters per hour. These volumes and pump rates are less than other transoceanic vessel types (table 8), and diminutive relative to the largest vessels on the lakes, the U.S.-flagged lakers, which have an average ballast capacity of 30,000 metric tons—three times that of Salty vessels, and double that of Canadian-flagged lakers (table 1). The ballast pump rate of these vessels—approximately 4,500 metric tons per hour—is also more than double that of the Salty and Canadian-flagged laker fleets (table 1).

Table 8. Comparison of ballast capacity and ballast pump rate across major vessel types

Ship Type	Ballast Capacity (m^3)	Ballast Pump Rate (m^3/hour)
Seaway-sized bulk carrier	10,000	600
Seaway-sized tanker	5,000	300
Seaway-sized general cargo carrier	8,000	900
Handymax bulk carrier	25,000	800
Panamax bulk carrier	35,000	1,000
Capesize bulk carrier	60,000	2,800
Aframax tanker	60,000	1,500
VLCC tanker	120,000	3,000
LNG carrier	50,000	2,400

Ballast Tank Residuals

Even when fully loaded with cargo, ships are rarely completely empty of ballast water. There is clearance below the bell mouths of the ballast lines in the ballast tanks to avoid clogging that makes some amount of water unpumpable using standard ballast pumps. The residual ballast water is a mixture of water and sediment from ports recently visited around the globe (e.g., fig. 19), with volumes up to 200 cubic meters per Seaway-sized transoceanic vessel (Johengen *et al.*, 2005). To reduce cost of displaced cargo capacity caused by unpumpable ballast residuals some shipowners/charterers (e.g., FedNav) require routine ballast purges in the high seas to ensure that unpumpable residuals are water only rather than heavier sediment (George Robichon, pers. comm.). Ships carrying extremely high-value cargoes may be equipped with a "stripper pump" system to remove water residuals as well (George Robichon, pers. comm.). When the cargo value is lower, the residuals are simply transported to the next port of call and become resuspended during subsequent ballast uptake.

On arrival in the Great Lakes system, vessels fully loaded with cargo, i.e., those declaring "no ballast on board" (NOBOB), generally off-load cargo in ports in the lower lakes where they take on ballast water, and proceed to a series of Great Lakes ports in the upper lakes to pick-up and off-load additional cargo (and ballast water). During these short voyages, the residual, unpumpable ballast water from overseas ports mixes with Great Lakes ballast water and is discharged—and thus diluted into the ports of call in the upper lakes where cargo is loaded.

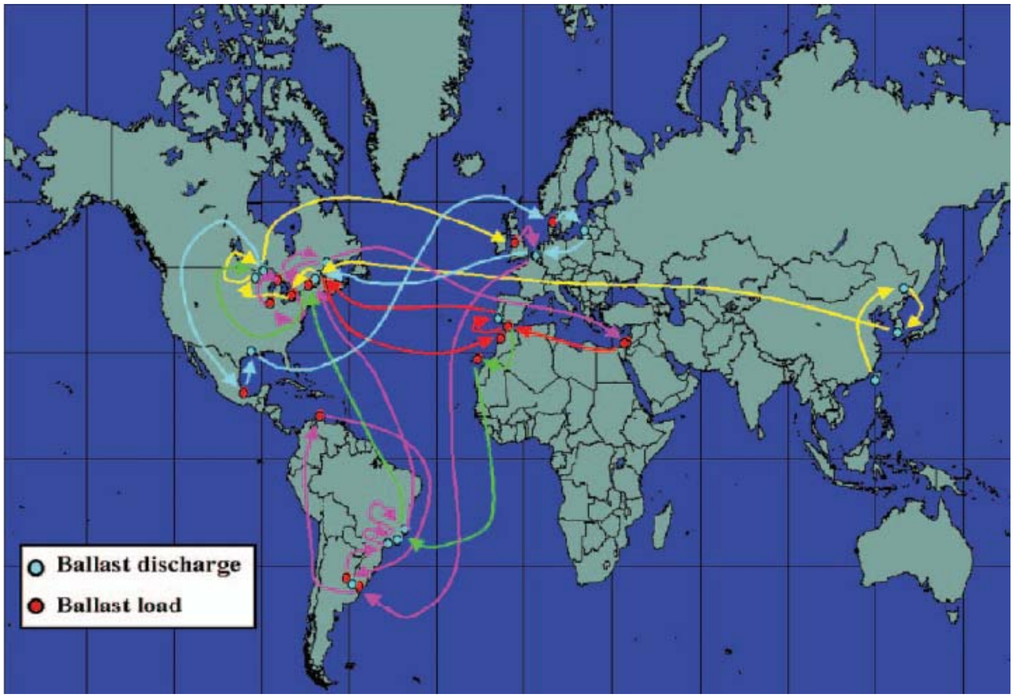

Fig. 19. Global activity of a single transoceanic vessel over a 14-month period. Circles indicate sites where ballast water was loaded (red) and discharged (light blue) (source: Holeck *et al*., 2004)

Ballast Water-Entrained Biota

Ballast water uptake in ports entrains ambient organisms and—if the port is shallow—suspended solids, as well as associated chemical pollutants. Similarly, ballast water taken up in the process of a BWE at sea contains an array of open ocean taxa. Ships transport these organisms and species, often in a viable condition, across natural biological barriers to distant receiving systems where they are released and may become invasive.

Nearly all major phyla can occur in ballast water; overall, ocean-going ships transport at least 7,000 species between continents every day (Carlton, 1999). A review of several European ballast water studies (Gollasch *et al*., 2002) reported 990 different taxonomic groups, including bacteria, fungi, protozoans, algae, invertebrates, and fish. The most frequently detected taxa in these studies were algae, and crustacean, molluscan, and polycheate invertebrates. Moreover, all life stages of these organisms, including resting stages, are entrained in ballast water. While species diversity in ballast tanks can be quite high, it can also vary greatly. The studies in the same review observed diversity ranging from 3–502 total taxonomic groups (Gollasch *et al*., 2002).

The numbers of individuals in these taxonomic groups in ballast tanks varies too, and can be high. An examination of vessels traveling on the U.S. East Coast found 3,800–39,000 live organisms per cubic meter in ballast water at the end of each voyage (Lavoie *et al*., 1999). Lenz *et al*. (2000) estimated abundances of more than 50,000 zooplankton and 110 million phytoplankton per cubic meter in ships' ballast water. In 2003, the International Council for the Exploration of the Sea (ICES) conducted a review of worldwide ballast water studies to determine the range of organism concentrations observed in ships' ballast water. Zooplankton concentrations in these studies ranged from 0–172,000 individuals per cubic meter, with a mean concentration of 464 organisms per cubic meter. In the same studies, phytoplankton concentrations ranged from 1,000–4.9 x 10^{10} per cubic meter, with a mean concentration of 2.9 x 10^{8} organisms per cubic meter (IMO MEPC 49/2/21, 2003).

Ballast tanks also have been shown to harbor pathogenic bacteria and viruses. The ICES review of ballast studies reported bacteria concentrations between 2.4 x 10^{11} and 1.9 x 10^{12} cells per cubic meter, with a mean concentration of 8.3 x 10^{11} cells per cubic meter, and virus-like particle (VLP) concentrations between 6 x 10^{11} and 14.9 x 10^{12} particles per cubic meter, with a mean concentration of 7.4 x 10^{12} particles per cubic meter (IMO MEPC 49/2/21, 2003).

In the United States, *Vibrio cholerae* have been observed in the ballast tanks of cargo vessels visiting ports of the Gulf of Mexico (McCarthy and Khambaty, 1994), and Drake *et al*. (2001) described microbial populations (including *V. cholerae*) aboard vessels arriving in the Chesapeake Bay. A number of fecal-indicating organisms and human pathogens also have been detected in ballast water residuals of transoceanic cargo vessels visiting the GLSLSS, including fecal coliforms, fecal streptococci, *Clostridium perfringens*, *Salmonella* spp., *E. coli*, *Vibrio cholerae*, *Cryptosporidium* spp., *Giardia* spp., and enteroviruses (Knight *et al*., 1999).

Niimi and Reid (2003) and Johengen *et al*. (2005) theorize that unpumpable ballast residuals in ships that enter the GLSLSS declaring no ballast on board (NOBOB) also present a high risk for continued species introductions to the Great Lakes. For example, Johengen *et al*. (2005) identified 186 taxonomic groups in residual ballast water and sediments from vessels. The most common of these were numerous dinoflagellate and diatom species, copepods, rotifers, cladocerans, and nematodes—many of which are nonindigenous to the Great Lakes. Other organisms—such as mites, ostracods, barnacle larvae, chironomids, hydrozoans, gastropods, bivalves, amphibods, crab, and shrimp—were found in lesser quantities. Furthermore, MacIsaac *et al*. (2002) estimated that residual water carried by these vessels could contain up to 10^{5} zooplankton per cubic meter. An examination of ballast sediments aboard vessels entering the Great Lakes by Bailey *et al*. (2003) found highly variable densities of copepod eggs, but estimated that each vessel could discharge between 5.3 x 10^{5} and 8.6 x 10^{8} of viable propagules (Bailey *et al*., 2003). Appendix B provides estimates of the ballast volumes and numbers of foreign organisms that may be discharged into the GLSLSS by transoceanic ships in light of current trade patterns and ballast management practices.

A Note on Hulls, Anchor Chains and Sea Chests

Though ballast water is considered the dominant vector of aquatic species introductions to the Great Lakes since the 1960's (Mills *et al*., 1993; Ricciardi, 2001), other components of vessels are also responsible for the introduction of aquatic species to disparate ecosystems. For example, hull fouling has played a significant role in the transport of sessile species—including ascidians, sponges, polychaetes, barnacles, bivalves, and gastropods—to brackish and marine waters in many ports and regions of the world. However, unlike ballast water, which threatens only receiving systems when a vessel discharges its ballast water, hull fouling is a risk to all ports that a vessel visits irrespective of a cargo condition.

In the Great Lakes, hull fouling is not considered a significant vector for new introductions from overseas because most freshwater fouling organisms would likely not survive prolonged exposure to highly saline (i.e., 30 ppt) oceanic water during transoceanic voyages. The vector may nonetheless be responsible for the subsequent spread of already introduced fouling species throughout the lakes by U.S. and Canadian laker vessels, particularly those that remain entirely within the lakes' freshwater system.

The significance of other possible ship-related vectors in the transport of species to the Great Lakes—including bilge discharges, sea chests, sea-sieves, anchors, chain lockers, intake pipes, bow thruster tunnels, rope guards, and piping—is unclear. A great deal more research, focusing on the ship as a whole, is needed to ascertain the degree to which these vectors are responsible for the movement of species, particularly in light of research indicating that well-known aquatic invaders—including the zebra mussel—are able to tolerate at least some level of salinity.

The State of the Art of Prevention

Both prevention policy and prevention technology related to ship-mediated biological pollution are in developmental stages. The absence of a regulatory standard and near-term implementation dates has stalled more active development of solutions (GAO, 2005). However, this situation is so unacceptable that a more advanced condition is likely on both fronts. In particular, Congress is likely to act this year or next to resolve questions of standards and timeframe. This section summarizes key policy and technology questions for preventing ship-mediated transfers of aquatic invasive species into the GLSLSS.

Prevention Policy

Fundamental policy questions remain unanswered and there is little consensus about the best approach to preventing ship-mediated biological pollution, even among advocates of rapid progress. Therefore the best next policy step will likely be a set of goals and contingencies should the goals be unachievable. The fundamental policy questions include:

How Clean is Clean?

Our society rarely precisely defines the word "prevention": is it reduction of risk to a particular acceptable level, or is it the absolute elimination of risk? Complicating this discussion relative to ship-mediated introductions of invasive species is the fact that the discharge rate (propagule pressure) associated with a particular level of risk, including no risk, is not known to science, and/or may vary dramatically among species, places, seasons, and years. The only scientific point of agreement seems to be that zero ship-mediated transfers of species beyond their range would attenuate ship-mediated species invasions. There is no agreement, and no direct evidence, to support a protective performance standard that exceeds zero. In the absence of this information, policymakers latch their proposed solutions to logic associated with one of at least two interacting schools of thought. These include:

- ***"Less is more" and "least possible is best":*** This theory holds that risk to the environment may be directly related to inoculation pressure, such that less inoculation pressure is likely to increase environmental protection, and the extent of environmental protectiveness could increase as inoculation pressure approaches zero.

- ***A threshold inoculation concentration:*** This theory holds that there may be an inoculation threshold level that should be the action level. Reductions below that level are irrelevant, either because organisms delivered via other vectors squelch any additional prevention benefits, or because the organisms are unlikely to become established if the inoculation falls below a given concentration. In the same way, partial reductions that do not breach the action level threshold are likely not worth the trouble.

It is not clear whether or to what degree either theory reflects reality. The resulting problem of how best to regulate in the context of these unknowns, while vexing, is not at all new to environmental policy. Policymakers encountered the same questions in the effort to regulate carcinogens, spurring the famous mega-mouse study, which consumed thousands of mice in its attempt to determine the nature of exposure risk (continuous or threshold-like) associated with carcinogens. The same issue also led to Great Lakes Water Quality Agreement language stipulating "virtual elimination" of high-priority toxicants in discharges to the Great Lakes, skirting the question of whether a numeric representation of virtual elimination is zero or some higher value. In the end, it is a matter of societal judgment whether the prevention should be absolute or a matter of minimizing risk to an acceptable level greater than zero.

Is Treatment a Viable Approach to Prevention?

In reality, treatment generally will never be 100 percent effective. Because ships are very large and can harbor very small organisms of concern that are capable of rapid asexual reproduction—including bacteria and viruses—in numerous places, a ship would need to be actively toxic inside and out throughout its journey to absolutely prevent incidental organism transfers. Likewise, a shore-based facility would have to immerse the entire ship—hulls, anchor chains, and all—and sterilize ballast tanks to avoid regrowth. For these reasons, those who want to eliminate risk with certainty may gravitate to the prospect of curtailing waterborne transportation into the GLSLSS from overseas generally. Taylor and Roach (2005) conducted an economic analysis that found that curtailing saltwater shipping into the Great Lakes would not be more expensive than sustaining further ship-mediated invasions. Under this scenario, goods shipped by waterborne transportation and destined to the Great Lakes region would be transferred to laker ships at a new transfer facility, or intermodally from existing East Coast port facilities.

Indeed, if society values sufficiently absolute and certain prevention of new direct ship-mediated introductions of invasive species into the Great Lakes, this outcome is likely to evolve naturally from economic forces ensuing from the escalating costs of waterborne cargo movement associated with meeting tight treatment requirements. However, this high value on absolute prevention would have to exist in the context of continued introduction (and consequent overland migration) or ship-mediated organisms to other coasts, and continued introductions of aquatic organisms by other vectors. If society can accept a solution that delivers prevention to a lesser degree or with less certainty, and/or wishes to improve protection of the Great Lakes through positively influencing global ship-vector prevention, then shipboard treatment is likely to be the preferred outcome.

Where to Treat, on Ship or Shore?

In theory, shipboard treatments (ballast and hull) could be pushed to a level of extreme effectiveness that virtually eliminates risk of organism transfer without commensurate side-effects for the environment, but this outcome would carry high cost and a protracted development horizon. Moreover, it would require the problematic monitoring of treatment systems operation on every ship.

Some practioners suggest shore-based ballast treatment as an alternative to shipboard treatment because there are fewer logistical constraints (such as space and power requirements) in shore applications. The hope is that resolving the technological problems in this way will make greater prevention effectiveness feasible sooner. As fixed entities, land-based treatment systems would also be easier to monitor using conventional approaches. However, though a greater range of technology options could be applied to ballast treatment in a land-based scenario, this advantage does not guarantee quicker or more effective prevention implementation than ship-based treatments.

First, ships would need to be retrofitted in dry dock to pump to a land-based facility. Second, the land-based facility or facilities would need to be authorized, funded, designed, constructed, and effectively operated, which implies substantial start-up time and effort. Finally, even if shore-based treatment could be organized rapidly, from a biological standpoint, the investment would be in a piecemeal treatment strategy, which given invasive organisms propensity to spread, does not spell effectiveness for any ecosystem. The few locations where motivated and resourceful operators might effectively undertake shore-based ballast treatment would not be adequate to staunch new source regions for pest species, and only a subset of these locations might actually choose to do so. Under these circumstances, eventually organisms would move over land, often quite rapidly, to protected ecosystems, negating the value of the investment in shore-based treatment.

In light of these realities, shore-based treatment may be most useful as a threat or fallback requirement should the development and implementation of shipboard treatment be too slow. This approach is embodied in the Great Lakes Regional Collaboration Strategy document (Great Lakes Regional Collaboration, 2005). In addition, the Australian Ballast Water Treatment Consortium (ABWTC)—a team of researchers based at James Cook University and a consortium of Australian government and industry partners—has developed a pilot plant to sterilize ballast water. Housed in a portable, 20-foot-long shipping container, the plant uses filtration, UV irradiation, chlorine dioxide injection, and a high-speed sonic/shear device to treat ballast water as it is loaded onto a ship (Hillman *et al*., 2004).

Even so, advocates of a shore-based backup plan will have to be very careful to prevent discourse over shore-based treatment from becoming a digression from, or an excuse for the industry to avoid, investment in shipboard solutions. Also, to the extent that public funds available to redress ship-mediated invasive species are limited, any investment in shore-based solutions—even as short-term or fallback options—will reduce the available funding for high-quality shipboard treatments.

How Can Governments Speed Development of Treatment Tools?

Once it is accepted that shipboard treatment is a necessary, if insufficient, answer to the problem of ship-mediated invasions into the Great Lakes, another important policy question emerges: How can governments exploit market forces to catalyze and accelerate research and development of effective treatment systems? A market analysis commissioned by the Northeast-Midwest Institute estimated that the ballast treatment system market could exceed $1 billion following ratification of the IMO treaty (Royal Haskoning, 2001). Current policy would appear a perfect recipe for delay. Though treatment has been heralded as the “long-term” solution to the problem since at least 1990, uncertainty over the performance requirement for treatment and deadlines for its application to ships has thwarted investment in treatment system development by vendors and venture capitalists.

Two types of performance requirements are under constant discussion:

- A benchmark for treatment performance that would essentially eliminate risk to the environment, also called an “environmentally protective standard”.
- A benchmark for ensuring that an alternative treatment performance exceeds that of BWE.

Presumably, the benchmark for exceeding BWE performance is lower than the environmentally protective benchmark. The question is how to stimulate the development of treatment systems that perform as close to the environmentally protective standard as possible—as soon as possible—without legislating the impossible.

Policy options under discussion include:

- ***Option 1: Set a treatment standard based solely on what is needed to protect the environment, and impose the standard upon availability of cost-effective treatments that meet the standard. In the meantime, use best management practice, including BWE.***

This alternative defines a treatment expectation and sets a tentative deadline for future application of the standard, but if no treatments are available to meet the standard in a cost-effective manner by the deadline, application of the standard will be delayed. If treatments are available sooner, the deadline will be moved forward. This approach is essentially consistent with pending legislation (S.363) as reported by the Senate Commerce Committee, which requires BWE of all ships until treatments become available that meet the ultimate, environmentally protective, discharge standard (though there is also a narrative provision for approving treatments that are better than ballast exchange).

The bill sets tentative dates (such as 2014 and 2016 for Seaway-sized ships) for imposition of the standard, but these deadlines are subject to change depending upon availability of suitable treatments. If no cost-effective treatments are deemed available, this approach means protracted use of BWE practices, which are known to be inadequate for protecting the Great Lakes. The distant and uncertain nature of the deadlines could reduce incentive for near-term treatment development activity. Politically, states are likely to regulate in the absence of faster federal controls. Still, advocates of this approach contend that it will result in the development of better technologies, though they may be fewer and longer in coming. It also means that ships will have to install treatment only once. For the same reason, this approach is highly feasible from a regulatory standpoint.

- ***Option 2: Set a treatment standard and deadlines for imposing it, and assess all policy options three years before the deadline.***

This approach essentially sets a treatment standard and a tentative deadline as a goal for treatment developers, but defers the decision of what to do if no treatments are available by three years before the deadline. Meanwhile, BWE is the primary if not exclusive alternative practice. Both the IMO convention on ballast water and S. 363 as introduced used this approach. The advantage and disadvantage of this approach is flexibility, which would never hold the industry to an impossible treatment standard, but also would provide little predictability for prospective vendors of treatment systems.

- ***Option 3: Set a standard and a deadline and stick to both.***

This option is designed to force a solution that allows the transportation/manufacturing industry to respond in whatever way it finds most efficient. Options include one or more of the following:

- Develop and use highly effective on-board treatment systems; shore-based treatments at a choke point in the GLSLSS; or backup port-based treatment systems that effectively render Salty ship operations in the GLSLSS risk-free.
- Use a cargo-transfer facility to move cargoes from Salty to captive laker fleets.

- Shift transportation modes to train or truck from saltwater ports.
- Relocate receiving industry to saltwater coastal port ranges.

In terms of costs, this approach reflects a gamble. It could truncate an unnecessarily protracted research and development effort and deliver truly protective treatment most efficiently because it attenuates the costs of nonindigenous aquatic invasive species in the GLSLSS most rapidly, and would set up a healthy competition among treatment vendors to supply the most cost-effective approaches. However, if industry cannot (or chooses not to) meet the deadline, this alternative could drive up costs, including protracted legal wrangling, the significant adaptations of current trade patterns listed above, and/or continued nonindigenous aquatic invasive species introductions while the best approach is being determined.

This option would require binational cooperation with Canada, and the United States or any other government would have to ensure that the method chosen does not transfer the problem elsewhere.

- ***Option 4: Set a protective standard and a date certain at which ships must use best treatments available; raise the performance floor over time as treatments improve until standard is met.***

This alternative, embodied in the National Aquatic Invasive Species Act (S. 770), manages the problem of uncertain treatment technology development by requiring ships to use best treatments available pending the development of treatments that achieve environmental protectiveness. Congress or the federal government would set a protective standard and a date certain for ships to install best treatments available, and as treatments improve, the less effective options will be dropped from the list of approved alternatives until the standard is met. Ships have a guaranteed approval period for any "best option" treatment systems they install; ships would have to upgrade their installations after the approval period, but probably not more than once per Salty ship.

This alternative implies a level of continued risk of nonindigenous aquatic invasive species until the perfect treatment systems develop, but immediate improvements in prevention are all but guaranteed. It is likely that the best-performing treatments currently exceed the effectiveness of BWE, but this fact requires verification. Meanwhile, this approach requires improved BWE—including practices such as flushing and stripping to mitigate NOBOB risk, more thorough purges of ballasted tanks (higher volume exchanges) and greater accountability, as well as management of hulls and other ship surfaces to prevent fouling. Setting a non-negotiable deadline and the ultimate standard for environmental protection will prevent shipowners from stalling treatment development at a mediocre stage. Assuming that the best treatments at least meet the IMO standard, even treatments approved early in the process will be internationally accepted.

Do All Ships Need to Treat?

There has been some discussion of how to best target regulations to achieve the best performance. Australia, in particular, has actively developed a risk assessment tool to target regulations on high-risk voyages. Some of this discussion stems from a resource-stakeholder interest in reducing political opposition to meaningful regulation, and some has been motivated by industry interest in reducing the economic impacts of regulation. The resulting proposals use risk assessment and other modeling exercises to predict the highest-risk voyages, based on identifying:

- Ecosystems that are most environmentally matched and therefore conducive to the establishment of transferred organisms.
- Receiving systems that appear to be invasion hot spots.
- Species in ballast-source regions that have characteristics conducive to invasive behavior, in a particular a receiving system like the Great Lakes.

Each of these approaches remains theoretical and controversial. The problem is not only identifying voyages associated with a known high risk of invasion potential, but ascertaining whether the risk of other voyages is actually low or just unknown. Moreover, such predictions must be reliable for all taxonomic groups that the ship may be carrying, across seasons and receiving- and source-system pairings. This would be a Herculean modeling task under the best of circumstances, but nature is also sending mixed signals. Recent studies in invasion biology have examined the relationships between ship-mediated invasions and commercial shipping patterns. Analysis of the sites of first discovery for aquatic invaders in the Great Lakes has indeed identified four invasion hot spots: the Lake Huron–Lake Erie corridor; the Lake Erie–Lake Ontario corridor; the Lake Superior–Lake Huron corridor; and the western end of Lake Superior (fig. 20). These hot spots comprise less than 6 percent of the total water surface area in the Great Lakes, but account for approximately 53.5 percent of the aquatic invasive species recorded since 1959 (Grigorovich *et al*., 2003a).

The locations of ballast discharge roughly correspond to these invasion hot spots. Four of the basin's significant ports—Cleveland, Detroit, Duluth-Superior, and Toledo—are in or around discharge areas. However, though southern Lake Michigan, with the ports of Chicago and Burns Harbor, is another major area where ocean-going vessels deballast, the area is not an invasion hot spot. Poor water quality and the need for ships to begin to deballast prior to arriving at shallow berths could explain some of this effect. Conversely, the Lake Superior–Lake Huron and Lake Erie–Lake Ontario hot spots are generally not near the basin's busier ports, but it is possible that ships discharge ballast water to reduce draft before entering these shallow passages (Carlton *et al*., 1995).

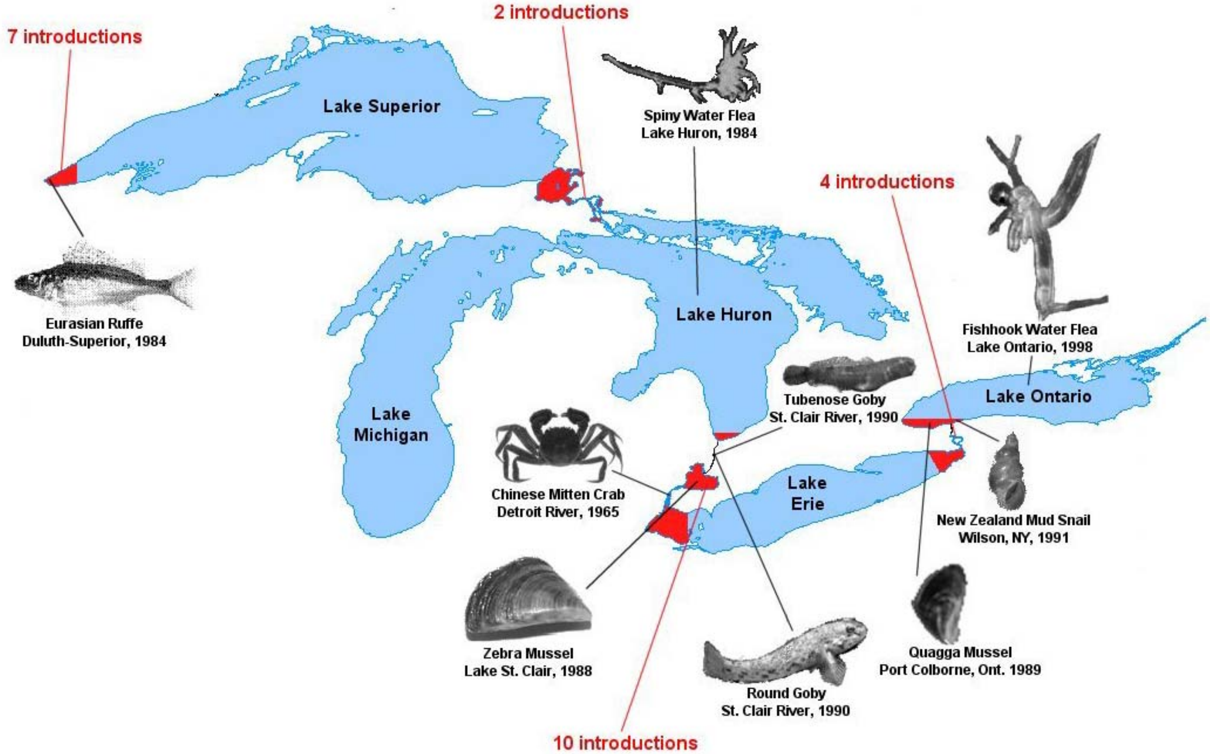

Fig. 20. Great Lakes map showing invasion hot spots, based on number of first sightings of presumed ballast-mediated invaders, including examples (source: Grigorovich *et al*., 2003a)

The conditions within the receiving system also may affect vulnerability to invasion. Despite the hot spot near Duluth–Superior, Lake Superior overall had a small number of invasions, especially considering that this lake receives a disproportionately large amount of ballast discharge from Salty vessels that initially enter the lakes declaring NOBOB. Since 1959, only eight species new to the Great Lakes were initially recorded in Lake Superior. This may be explained by bias in research efforts to survey and identify invasive species in Lake Superior. However, other factors, such as mismatches of Lake Superior's physiochemical characteristics with potential invasives' physiological tolerances, or food limitation associated with low productivity, may also contribute to this lower invasion rate (Grigorovich *et al*., 2003b).

Unfortunately, the relationship between known ballast-discharge areas and invasion hot spots is weak enough that it cannot justify geographically targeting regulatory activity. Moreover, intensified restrictions at invasion hot spots in the lakes could have the effect of simply shifting commercial shipping activity—invasion risk—to the less-regulated areas. Given the high stakes of relaxing prevention erroneously, and the inherent complexity of prediction, the best policy outcome of a serious modeling exercise would likely resemble a blanket prevention policy, like the current U.S. policy.

Prevention Techniques

Ballast water is the suspected primary means among many for a ship to transport organisms to the GLSLSS. Shipboard prevention measures will require changes or additions to normal ship operations, such as management practices and treatment systems. Some of the prospective methods and their development status are outlined below.

Ballast Water Management

Ballast water management can take the form of management practices, treatment systems to alter the quality of ballast discharge, or revisions to ship design that eliminate the need for ballast water.

Ballast Water Exchange (BWE)

Federal law requires ships to undertake ballast water exchange (BWE) before entering any U.S. port after operating outside the EEZ. BWE is an accepted practice, both nationally and internationally,[5] to attenuate ballast-mediated species transfers by replacing ballast water taken on board in coastal areas, including at docks and ports, with open-ocean water prior to discharge in subsequent ports of call. The theory behind the practice of BWE is that open-ocean organisms, adapted to high seas conditions, are much less likely to become established in near-coastal areas than organisms from ports of origin, which are adapted to near-coastal conditions—even though there has been little empirical research on its effectiveness as a prevention measure (Locke *et al*., 1993). Open-ocean water is defined variously depending on the regulatory body. For example, the National Invasive Species Act of 1996 defines open ocean as "water beyond the 200-mile exclusive economic zone." Similarly, the International Convention for the Control and Management of Ships' Ballast Water and Sediments defines it as water "at least 200 nautical miles from the nearest land and at least 200 meters in depth." In contrast, Australia's ballast water requirements define open ocean as "outside the Australian 12-nautical-mile limit."

There are two forms of BWE: flow-through and empty refill (fig. 21). Ships undertaking flow-through exchange gradually flush water through full ballast tanks. Empty refill involves discharging the ballast water completely and then refilling the tank. BWE has several limitations as a preventive measure; the volumetric purge is never a complete one, and organism purges are less efficient yet. While the uppermost volumetric purge using these operations is 99 percent, the purge of these two operations for replacing near-coastal zooplankton with open ocean zooplankton, for example, is closer to 70 percent (Locke *et al*., 1991; Taylor *et al*., 2002).

[5] National Invasive Species Act of 1996 (NISA) and International Convention for the Control and Management of Ships' Ballast Water and Sediments

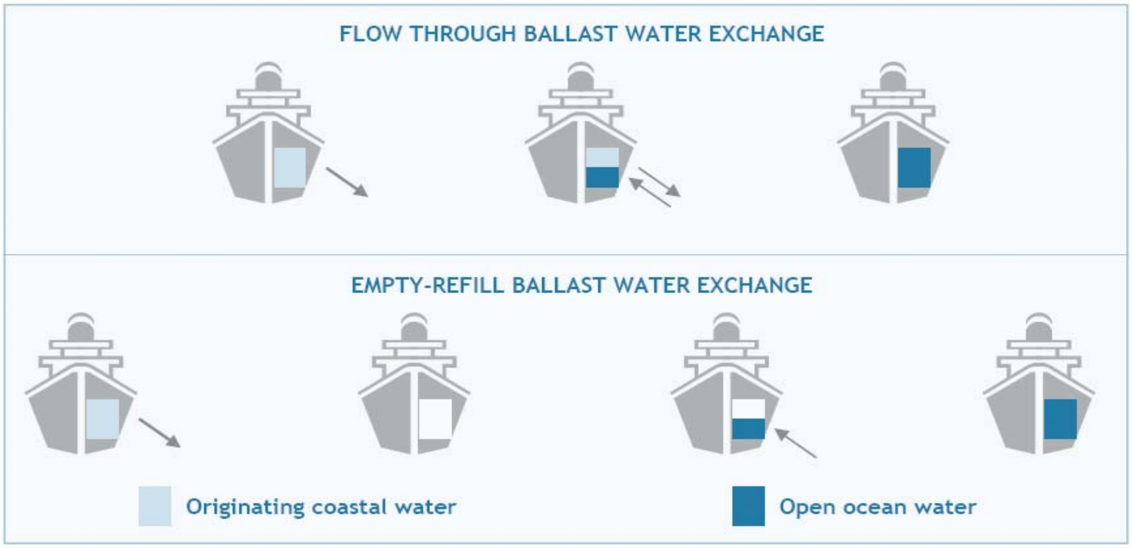

Fig. 21. The two forms of ballast water exchange: flow through and empty-refill. A flow-through exchange continuously pumps ocean water into ballast tanks, forcing coastal water out. In an empty-refill exchange, a ballast tank filled with coastal water is completely flushed and refilled with ocean water.

Both BWE methods likely offer some prevention capabilities, but are encumbered with limitations such as the following:

- Vessels in the NOBOB (unballasted) condition cannot conduct complete exchange of their ballast water and thereby purge residuals due to load limits.
- Industry representatives claim that some ships are not structurally designed to safely carry out BWE in the open-ocean, even when empty of cargo.
- BWE may not be possible in rough weather, even for ships well adapted to it.
- Some coastal organisms can survive in ocean water.
- BWE does little or nothing to attenuate risk of transfers by ships plying exclusively near coastal areas.
- BWE effectiveness trials have produced mixed and inconsistent results, and implementation is difficult to monitor for enforcement purposes with any precision.

A recent Great Lakes-based study by Johengen *et al*. (2005) calculated the efficiency of BWE using changes in the concentration of the physical tracers, salinity and rhomadine dye, on board three vessels—the *Federal Progress*, *Berge Nord*, and *Kenai*—and found high overall exchange efficiency for all three. Based on salinity measurements, exchange efficiencies ranged from 80 percent (*Federal Progress*) to 100 percent (*Berge Nord*); based on rhodamine dye measurements, exchange efficiencies ranged from 86 percent (*Berge Nord*) to 98 percent (*Federal Progress*). Also, there were no noticeable differences in calculated exchange efficiencies when comparing type of exchange (e.g., flow-through and empty-refill) or starting salinity (e.g., high versus low).

Ballast Water Treatment (BWT)

There is global demand for ballast water management options that are more practical and environmentally protective than the current mandatory practice of BWE (GloBallast, 2005), spurring private- and public-sector researchers worldwide to develop and evaluate alternative ballast water management options. The seminal inventory of prospective treatment methods was published in 1996 (National Research Council, 1996). The need for a transition to BWT is particularly acute in the Great Lakes region because some 85 percent of ship visits occur in the unballasted condition, precluding BWE but nonetheless presenting a risk to the receiving system. Some of the first empirical work to test prospective BWT took place in the Great Lakes region through the Great Lakes Ballast Technology Development Project (see below).

The technological challenges associated with effective BWT are significant and the suitability of treatment options depends on many crucial considerations, including the biological effectiveness across the entire array of ambient aquatic organisms found in ports globally; operational and maintenance concerns in the harsh environment of the commercial vessel; ship and crew safety; power and space requirements; environmental soundness; cost; maintenance; compatibility with ship operations; and ease of use.

BWT can be achieved by physically separating organisms from ballast flow; killing organisms prior to discharge; or rendering them reproductively inviable. These processes could be carried out on board a vessel or made available to multiple vessels at a shore-based facility. If installed on board, systems can treat water during ballast intake and/or discharge, or en route. Systems also can be used alone or in combination with other treatment options. The majority of proposed treatment options are derived from technologies with proven effectiveness in a wastewater or industrial treatment arena, but all of them require require further research on their efficacy and safety.

Candidate Technologies

Specific technologies under consideration include:

Filtration: Filtration—the use of a porous surface or medium to remove organisms from the ballast stream—has been shown to be operationally feasible for Seaway-sized ships at the 50 micrometer pore size (Parsons & Harkins, 2002). This pore size also has effectively removed all ambient macrozooplankton and most ambient micrzooplankton from Lake Superior water (Cangelosi *et al*., 2001). The technology may prove to be one of the more primary viable treatment options, as particles and organisms too large to fit through the filter can be diverted back into the source water by automatic cleaning mechanisms. In addition, the process does not generate any chemical or thermal residue. However, because flow rate constraints may limit a filter's capacity to eliminate smaller organisms from the ballast water, filtration will need to be combined with a secondary technology, such as UV irradiation, to improve overall biological performance (Cangelosi, 2002). Several vendors are researching and developing ballast water filtration systems.

Ultraviolet Irradiation (UV): UV generates photochemical reactions that inactivate organisms either by burning them generally or damaging cellular processes involving DNA and

RNA. UV can be used on both ballast intake and discharge, and as a secondary treatment to filtration. This treatment also produces no residuals and can have broad spectrum effectiveness with adequate wavelength and dose. It has yet to be shown whether systems can be designed to deliver a stable dose of a given wavelength of UV to the entire ballast flow given a range of water quality, and they must be adequately durable to withstand shipboard use.

Deoxygenation: Deoxygenation kills organisms by depriving them of oxygen. Treatment concepts include purging oxygen from ballast water with an inert gas or binding the oxygen to a chemical additive. Such a treatment would involve no residuals, and has the added advantage of possibly altering pH—further harming organisms—and having anticorrosion qualities. Disadvantages of this treatment technology may include its inability to kill certain species such as cysts, spores, and anaerobic bacteria that can survive without oxygen.

Cyclonic Separators: Cyclonic separators use centrifugal forces to separate particles with specific gravity greater than water from the ballast flow. In theory, the technology is simple—with no moving parts, environmentally sound, and inexpensive. However, space requirements could be prohibitive for systems that can manage the high flow-rates of ballast water while still separating planktonic organisms—which tend to be almost neutrally bouyant—from the intake flow (Glosten-Herbert & Hyde Marine, 2002). Pilot-scale and shipboard studies on commercially available cyclonic separators to date have revealed little or no biological effectiveness (Sutherland *et al*., 2001; Cangelosi *et al*., 2001), but the technology is still under development.

Hydrodynamic Cavitation: Cavitation has been effectively used for a variety of industrial applications, such as chemical synthesis, wastewater treatment, and biotechnology. These applications are attributed to the generation of local conditions of high pressures and temperatures, turbulence with associated liquid circulation, and generation of free radicals. Hydrodynamic cavitation—an alternative to the use of acoustic cavitation (ultrasound)—for the generation of cavitating conditions has been studied in detail recently, and appears to be suitable for ballast water treatment applications. Hydrodynamic cavitation can be generated by the passage of water through a constriction such as throttling valve. The geometry of the constriction strongly influences the intensity of the cavitating conditions as well as the zone of influence of cavitation.

Nonoxidizing Biocides: Nonoxidizing biocides are widely used in water-treatment scenarios to control for bacteria and algae. Compounds include ammonium compounds, aromatic hydrocarbons, and metals and their salts, which treat by destroying cellular structures and metabolic processes. In theory, these biocides could be added to ballast water during intake and used to treat ballast water en route. However, certain environmental requirements may need to be met, including detoxification or deactivation of compounds to meet discharge standards. Compounds also may have associated cost, and ship and crew safety issues.

In-Tank Coatings: In-tank coatings could be used to reduce biological fouling on ballast tank surfaces. Such compounds are composed of toxic polymer or chemical binding agents that are lethal to biota that settle on the surface. They require a great deal more research and development, and issues of concern include the movement of water inside the ballast tank, the limitation of the treatment to organisms that settle on surfaces, and the discharge of chemical residuals with the ballast water

Magnetic Fields: Magnetic fields involve the generation by ferromagnetic or electromagnetic systems of a magnetic field of specified flux. This technology has been demonstrated to control zebra mussels and may have wider application for ballast water treatment. However, the biological and chemical effects of magnetic systems are not well understood, nor are the effectiveness of magnetic treatments on board operating ships, especially in saltwater situations. A great deal more research is needed on the biological and chemical effects of magnetic systems, and the effectiveness of magnetic treatment on board operating ships—especially in saltwater.

Oxidizing Biocides: Oxidizing biocides, such as chlorine, chlorine dioxide, ozone, hydrogen peroxide, and bromine, treat by destroying cellular structures and metabolic processes. In theory these compounds could be added to the intake ballast stream and used to treat ballast water en route. Disadvantages of oxidizing biocides, however, include environmental requirements for minimal discharge of inert chemical concentrations, high cost, safety issues, and risks of corrosion.

Pulsed Electric Fields and High-Energy Pulses: Pulsed electric fields and high-energy pulses have the potential to seriously damage and/or kill the types of organisms contained in ballast water. Pulsed electric fields involve the transfer of an electric pulse between two electrodes. High-energy pulses form an arc across an electrode gap by short, high-energy pulses to produce chemical reactions. Disadvantages of this technology for shipboard application include high installation and operational costs. Little research has been conducted on these technologies; more research is needed on its suitability to treat all taxa contained in ballast water, as well as the formation of chemical byproducts and issues of crew and ship safety.

Thermal Energy: Thermal energy is commonly used to sterilize water. Many harmful organisms found in ballast water can be killed or inactivated at temperatures around 40 degrees Celsius. The application of waste heat from the main engine-cooling circuit to heat the ballast water is one example of how this technology can be used. Treating ballast water en route in this form is advantageous because organisms entrained within sediments also are treated, and possibly at higher temperatures. There also is the opportunity for recirculation of the ballast water. However, the process may not be applicable to short, domestic voyages or appropriate in temperate regions because of high heat loss to the ocean.

Ultrasonic Treatment: Ultrasonic treatment uses in-line transducers that apply sound energy of specified amplitude and frequency to the water. Sound energy can biologically inactivate organisms in the ballast water by producing mechanical stresses that disrupt cells or cause cavitation. The overall effectiveness of the technology is influenced by many factors including frequency, water temperature, and concentration of dissolved matter. A great deal more research and development is needed to ascertain the suitability of this technology to ballast water treatment, particularly in relation to crew health and safety and the technology's impact on a ship's structural integrity.

Design Innovations: Another "technology" that could reduce ballast-mediated transfers of species is the redesign of the ballast system of ships to either reduce the volume of ballast that must be transported, or otherwise improve the extent to which organisms can be flushed or removed before or during a voyage. Ideas include the design of a "ballastless" ship. Two research teams at the University of Michigan and in Europe each have proposed a ballast-free ship—a concept that will essentially eliminate the transport of ballast-mediated aquatic organisms (Kotinis *et al.*, 2004; van Dyck, 2005). The ballast-free ship concept involves a shift in paradigm that approaches ballast-water operation as the reduction of buoyancy, rather than the addition of weight to get a vessel to its required drafts (Kotinis *et al.*, 2004). Under a U.S. patent, the concept replaces traditional ship ballast tanks with longitudinal structural ballast trunks that surround the cargo hold below the ballast draft. These trunks are connected to an intake plenum near the bow and a discharge plenum.

Treatment Systems under Commercial Development

Specific technologies currently under commercial development include:

Filtration:

- Arkal Filtration Systems of Israel is marketing automatic backflush disk filtration systems of various nominal ratings for use on board vessels to treat ballast water. The systems have been extensively used in other water treatment applications including shipboard grey water. In 2000, Arkal joined with Hyde Marine of Cleveland, Ohio, to install a 100-micron Arkal Galaxy automatic backflush filter for full-scale testing on board the Great Lakes Ballast Demonstration Project's barge platform in Duluth, Minnesota. A similar model, capable of 50-micron filtration was next installed on board the Princess Cruises vessel the *MS Coral Princess* in conjunction with an Aquisonics UV system. Testing of this treatment combination was conducted in the fall of 2004. Total capital and operating costs of the system is approximately \$3-\$4 per ton of ballast water (Glosten-Herbert & Hyde Marine, 2002).
- OptiMarin AS of Norway has developed a filter by the name of MicroKill FilterSep that has the same operative features as the company's cyclonic seperator (see below) but is fitted with a filter element that filters down to grades of 50-microns. The patent-pending MicroKill FilterSep has been tested at the pilot-scales, and will soon be tested at the full-scale (OptiMarin, 2006). The price for a system is not available, though it is expected to be in the hundred's of thousands of dollar-range, depending on vessel size and ballast system specifications.

UV:

- Aquionics Inc. of Erlanger, Kentucky, has developed a UV system for the treatment of ballast water known as the Aquionics In-Line UV system®. In 2001, the system was tested at full-scale on board the *U.S.S. Cape May* in Baltimore Harbor, in combination with a primary cyclonic separator. In 2003, Aquionics partnered with Hyde Marine, to install it's In-Line UV system as a secondary treatment to filtration on board the Princess Cruise's ship, the *Coral Princess*. The price for a system is not available, though it is expected to be in the hundred's of thousands of dollar-range, depending on vessel size and ballast system specifications.

- OptiMarin AS of Norway has developed the MicroKill UV system for use as a secondary treatment of ballast water. The system has been installed and tested in combination with several primary treatment technologies including filtration and cyclonic separation on board five vessels: the *Regal Princess*, the *Sea Princess*, the *Star Princess*, the *R.J.Pfeiffer*, and the *Stolt Aspiration*. Total capital and operating costs of the system is approximately $3-$4 per ton of ballast water (Glosten-Herbert & Hyde Marine, 2002).

Deoxygenation:

- Browning Transport Management, a private company based in Norfolk, Virginia, has patented a ballast water treatment system called AquaHabiStat. The system involves the removal of dissolved oxygen from the ballast water as it is pumped on board. A full-scale prototype system for a 30,000 DWT vessel was tested in a dockside setting in 2000. Plans are currently being formulated to test the system on board an operating vessel. The price for a system is expected to range between $500,000 and $1,000,000, depending on vessel size and ballast system specifications (Davis, 2003).
- MH Systems of San Diego, California, is testing the efficacy of deoxygenation combined with elevated levels of carbon dioxide in treating ballast water. Though the practical application of the system still needs to be verified in a large scale effort, the system is estimated to cost approximately $3 million, including parts and materials, labor, installation and maintenance (Husain *et al*., 2003).
- NEI Treatment Systems, LLC of Los Angeles, California, has patented the Venturi Oxygen Stripping System—a deoxygenation technology that rapidly removes 95 percent of dissolved oxygen from ballast water. The technology, after years of research and development, has recently been installed on an actively trading US-flagged bulk carrier the *TECO Ocean*, where biological trials, at flow rate of 1,000 m^3/hour, have shown the system capable of meeting the IMO's new performance standard for ballast water treatment systems (MarineTalk, 2005). Installation of the Venturi Oxygen Stripping System is expected to cost around $500,000.

Cyclonic Separators:

- Maritime Solutions Inc. of New York, New York, has developed a cyclonic seapartor known as the MSI Microfugal Separator® to treat ballast water. The patented system utilizes the proprietary MSI Microfugal Model 1500 Separator to separate the components of the influent ballast water in the primary treatment stage. In 2001 the system was tested at full-scale on board the *U.S.S. Cape May* in Baltimore Harbor, in combination with a secondary UV system. The price for a system is not available.
- OptiMarin AS of Norway has developed the MicroKill Separator as a primary ballast water treatment mechanism. Following extensive laboratory tests, the system was installed and tested at full-scale on board the *MV Regal Princess* in 2000. Since then it has been installed and tested on board two Princess Cruise Line vessels, the *MS Sea Princess* and the *MS Star Princess*, as well as the U.S.-flagged container ship, *R.J. Pfeiffer*, and the chemical tanker, *Stolt Aspiration*. All five installations involved systems arranged in combination with the MicroKill UV system. Total capital and operating costs of the system is approximately $3-$4 per ton of ballast water (Glosten-Herbert & Hyde Marine, 2002).

Non-Oxidizing Biocides:

- Vitamar Inc. of Memphis, Tennessee, has developed SeaKleen®, a patented formulation of vitamin K_3, which in very small doses may be effective at killing most organisms contained in the ballast water. In 2000, Vitamar, Inc. joined with Hyde Marine of Cleveland, Ohio and researchers at the University of Maryland to test SeaKleen® at full-scale on board the *U.S.S. Cape May* in Baltimore Harbor. Results from the tests indicate that one gram of SeaKleen® is capable of treating one metric ton of ballast water (Cutler *et al*., 2003). At current prices, it would be anticipated that ballast water treatment using SeaKleen® would cost approximately 15 cents per metric ton with very low or non-existent initial capital costs (Wright, 2004).
- Baker Petrolite Corporation of Sugar Land, Texas, is marketing the organic biocide, Acrolein® as a treatment option for ballast water. The company has conducted extensive laboratory experiments of the chemical, as well as carried out full-scale trials of its use on board a container vessel operating in the Gulf of Mexico (Penkala *et al*., 2003). More full-scale studies are planned. The estimated cost of Acrolein® application in ballast water is projected to be between $0.16 and $0.19 per metric ton (State Water Resources Control Board *et al*., 2002).

Oxidizing Biocides:

- Nutech o3, Inc. of Arlington, Virginia, has designed a ballast water treatment system that injects ozone into a ship's ballast water, as it is taken on board the ship. The system has been tested on board a British Petroleum oil tanker, the *ST Tonsina*, since the summer of 2000, and most recently on board the *ST Prince William Sound*. The technology has also undergone extensive laboratory testing at the University of Washington's Marrowstone research facility in Puget Sound and at the La Que Center for Corrosion Technology in Wrightsville Beach, North Carolina. Additional, fresh water testing on freighters operating on the Great Lakes is being planned for 2006. Projected costs of the system are estimated to be approximately $1.5 million per vessel based on a 125k dwt prototype (Canadian Board of Marine Underwriters, 2005).
- Degussa AG of Germany is marketing a liquid biocide called Peraclean® Ocean as a chemical ballast water treatment option. The product is a special formulation of peracetic acid and hydrogen peroxide. The first evaluations of the performance of Peraclean® Ocean were conducted in the laboratory using various indicator organisms. Field trials were next conducted in the U.S. in association with Maritime Solutions Inc. at Baltimore Harbor on board the *U.S.S. Cape May*. Although no cost projections are yet available, researchers estimate that approximately 150 liters of Peraclean® Ocean is sufficient for treating 1,000 tons of ballast water (Degussa, 2006).

Thermal Energy:

- Hi Tech Marine of Sydney, Australia, has developed several treatment systems that uses waste heat from a ship’s engine room to disinfect ballast water. The systems are suitable for both on board and shore-based applications. Biological tests of these systems has been conducted at various capacities, including on board the Australian bulk carrier *MV Sandra Marie*. Total capital and operating costs of one example system for a Cape Size bulk carrier is estimated at $5.43 cents per metric ton (Thornton & Chapman, 2003).

- Aquacide LLC of Michigan City, Indiana, is currently developing an on board system that uses waste heat from the ship's power plant to pasteurize ballast water. No shipboard results or information on costs are yet available.

Multi-Component Systems:

- Degussa AG and Hamann AG, both of Germany are working together to develop a modular concept for treating ballast water. Their proposed system involves several stages: a hydrocyclone to filter out solids; a filter to remove particles greater than 50 microns; and a chlorine-free oxidant disinfection stage (Peraclean® Ocean). The estimated cost of the multi-stage system is $0.30 per treated meter of ballast water.
- Marine Environmental Partners, a private company based in Ft. Lauderdale, Florida, has patented a treatment system called MariSan® that uses 50-micron pre-filtration and electro-ionization to treat ballast water. The company is operating a scale version of the system at the Oceanographic Center of Nova Southeastern University, and installed a pilot version of the system on a cruise ship in California (the *MS Elation*) in 2002 for formal testing by the California Lands Commission. Costs of treatment are estimated to be low as 0.5 cents per metric ton.
- Maritime Solutions Technology, Inc. has developed a patent-pending multi-component ballast treatment system using the company's separation technology as the first stage, and either the UV technology of Aquionics, Inc., the chemical biocide technology of Degussa AG, or the ozone treatment of Norsk Ozon AS as a second stage treatment. The estimated cost for a system is not available, though it is expected to be in the hundred's of thousands of dollar-range, depending on vessel size and ballast system specifications.
- OceanSaver AS—a fully owned subsidiary of MetaFil AS—is currently developing the OceanSaver®—a Norwegian-made three-component treatment system that is composed of a 50-micron filter, a nitrogen super-saturation generator, and a hydrodynamic cavitation unit. The system is currently undergoing full-scale tests on board several vessels including the *MV Federal Welland* and the *Hual Trooper*. The technology is expected to be commercialized in 2006, and will cost approximately $800,000 per unit. The development is supported by Innovation Norway, Statoil, and major shipowners, research institutions, and key industrial companies from Norway and abroad.

Table 9 also details examples of ballast water treatment systems currently undergoing commercial development.

Table 9. Examples of ballast water treatment systems currently undergoing commercial development

Trademark name	Vendor	Location	Treatment technology	Test stage
Acrolein	Baker Petrolite Corporation	Sugar Land, Texas	Non-oxidizing biocide	Tested at full-scale
AquaHabiStat	Browning Transport Management	Norfolk, Virginia	Deoxygenation	Tested at full-scale
Aquionics In-Line UV system	Aquionics Inc.	Erlanger, Kentucky	UV	Installed onboard operating ship
Arkal Galaxy Filter	Arkal Filtration Systems	Israel	Filtration	Installed onboard operating ship
MariSan	Marine Environmental Partners Inc.	Fort Lauderdale, Florida	Multi-component	Tested at full-scale
MicroKill FilterSep	OptiMarin AS	Norway	Filtration	Tested at pilot-scale
MicroKill Separator	OptiMarin AS	Norway	Cyclonic separation	Installed onboard operating ships
MicroKill UV	OptiMarin AS	Norway	UV	Installed onboard operating ships
MSI Microfugal Separator	Maritime Solutions Inc.	New York, New York	Cyclonic separation	Installed onboard operating ship
OceanSaver	OceanSaver AS	Norway	Multi-component	Installed onboard operating ships
Peraclean Ocean	DeGussa AG	Germany	Oxidizing biocide	Tested at full-scale
SeaKleen	Vitamar Inc.	Memphis, Tennessee	Non-oxidizing biocide	Tested at full-scale
Venturi Oxygen Stripping System	NEI Treatment Systems Inc.	Los Angeles, California	Deoxygenation	Installed onboard operating ship
--	Aquacide LLC	Michigan City, Indiana	Thermal energy	Not known
--	DeGussa AG & Hamann AG	Germany	Multi-component	Not known
--	Hi Tech Marine	Australia	Thermal energy	Tested at full-scale
--	Maritime Solutions Inc.	New York, New York	Multi-component	Not known

--	MH Systems	San Diego, California	Deoxygenation	Tested at pilot-scale
--	Nutech o3 Inc.	Arlington, Virginia	Oxidizing biocide (ozone)	Installed onboard operating ship

Ballast Water Treatment Research and Development Activities

Research and development of shipboard treatment is occurring in locations around the world, and accelerating in response to recently negotiated International Maritime Organization treatment objectives, evaluation methods, and implementation deadlines. Research and development activities take place at the bench-, pilot-, and ship-scale and involve operational and biological effectiveness concerns.

Ballast Treatment Research Development Testing and Evaluation Facilities: A limited number of test facilities capable of conducting rigorous ballast treatment tests is emerging domestically and internationally. These facilities are being developed because the shipboard environment is too difficult a test environment to successfully meet all information needs. Tests at stationary facilities, while more controllable than the shipboard tests, nonetheless require specialized and expensive test infrastructure including large tanks and pumps in order to detect performance with any degree of certainty at levels relevant to standards for ballast discharge. The earliest of these facilities were designed prior to the development of the IMO standard. More recently facilities are coming on line capable of testing according to IMO requirements.

In the United States, the Naval Research Laboratory, in partnership with the U.S. Coast Guard, has established a ballast water treatment testing facility in Key West, Florida. The facility functions as an instrumented scientific test platform for the evaluation of technologies designed to eliminate aquatic nuisance species in shipboard ballast.

The National Oceanic and Atmospheric Administration recently solicited proposals for establishing regional testing facilities in the Great Lakes and elsewhere. The solicitation—the NOAA-Fish and Wildlife Service Ballast Water Technology Demonstration Program grants competition for Research, Development, Testing and Evaluation (RDTE) facilities (OAR-SG-2006-2000364)—offered more than $1 million over a four year period to a Great Lakes facility, and start-up grants for facilities in other regions. The Northeast-Midwest Institute and several partners were awarded the Great Lakes funds. The Maritime Administration is providing barge platforms to support pilot level tests to qualified regions as an in-kind contribution. The Northeast-Midwest Institute has custodianship of one such barge which will be retrofitted to conduct a variety of pilot level tests.

Internationally, there are several countries with test pads under development. Singapore is likely to develop a facility consistent with IMO specifications. Meanwhile, other facilities are under development in the Royal Netherlands Institute for Sea Research and at the Norwegian Institute for Water Research (NIVA).

Shipboard Tests: One of the first shipboard tests of a treatment technology was conducted by the Great Lakes Ballast Technology Demonstration Project (GLBTDP). Co-led by the Northeast-Midwest Institute and the Lake Carriers' Association, the Project undertook field trials of a deck-mounted filtration system in 1997 on board an operating bulk cargo vessel, the *MV Algonorth*, at various locations in the Great Lakes system. Most recently, the GLBTDP has investigated a full-scale UV treatment system installed on board an operating chemical tanker (the *MT Stolt Aspiration*) that routinely visits the Great Lakes from ports in northern Europe.

Outside of the Great Lakes, members of the GLBTDP team investigated the performance of cyclonic separation in combination with UV on board the *MS Regal Princess* as it plied waters in British Columbia, Canada and Alaska in 2000. Following, Princess Cruises installed the same technologies on two more of its vessels (the *MS Star Princess* and the *MS Sea Princess*), and an alternative treatment combination (filtration and UV) on board the *MS Coral Princess*. All three treatment systems have undergone extensive biological testing primarily by the California State Lands Commission, in association with researchers from the Moss Landing Marine Laboratories, San Jose State University and San Francisco State University. These parties have also undertaken shipboard evaluations of a similar cyclonic separator and UV system installed on the bulk carrier, the *MV R.J. Pfeiffer*. The Monterey Bay Aquarium Research Institute is also undertaking shipboard evaluations of two separate systems.

Researchers from the Chesapeake Biological Laboratory have undertaken extensive testing of various treatment systems installed on board a commercially operating vessel (the *U.S.S. Cape May*) moored in Baltimore Harbor, including a cyclonic separator, a UV system, and the biocide SeaKleen. While, researchers from the University of Washington among others have investigated the biological effectiveness of ozone on board the oil tanker, *ST Tonsina*, since the summer of 2000, and most recently on board the *ST Prince William Sound*.

Internationally, the Norwegian-based OceanSaver AS is currently testing its three component ballast water treatment system (the OceanSaver®) on several ships, including the *M/V Federal Welland*, which plies routinely to the Great Lakes, and the auto transport, the *Hual Trooper*. Preliminary laboratory and land-based tests of this treatment process confirm the theory and support the likelihood that OceanSaver® will meet the requirements of the new IMO convention. Several shipboard studies of heat treatment have also been conducted by researchers in the Pacific Rim, including two by Australian scientists on the *MV Iron Whyalla*, and the *MV Sandra Marie*.

Table 10 also details examples of ballast water treatment systems tested on board commercially operating vessels.

Table 10. Examples of ballast water treatment systems tested on board commercially operating vessels

Treatment technology	Ship name	Ship type	Flow rate (m^3/hr)	Visits Great Lakes	Test year(s)	Contact
Cyclonic separation and UV	MS Regal Princess	Cruise ship	200	No	2000	Allegra Cangelosi Northeast-Midwest Institute
Cyclonic separation and UV	MS Sea Princess	Cruise ship	220	No	2001	Tom Mackey Hyde Marine Inc.
Cyclonic separation and UV	MS Star Princess	Cruise ship	255	No	2003	Tom Mackey Hyde Marine Inc.
Cyclonic separation and UV	R.J. Pfeiffer	Containership	350	No	2003	Tom Mackey Hyde Marine Inc.
Cyclonic separation and UV	MT Stolt Aspiration	Chemical tanker	250	Yes	2004	Allegra Cangelosi Northeast-Midwest Institute
Cyclonic separation, UV, SeaKleen, Peraclean Ocean	U.S.S. Cape May	Bulk/container	350	No	2000, 2001	Dr. David Wright Chesapeake Biological Laboratory
Filtration	MV Algonorth	Bulk carrier	273	Yes	1997	Allegra Cangelosi Northeast-Midwest Institute
Filtration and UV	MS Coral Princess	Cruise ship	250	No	2004	Tom Mackey Hyde Marine Inc.
OceanSaver	Hual Trooper	Auto transporter	--	No	2005	Aage Bjørn Andersen OceanSaver AS
OceanSaver	MV Federal Welland	Bulk carrier	~300	Yes	2005	Aage Bjørn Andersen OceanSaver AS
Ozone	ST Prince William Sound	Oil tanker	2,200	No	2005	Joel Mandelman Nutech O_3, Inc
Ozone	ST Tonsina	Oil tanker	~2,200	No	2000 - 2004	Joel Mandelman Nutech O_3, Inc
Thermal energy	MV Iron Whyalla	Bulk carrier	2,000	No	1997	Dr. Geoff Rigby Reninna Consulting
Thermal energy	MV Sandra Marie	Bulk carrier	--	No	1997	Glenn Thornton Hi Tech Marine
Venturi Oxygen Stripping System	TECO Ocean	Bulk carrier	1,000	No	2004	NEI Treatment Systems

Other Studies: Several barge- and land-based full scale tests of treatment technologies have been conducted around the world. In 1998, the Great Lakes Ballast Technology Demonstration Project continued trials of the same filter unit tested onboard the *MV Algonorth* on a stationary barge platform moored in Duluth Harbor, Minnesota (fig. 22), and compared the effectiveness of 25- and 50-micron screen sizes. In 2000, the same barge platform was used to evaluate two ballast treatment combinations: 40-micron filtration in combination with UV, and cyclonic separation in combination with UV. Experiments were undertaken in Two Harbors and Duluth Harbor, Minnesota. In August of 2001, the Project returned to the barge platform to investigate the effectiveness of 100-micron depth filtration in combination with an upgraded UV system.

Outside the Great Lakes, researchers from the San Francisco Estuary Institute are assessing on-shore treatment of ballast water discharges using both existing wastewater treatment plants and purpose-built treatment plants. Researchers from the University of Miami have also conducted evaluations of several technologies including self-cleaning screens, hydrocyclones and UV irradiation at a dockside pilot facility.

Globally, a team of researchers based at James Cook University, and a consortium of Australian government and industry partners are working together as the Australian Ballast Water Treatment Consortium (ABWTC). The ABWTC has developed a pilot plant to sterilize ballast water. Housed within a portable, twenty-foot long shipping container, the plant utilizes filtration, UV irradiation, chlorine dioxide injection and a high speed sonic/shear device to treat ballast water as it is being loaded on board a ship. In Singapore, researchers at the Environmental Technology Institute of the Nanyang Technology University have evaluated various treatments at the pilot scale, among other scales, including filtration, UV, ozone, and chemicals.

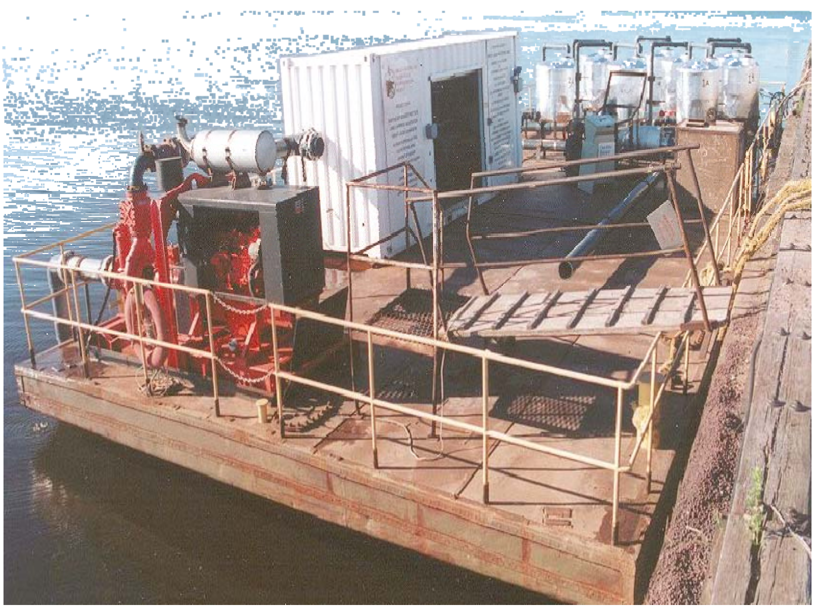

Fig. 22. Great Lakes Ballast Technology Demonstration Project Barge Platform moored in Duluth-Superior Harbor

Hull Management

The need to effectively manage fouling on a ship's hull has been universally recognized for decades. Hull fouling creates a pathway for the introduction of non-native aquatic species to disparate waterways, and the increased weight and presence of fouling organisms on the hull also can significantly reduce a ship's speed and increase fuel consumption.

Chemicals, including organo-mercury compounds, lead, arsenic, and DDT, have historically been used to treat hull fouling. However, such compounds pose severe environmental and human health risks, and were withdrawn from use during the early 1960s. They were replaced largely by tributyltin (TBT) compounds. Initially, TBT was incorporated into free-association paints, in which the biocide was dispersed in a soluble resinous matrix. However, release rates were uncontrolled, causing performance to quickly diminish. In the mid-1970s, TBT was incorporated into self-polishing copolymer paints that were widely acclaimed as the most effective antifoulants ever devised, providing antifouling cover for five or more years.

The benefit of TBT-based paints in preventing hull fouling, however, has been counterbalanced by concerns about TBT's high toxicity. Environmental studies worldwide have provided evidence that TBT compounds persist in the water and sediments, killing aquatic life other than that attached to the hulls of ships, and possibly entering the food chain. Specifically, TBT has been shown to cause shell deformations in oysters; sex changes (imposex) in whelks; and immune response, neurotoxic, and genetic affects in other marine species.

In response to these environmental concerns, many countries have banned the use of TBT-based paints on vessels of less than 25 meters in length, and on marine and estuarine structures such as piers and buoys. For example, in the United States, the Organotin Antifoulant Paint Control Act restricts the use of TBT-based paints on vessels of less than 25 meters in length. The Act also requires that TBT-based paints applied to vessels greater than 25 meters have a release rate of less than 4 µg TBT per cm^2 per day. Other countries, including Japan and New Zealand, have gone one step further and placed a total ban on TBT-based paints on all vessels, regardless of length. However, ships coated with TBT-based paints are still permitted to visit these countries.

Internationally, there is pressure from the IMO to phase out the use of TBT-based paints worldwide within the next 10 years. In 1999, the IMO adopted an Assembly resolution that called on the Marine Environment Protection Committee to develop an instrument to address the harmful effects of antifouling systems used on ships. This resolution called for a global prohibition on the application of organotin compounds on ships by 1 January 2003, and a complete prohibition by 1 January 2008. In 2001, the IMO adopted a new International Convention on the Control of Harmful Antifouling Systems on Ships, prohibiting the use of harmful organotins in antifouling paints used on ships and establishing a mechanism to prevent the potential future use of other harmful substances in antifouling systems. This convention will enter into force 12 months after 25 states representing 25 percent of the world's merchant shipping tonnage have ratified it. To date only 11 countries have signed on to the convention, representing 9 percent of the world's tonnage.

In the wake of this international and national pressure, the challenge for paint manufacturers has been to formulate products that perform as well as TBT-based paints but have minimal impact in the aquatic environment. Currently copper oxide-based paints are considered the best alternative to TBT-based paints. However, these compounds remain problematic due risks of corrosion to aluminum hulls, a short lifespan, and the demand for regular in-water hull cleaning. Also, though less toxic than TBT-based paints, paints containing copper oxide are still highly toxic to aquatic organisms. One promising alternative under development is the use of fouling release coatings. These are nontoxic, silicone-based nonstick coatings that weaken the adhesive bond between fouling organisms and the ship's hull, such that organisms are removed as the vessel moves through the water. Other potential options include coatings with microscopic prickles, natural biocides, and electrical charges across the hull.

Sea Chest, Anchor Chain Management

Currently there are no international, national, or state requirements for the treatment of ships' sea chests, anchors and anchor chains, bilge discharges, sea-sieves, chain lockers, intake pipes, bow-thruster tunnels, rope guards, and piping. Antifouling paints such as those mentioned above probably could be used to control the buildup of fouling organisms on these structures. The possibility of application however, is likely to be directly related to the need to reduce fuel consumption by lessening the opportunity for fouling organisms to reduce a ship's speed.

Regulatory Regimes

Since the problem first came to light, several levels of government, including national, international, regional and state/local entities, have become active in the attempt to reduce the problem through regulation. Of these, the most influential with respect to Great Lakes protection are regulations issued by the United States government and a convention negotiated by the International Maritime Organization. The private sector also has begun to self-regulate around the problem. This section briefly describes the various regulatory regimes and estimates through calculations and assumptions the current or projected effect of these regulations on the risk of new introductions to the Great Lakes.

Domestic Regulation

U.S. law (the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990) set up the first regulatory program directed at minimizing ballast introductions of invasive species. This early program was focused on ships entering the Great Lakes after operating outside the exclusive economic zone. The National Invasive Species Act of 1996 (NISA) then expanded the program to be national in scope. Both programs require vessels to manage their ballast water either by conducting ballast water exchange (BWE) or by using a ballast water treatment (BWT) that is demonstrated to be as effective as or more effective than BWE. NISA charged the U.S. Coast Guard with first establishing a voluntary national program and, in the event it was found to be ineffective, making its provisions mandatory. In 2001, the U.S. Coast Guard reported to Congress that the number of vessels that provided information on ballast water management was too low for an effective assessment of compliance with the voluntary guidelines. As a result, it began the process of making the voluntary guidelines mandatory, publishing a notice of proposed rulemaking for a mandatory national ballast water management program in July 2003, and a final rule in July 2004.

In September 2005, the U.S. Coast Guard established voluntary best management practices for residual ballast water and sediment carried by transoceanic vessels that enter the Great Lakes from outside the Exclusive Economic Zone declaring "no ballast on board" (NOBOB). These best management practices include:

- Conducting mid-ocean ballast water exchange during ballast-laden voyages in an area 200 nautical miles from any shore and in water 2,000 meters deep whenever possible, prior to entering the U.S. Exclusive Economic Zone.
- For vessels unable to conduct mid-ocean ballast water exchange, conducting saltwater flushing of their empty ballast water tanks in an area 200 nautical miles from any shore, whenever possible.

NOBOB vessels that do conduct the practices are asked to incorporate them into their required ballast water management plan. The U.S. Coast Guard intends to monitor NOBOB vessels engaging in these practices to determine the efficacy of the program. If the best management practices are not effective in preventing aquatic invasive species introductions, the U.S. Coast Guard may consider other alternatives.

In recent years, many bills have been proposed in Congress to reauthorize the National Invasive Species Act's ballast water program, but none has been enacted. A full listing of current legislation can be found at http://www.uscg.mil/hq/g-m/mso/legislation.htm. All of these bills would expand the ballast water management program already in place under NISA, but they vary widely in nature and scope. For example, the National Aquatic Invasive Species Act (S.770) would strengthen national ballast water regulations and focus on introduction pathways other than ballast water and other needs, such as early detection and monitoring, rapid response, controlling spread, and research. The Ballast Water Management Act (S.363) would amend the national ballast water program with provisions similar to those in the IMO Convention (see below). Furthermore, various committees in the House of Representatives and Senate are likely to develop their own ballast water bills. There is clearly interest in passing federal ballast water legislation, but it is uncertain what form such legislation would take.

International Treaty Requirements

In February 2004, the International Maritime Organization adopted the International Convention for the Control and Management of Ships' Ballast Water and Sediments, which will require ships to conduct ballast water management through BWE or BWT. The convention includes standards for the operational effectiveness of BWE and the biological effectiveness for BWT.

Although the adoption of an international agreement on ballast water is a significant development, the IMO Convention is unlikely to effectively prevent further ballast water introductions in the near future. The convention gradually phases in BWT standards—based on vessel size and construction date—that do not apply to many ships until 2014 or 2016. This ensures that in the short term, BWE will be the main management activity required. Furthermore, the convention does not enter into force until one year after ratification by 30 nations representing 35 percent of the world's shipping. As a result, it is doubtful that any meaningful ballast management will be required internationally in the near future.

Seaway Development Requirement

Both the U.S. and Canadian Seaway Development Corporation issued a Code of Best Practices for Ballast Water Management of the Shipping Federation of Canada on September 28, 2000. Ships entering the Seaway that operate within the GLSLSS must agree to comply with the *Voluntary Management Practices to Reduce the Transfer of Aquatic Nuisance Species Within the Great Lakes by U.S. and Canadian Domestic Shipping*, adopted by the Lake Carriers Association and Canadian Shipowners Association on January 26, 2001.

State/Provincial Requirements

A number of states have passed legislation pertaining to ballast water and ballast water management, which vary widely in scope. A Michigan law charged the Department of Environmental Quality with determining whether vessels are employing voluntary ballast water management (BWM) guidelines or BWT; determining if BWT systems could be used to prevent introductions, and if so, at what date; and compiling a list of vessels employing voluntary guidelines or ballast treatment systems. The Rhode Island State Legislature charged the Department of Environmental Management with gathering information on international, federal, and state ballast water management policies, and making recommendations for the establishment of a state BWM program.

Other states, such as Alaska, Maryland, and Virginia, have laws requiring vessels to report their ballast operations. Oregon also has reporting requirements and requires vessels arriving from overseas to conduct BWE. California has a mandatory state BWM program that is supported by fees charged to vessel operators, and Washington State's program requires ballast water reporting and monitoring, and establishes standards for BWT systems. Furthermore, in the past several years, ballast water bills have been introduced in the legislatures of several Great Lakes states, including Illinois, Indiana, Minnesota, New York, and Wisconsin. Although they were not enacted, these bills further demonstrate that in the absence of effective federal ballast water regulation, the states are prepared to address the issue.

Port-Specific Regulation

Two North American ports have taken action to regulate ballast discharges. In 1997, well in advance of any Canadian federal requirements, the Port of Vancouver, British Columbia, began requiring vessels to perform mid-ocean BWE prior to arrival. The Port of Oakland, California, enacted similar requirements in 1999, though these requirements have since been superseded by state and federal regulations (*Bay Area Monitor,* 2000).

Pending Legal Action

In September 2005, attorneys general from six Great Lakes states including Illinois, Michigan, Minnesota, New York, Pennsylvania, and Wisconsin, filed a brief in federal court proposing several remedies to better regulate ballast water discharges under the Clean Water Act. The action complements a March 2005 ruling by the U.S. District Court for the Northern District of California in San Francisco that required the U.S. Environmental Protection Agency to begin regulating ballast water discharges. Specifically, the brief asks the court to order the U.S. Environmental Protection Agency to:

- Promptly repeal the rule, 40 CFR § 122.3(a), that exempts aquatic nuisance species from regulation under the Clean Water Act.
- Establish interim regulatory controls by April 1, 2006, which marks the start of the next shipping season on the Great Lakes.
- Establish final regulatory controls by October 1, 2007, that include strict standards for vessel ballast water discharges.

The brief is the latest attempt by the six Great Lakes states to incite federal action on the issue. In July 2005, the group sent a letter to the U.S. Senate opposing S.363, the Ballast Water Management Act of 2005, which would place sole responsibility for regulating ballast water discharges on the U.S. Coast Guard, rather than the U.S. Environmental Protection Agency.

Industry Self-Regulation

Examples of carrier self-regulation for ballast water management include

- Lake Carriers' Association and Canadian Shipowners Association voluntary guidelines. Ships entering the GLSLSS must agree to comply with the *Voluntary Management Practices to Reduce the Transfer of Aquatic Nuisance Species Within the Great Lakes by U.S. and Canadian Domestic Shipping*, adopted by the Lake Carriers Association and Canadian Shipowners Association in January 2001. Appendix A provides more detail on these voluntary measures.
- Fednav International Limited, a leader in the international shipping business into the Great Lakes, also requires routine ballast purges by its vessels in the high seas to assure that unpumpable residuals are water only (not heavier sediment).
- CMA CGM, a leading worldwide container shipping company, has implemented a ballast water management plan on all vessels it operates. The plan underlines the fact that the uptake of ballast water must be carried out in deep water, at least 200 nautical miles away from the coast. All ballast operations are also to be recorded in a ballast water record book at the disposal of the authorities.
- The Clean Cargo Group within the Businesses for Social Responsibility is the only clear example of a shipper regulating ballast water management of waterborne transportation services. The group's main goal is to develop cost-effective environmental specifications for waterborne carrier service providers in order to significantly improve air quality (e.g., by reducing emissions and improving fuel/engine efficiency) and reduce the introduction of aquatic invasive species (e.g., by endorsing process standards for BWE and BWT). To

- On a more integrated scale, recently the maritime industry of the GLSLSS has been investigating the prospect of a Green Marine initiative to address the wide range of environmental problems it faces. Biological pollution associated with the industry will clearly be a priority.

IV. Analysis

In recent months, the invasive species problem associated with commercial shipping on the GLSLSS has received heavy media coverage (e.g., Egan 2005a; Egan, 2005b; Egan, 2005c; Passi, 2005b; Passi 2005c), sparked in part by the release of an academic report and scientific article laying out environmental and economic rationales for prompt and dramatic action (Johengen *et al*., 2005; Taylor & Roach, 2005). Some of the media coverage even raises the prospect of closing the GLSLSS to transoceanic shipping as a ready solution. In the wake of this media attention, it is clear that both the maritime industry and those negatively affected by ship-mediated introductions of invasive species in the GLSLSS would benefit from rapid and effective action to prevent future introductions.

Niche for Industry Action

The content of the media discourse charts a clear course for an industry initiative to develop and implement solutions to the problem of ship-mediated invasive species in the Great Lakes. It can be argued that the environmental advocates' job is done when they have proposed a solution (like closing the Seaway) whose benefits of preventing further invasions outweigh the costs to society. Questions of cost-effectiveness—the most economically efficient means to achieving a commonly held societal objective—are best addressed by the private sector, especially in the case of highly technical questions of marine technology. Accordingly, the industry, in its responses to this media assault, was wise not to argue claims that the problem is serious (Jacquez & Corfe, 2005; Passi, 2005b). Instead, the industry took issue with closing the GLSLSS to salty ships as the best approach to curtailing the problem (Jacquez & Corfe, 2005), and argued that shipboard treatment is the most cost-effective approach, and the approach embraced by the international community.

If an approach identified by industry provides adequate certainty of resolving the problem, it is likely to attract support from environmental advocates and ultimately be embraced by policymakers in lieu of more drastic measures. Often such a broadly supported approach also benefits the environment, because a consensus response is likely to move more quickly to regulation than one that is opposed by industry or environmental interests.

Industry initiatives to design and implement cost-effective solutions to environmental problems have grown dramatically in the U.S. and internationally over the last decade. Industry often implements environmental management initiatives through the structure of Environmental Management Systems (EMSs). These initiatives are often organized around principles of the Environmental Management System (EMS) model developed by the International Standards Organization (ISO), a nongovernmental organization that seeks to develop voluntary standards for many aspects of international commerce and trade and may also address ship-mediated invasive species. Standards developed by ISO address traditional activities, such as agriculture and construction; mechanical engineering; to medical devices; and the newest information technology, such as the digital coding of audio-visual signals for multimedia applications. ISO also standardized the dimensions of freight containers, increasing the speed and reducing the cost of international trade. Two of the best-known standards are ISO 9000 and ISO 14000, which set quality and environmental management standards throughout the production and delivery process (ISO, 2005). The ISO 14001 model helps industries organize an effective and comprehensive response to environmental concerns. In particular, the model contains the following generic components of an EMS:

- Policy, leadership, and guidance
- Planning and management of change
- Implementation, operation, and accountability
- Performance measurement and corrective action
- Management review

Ports are already actively involved in the EMS approach to pollution reduction. The Port of Houston Authority is recognized for its leadership in EMS development and implementation. The objectives of the port's EMS include reducing stormwater impacts from scrap-metal storage, and reducing NOx and VOC emissions. The American Association of Port Authorities (APPA) and the U.S. Environmental Protection Agency are supporting a two-year training effort called the Port Environmental Management System Assistance Project. Eleven port districts were chosen to participate in this program (no Great Lakes ports applied to participate) and will be trained in developing EMS for their facilities. U.S. Environmental Protection Agency Region 5 (Chicago) is considering a similar effort for Great Lakes Ports.

Currently certification under ISO 14001 does not imply action to address ballast water. However, the 2004 work plan for the ISO's Ships and Marine Technology Technical Committee (and its Marine Environment Protection Subcommittee) identifies ballast water management as a "possible new work item" (ISO/TC 8, 2004).

Economic Feasibility of Industry Action

From society's standpoint, there are clear benefits to an industry-led initiative to address biological pollution in the GLSLSS. The upper-end cost estimates for effective methods of prevention are \$1.5 million per ship (Glosten-Herbert & Hyde Marine, 2002; Rigby & Taylor, 2001; Taylor *et al*., 2002), totaling about \$330 million for all ships that visit the GLSLSS from overseas. This value is less than even modest estimates of the overall costs to society of invasive species in the GLSLSS (e.g., GAO, 2002; Leigh, 1998; Park & Hushak, 1999). Moreover, an industry-led effort will likely identify more cost-effective methods than nonindustry-led efforts, and this cost-effectiveness also benefits society because the costs of pollution prevention are ultimately passed on to the public.

However, from industry's standpoint, there are difficult unanswered questions about the benefits of action. Can waterborne transportation within the GLSLSS absorb the costs of biological pollution prevention? If so, is taking action ahead of regulations through an industry-led initiative preferable to waiting for regulations or other outcomes? Which combinations of incentives and cost-sharing arrangements would make an effective EMS for the Great Lakes-St. Lawrence Seaway maritime transportation system most economically and financially feasible?

Industry's Ability to Absorb the Costs of Prevention

Because the GLSLSS shipping industry has clear cost advantages of \$8 – \$21 per metric ton over rail and truck competitors (Martin Associates, 2001), the industry could absorb some additional costs without the industry or the regional economy suffering serious economic hardship. With approximately 12 million metric tons shipped to and from overseas through the GLSLSS per year, the industry's cost advantage implies an ability to absorb fleetwide treatment costs of \$96 million – \$252 million per year, potentially indicating that amortization could occur within two years. Shippers would continue to use the GLSLSS so long as it has any positive cost advantage.

However, the wildcards here are the cost and length of the research and development process for approved treatment solutions and the price response of alternative modes of transportation should waterborne transportation become less advantageous. Although the range of cost increases that GLSLSS maritime industry could absorb over the short term appears more than adequate for one-time treatment installations, sustainable long-term cost increases associated with a protracted and expensive research and development process could stop well short of \$8 – \$21 per ton.

If the cost advantages that the GLSLSS imparts to Great Lakes industries disappeared over a sustained period, industry would relocate, and the region's economy would experience reduced activity and losses of income and employment. In particular, if GLSLSS shipping became more expensive, more imports would go to East Coast and Gulf of Mexico ports. Vogt *et al*. (2002) illustrate this relationship in reverse, estimating that a hypothetical reduction in shipping costs in the GLSLSS would have a positive economic development impact on the Great Lakes region that would be almost exactly balanced by a negative effect on regional economic development on the East Coast. However, over the long term the cost advantages of GLSLSS waterborne transportation could be bolstered by commensurate increases in prices for alternative modes of transportation as demand for the alternatives rose. In addition, it can be expected that waterborne transportation costs to other regions will reflect biological pollution prevention costs as domestic and International Maritime Organization requirements are imposed.

Benefits of Action Ahead of Regulations

Industry enjoys several benefits by launching environmental initiatives generally. These include:

- Improved environmental performance
- Enhanced compliance
- Attraction of new customers and markets
- Increased efficiency and reduced costs
- Enhanced employee awareness and morale
- Integration of environmental practices into business systems
- Enhanced image with public, regulators, lenders and investors, and
- Qualification for recognition and incentive programs

In the context of transoceanic shipping to the GLSLSS and managing biological pollution, an industry initiative could have the following specific benefits and value:

- Public/consumer preference for environmental approach
- International trade preference
- Acceleration of the research and development process
- Influence regulatory requirements in the United States and internationally
- Compliance assistance with federal/state regulations
- Assistance with voluntary government programs, (such as the U.S. Coast Guard STEP program)

Waiting for regulations would offer little reduction of installation costs because biological pollution prevention requirements are expected globally within 10 years regardless of industry action. Waiting to be forced to act also could have dramatic negative effects including:

- Public demand for prevention approaches that are not cost-effective
- Negative public relations for the waterborne transportation industry vis-a-vis other modes of transportation
- Promulgation of poorly advised federal regulations that cannot be implemented
- A political patchwork of regulations at the local, state and regional level
- Conflicts, potentially legal in nature, between natural resource stakeholders and the GLSLSS maritime industry

Ways to Optimize Economic Feasibility of Industry Pro-action

The problem of ship-mediated invasive species will be difficult to resolve, and at the early stages of research and development identifying and implementing solutions could carry significant expense. Moreover, the precise costs are uncertain pending the identification of effective approaches and the finalization of a regulatory standard and timeframe. Therefore, it has been difficult for inventors to attract venture capital from financers to assist in startup (Northeast-Midwest Institute and Lake Carriers' Association, 2001; Royal Haskoning, 2001). The remaining sources of capital for investment in treatment solutions in advance of the regulatory regime are government and the treatment customers themselves, i.e., the maritime industry. Cost-sharing among the public and private prospective beneficiaries of timely, cost-effective ballast treatment solutions appears to be an essential prerequisite to achieving these solutions.

Cost-Sharing Opportunities with Government

There is understandable general resistance to government investment in research and development of technology that is thought to be part of the cost of doing business in the private sector. In particular, environmentalists hold to the principal of "the polluter pays" when that technology is associated with pollution cleanup. However, some have argued that there is a role for public funding of ballast treatment development to support prevention rather than cleanup. Moreover, the special circumstances surrounding ballast treatment research and development—

especially the fact that it is not yet required—make private investment unlikely and government investment necessary if development progress is to occur.

To date, United States federal investment in treatment research and development has occurred primarily through the Ballast Technology Demonstration Project (BDTP), administered by the National Oceanic and Atmospheric Administration. Authorized in 1996 in the National Invasive Species Act, the BTDP has historically issued national requests for proposals for technology development assistance. The proposals referenced a wide range of technologies and a variety of ship types. In all, the program has granted approximately $10 million to more than 50 treatment research teams. This effort has made slow progress, however, perhaps because its solicitations have been so general in nature. Program leadership has most recently redirected the funds to more targeted objectives, issuing an RFP for ballast treatment development specific to the needs of the GLSLSS (NOAA, 2006).

Additional federal agencies, including the U.S. Maritime Administration, Environmental Protection Agency, Coast Guard, and Defense Department, are also investing in treatment research and development.

- MARAD has launched a program of retrofitting retired barge platforms for ballast treatment testing.
- The U.S. Environmental Protection Agency's Great Lakes National Program Office has invested in ongoing Great Lakes work through the Great Lakes Ballast Technology Demonstration Project.
- The U.S. Coast Guard has conducted contract research on treatment systems in Florida (Waite *et al*., 2003).
- The U.S. Coast Guard has partnered with the Naval Research Laboratory (NRL), Department of Defense, to design, construct, and operate a prototype, pilot-scale ballast water treatment system test facility at the NRL's facility in Key West, Florida.

Other forms of federal and state government cost-sharing could help defray the cost of purchase and installation of treatments that achieve governmental approvals. These incentives include:

- Waivers of GLSLSS tolls
- Waivers of port fees
- Financing assistance by public port authorities
- Tax incentives

Cost-Sharing Opportunities within Industry

There is a strong case to be made for industry to share the costs of resolving the ship-mediated invasive species problem across the supply chain involved in waterborne transportation on the GLSLSS, rather than encumbering carriers alone. First, the cost-effectiveness of waterborne transportation on the GLSLSS may hinge on the rapid resolution of the problem of ship-mediated invasive species. Second, the cost of alternative transportation would likely increase in the absence of competition with the waterborne-freight rates affecting all shippers and their customers. Both land-side and ship-side components of the industry in the United States and Canada share the freight rate benefits that competition supports.

The most straightforward example of cost sharing for research and development process is the FedNav Ltd. decision to partner with a ballast treatment vendor, OceanSaver AS, to develop a ballast treatment system that could later be supplied to the FedNav fleet. The benefit is mutual: FedNav Ltd. will enjoy a return on its investment in any purchases (including its own) of the system once approved, and the vendor benefits from access to operating ships and ship-engineering expertise to trial its system, as well as capital to help finance treatment development. This simple relationship is a lean and efficient means to an end for the maritime industry, but also risky. If the selected system does not yield a usable product, the entire industry still goes wanting.

Cost sharing of treatment dissemination and installation in ships has taken the form of shippers granting "preferred ship" status to carriers that undertake measures that surpass or pre-date legal requirements. This approach presupposes the identification and availability of treatment solutions. Such shipper policies have the effect of reducing the fleet "supply" available for carrying goods to those who meet the shippers' environmental standards, enabling eligible carriers to raise their prices above those of noneligible shippers, underwriting the expense associated with installing treatments. The Clean Cargo Group in the Businesses for Social Responsibility is an example of a group of shippers that voluntarily limits the supply of eligible carriers through requiring that they meet certain environmental standards.

Cost-Sharing within Government and Industry

One example of the more complex system of cost sharing—involving the maritime industry *and* government entities pooling resources to support mutually beneficial research/development *and* installation outcomes—happens to have occurred in the Great Lakes maritime industry. In advance of national and international processes, the GLSLSS maritime industry pooled its resources to develop and implement Automated Information Systems for ships visiting the GLSLSS (box 7). In particular, the St. Lawrence Seaway Development/Management Corporations were extremely active in contracting the development work, visiting shipyards to ensure proper installation, and providing technical assistance on system operation to crews. The corporations are credited with significantly speeding domestic adoption of the technology generally, and have received international recognition for their role.

This broader approach to cost sharing is most suitable to addressing ship-mediated invasive species development because ballast treatment development and evaluation are extremely capital intensive. In addition, collective and cross-sector cost sharing, if applied to ballast treatment, would not preclude entrepreneurial activity resulting in individual cost-sharing arrangements like those undertaken by FedNav Ltd. and the Clean Cargo Group. Instead, collective cost sharing would integrate them into an industrywide push, and maintain momentum in research and development even if treatments subject to private investment failed to meet expectations. The treatment system being nurtured by FedNav Ltd., for example, could serve as one candidate for collective research and development services, and dissemination and implementation support.

In particular, supply chain members may wish to cost share for public relations reasons when they are:

- Functionally close to the waterborne transportation step
- Geographically close to the waterborne transportation step
- Functionally or geographically close to consumers affected by the waterborne transportation step

Box 7: Automatic identification System (AIS)

The implementation of an Automatic Identification System (AIS) on Great Lakes vessels is an example of a program that solved a series of critical problems facing the Great Lakes shipping industry related to ship safety, vessel traffic management, and maritime security. The AIS is a shipboard broadcasting transponder system operating in the VHF maritime band that is capable of send and receiving information such as identification, position, speed heading, to other ships and to shore. All ships over a certain size are required to be equipped with an on-board AIS transponder that will communicate with shore-based units as well as other ships in the system. The benefits of the AIS include enhanced safety through real-time ship-to-ship communications of vessel locations, speeds, and courses, reduced transit times, enhanced fleet management, and faster response times in the event of an accident or incident.

The AIS project was implemented by a team that included the U.S. Saint Lawrence Seaway Development Corporation (SLSDC), the Canadian St. Lawrence Seaway Management Corporation (SLSMC), and marine transportation interests, with technical support from the U.S. Volpe National Transportation Systems Center.

Full-scale shipboard AIS testing and evaluation was completed during the 2002 navigation season. Final rules for mandatory AIS carriage were issued on December 23, 2002, and the system is now fully operational. All shore-based units are in place and approximately 300 vessels now are equipped with AIS transponders.

The total cost of implementing the AIS is estimated at $1.8 million, which is lower than original estimates. The cost of individual shipboard units has dropped from upwards of 20,000 per unit to about 5,000.

Agenda for Industry Action: A Great Ships Initiative

What would a GLSLSS maritime industry-led initiative to achieve a cost-effective, timely, and protective response to the problem of ship-mediated invasive species look like? What would be its specific objectives?

A conventional EMS is facility specific and prescribes a set of practices associated with all relevant links of the supply chain that ensure the desired outcome. To the extent that there are regulations, the EMS also ensures cost-effective compliance. Unfortunately, technical methods that eliminate risk of new introductions of invasive species by ships are not yet available and cannot be prescribed. Government regulations are "to be determined." In addition, carriers do not have the resources they need, including large shore-based evaluation infrastructure and extensive field biological expertise, to vet prospective treatment methods in-house, nor are these resources yet available for hire elsewhere.

This technological and policy uncertainty need not prevent an industry response to the problem of ship-mediated biological pollution. However, the process for making a cogent response would be unconventional enough that "EMS" may be an improper moniker. Rather than a facility-specific and strictly implementation-oriented response associated with most EMS processes, this process needs an integrated initiative, staged over time across government and the GLSLSS maritime industry.

Such an EMS initiative will require the development prevention practices in phases that involve supplying information to government entities that can help inform the regulatory process. It will also require a "trigger point" at which the project emphasis shifts from tool development and approval to more conventional EMS activities, including installation and implementation exercises within the fleet of ships that visits the Great Lakes—and to the extent that regulations are in place, compliance assistance. Finally, the initiative should include careful monitoring to allow the early detection of any arriving alien species in GLSLSS harbors, which would greatly facilitate successful rapid response.

An industry-led initiative would be most productive as a collective effort across the GLSLSS port range, throughout the maritime commerce related industry, and between the public and private sectors. The problem is systemic and global in nature and requires a systemic solution that is consistent with international and domestic regulatory programs; no individual port, state, or ship can solve the problem for itself without solving the problem for all ports, states, and ships that share the waterborne trade patterns and resource. In addition, research and development is generally hobbled by disparate and sporadic support. Research and development of ballast treatment needs adequate and sustained support to carry candidate systems with commercial potential through significant regulatory uncertainty. The public sector alone cannot fill the void because expertise in the unique problem of designing technologies for the vessel environment resides primarily in the waterborne transportation industry. Finally, the involvement of the entire supply chain would add substantial value during the implementation phase because important incentive opportunities reside with the companies hiring vessels to carry their goods.

Recommendation Actions

Without the implementation of effective prevention measures by ships, the Great Lakes will remain at high risk of invasion from organisms carried in ballast water. The environmental and economic problems caused by continued introductions of ship-mediated invasive species are extremely serious and costly. A conventional Environmental Management System (EMS) will be difficult for industry to execute to address the problem because of the developing state of technology and policy, as well as the tight financial margins, complex transaction chains, and collective nature of the economic and infrastructural drivers behind GLSLSS shipping.

Recommendation 1: The Great Lakes/St. Lawrence Seaway maritime industry—ports, carriers, and shippers—collectively should launch a Great Ships Initiative (GSI) to speed protection of the Great Lakes freshwater resource from ship-mediated invasive species.

Recommendation 2: The GSI should comprise two fundamental stages: incubation of treatment solutions and dissemination of treatment solutions. It should involve the following specific activities:

- Treatment Incubation - Identifying, testing, and otherwise supporting the development of promising methods for preventing ship-mediated invasive species applicable to Seaway sized ships (plying anywhere) at a common, fully equipped test site on Great Lakes
- Approval Assistance - Facilitating the successful induction of meritorious systems into regulatory approval processes, including both experimental or type-approval exercises (such as STEP), by generating relevant empirical information on treatment performance and providing technical support
- Installation Assistance - Defraying the cost of installing approved systems and methods on the fleet of ships that visit the Great Lakes through financing tools, grants, toll and fee relief, and/or shipper preference policies
- Monitoring - Supporting states in monitoring their shores and harbors for, and responding to, newly established organisms
- Communication with Regulators - Communicating outcomes fully to the relevant state, national, and international regulatory agencies

Recommendation 3: While the GSI should be driven by the maritime industry, it should be coordinated to the greatest extent possible with the U.S. Coast Guard and other relevant regulatory agencies.

Recommendation 4: The GLSLSS should use its own resources to leverage adequate public and private funds and enhance the productivity of publicly funded research.

Recommendation 5: The GLSLSS should imbed this effort within a more broadly focused Green Ships EMS. Recently the maritime industry of the GLSLSS has been investigating the prospect of a Green Marine initiative to address the wide range of environmental problems it faces. Biological pollution associated with the industry will clearly be a priority. The GSI should serve as the mechanism for managing those issues associated with biological pollution within the broader Green Marine initiative.

Summary and Conclusion

Regardless of the competing strategies for redressing the problem of ship-mediated invasive species introductions into the Great Lakes, shipboard treatment systems for Seaway-sized ships need to be developed and implemented as quickly as possible. Treatment tools to prevent ship-mediated aquatic invaders generally are developing too slowly. Private sources are reluctant to provide financing because of uncertain regulatory standards and deadlines. Government grant programs have been general and applicants often lack sufficient expertise—maritime, process, or biological—to proffer successful and productive projects. Meanwhile, official processes to test treatment performance (e.g., the Shipboard Treatment Evaluation Program and ETV) require substantial investment and are most suitable for relatively well-vetted treatment prospects. A Great Ships Initiative (GSI) could fill a critical gap by narrowing the focus to Seaway-sized vessels, training the combined resources and input of GLSLSS maritime and government interests on treatment development, and providing financial support and technical services to bring treatment prospects to verification/approval-ready and market-ready condition.

End Note: Recent Developments

The American Great Lakes Ports Association—in collaboration with the Northeast-Midwest Institute; National Fish and Wildlife Foundation; University of Wisconsin-Superior; relevant federal, state, and provincial agencies; and interested carriers—has established a Great Ships Initiative (GSI) to focus public and private resources on producing solutions to the problem of ship-mediated invasive species in the Great Lakes. The GSI objectives include:

- Enabling systematic monitoring of Great Lakes ports for new introductions by ships
- Activating a set of incubators to accelerate the identification and verification of treatment tools to stop organisms introductions by Seaway-sized ships
- Accelerating the fleet-wide installation and use of effective treatment systems as soon as they are developed

These GSI activities will be carefully coordinated with national and international programs and regulating agencies to ensure that there is no duplication of effort and maximize national and international impact.

GSI Management

GSI activities will be overseen by an executive committee comprising volunteer principals of private, public, and nonprofit organizations that contribute funds or other capital to the GSI effort. The committee will use advisory groups and administrative staff to make major project-management decisions, such as budgeting, fundraising, project review outcomes, industry outreach, and state and federal relations. The National Fish and Wildlife Foundation (see box 8) will manage the funds assembled by the EC to support GSI activities, while the Northeast-Midwest Institute serves as the GSI's managing entity.

GSI Programs

Harbor Monitoring

The Harbor Monitoring Program aims to detect new aquatic invasive species as soon as possible so that rapid response measures can be taken. The program will seek to facilitate consistent harbor monitoring activity at the major U.S. and Canadian commercial ports on the Great Lakes. Local port authorities will act as sponsors, working in partnership with their own state/provincial environmental and natural resource agencies.

Technology Incubators

The GSI Incubators will function as a partnership of industry, state and federal government, and NGOs with the goal of accelerating the development, installation, testing, and use of viable shipboard technologies/methods suitable to Seaway-sized ships to prevent aquatic invasive species introductions. Through an RFP (or similar means), the GSI will invite vendors to bring forward promising prevention treatments for consideration. The GSI may offer incentives as a means of inducing participation. Technical Advisory Groups established by the Executive Committee (EC) will serve as the front-door evaluators of the potential for candidate systems to meet GSI goals if given adequate attention and support. They will also recommend to the EC the type and amount of "incubation" that is necessary to ready the treatments for shipboard use.

The specific incubators offered by the GSI may include over time:

- A Marine Engineering Incubator, serving treatment vendors whose products would be improved with greater technical understanding of ships
- A Business Incubator, serving treatment vendors with promising systems but too little financial wherewithal to succeed in the marketplace
- A Research and Development Incubator, serving treatment vendors with treatments that lack sufficient performance information to determine their possible effectiveness, or which could be improved with the benefit of shake-down trials

The EC will offer to supply the specific suite of incubator services likely to prepare promising candidate systems for the market, under financial terms and conditions that may vary depending on the EC's estimation of the promise and/or needs of the candidate systems and their vendors. At the discretion of the EC, the costs of these services and general development of the systems could be directly underwritten by the GSI or provided in return for a profit-sharing arrangement or other financial mechanism.

Research and Development Incubator

The Research and Development Incubator is being launched first to assist vendors in developing their treatment systems and ultimately prepare those systems for the market and routine use. The incubator will have capacity at three scales:

- Bench scale (laboratory): Bench-scale tests will take place at the University of Wisconsin and will address questions of treatment mechanism, dose-effectiveness, and residual toxicity.
- Pilot scale (barge-based): Pilot-scale tests will take place in a shore-linked barge platform, and will supply information on treatment performance at a scale approximating shipboard flow rates, and will include "grow-out" studies (what happens to treated organisms post-discharge).
- Shipboard scale: Shipboard tests could take place on volunteer Canadian lakers or transoceanic Seaway-sized vessels, depending on the stage of research and development. These tests will be designed to verify that treatment performance is not altered dramatically by shipboard conditions, and to test operational endurance of the systems.

Over $1 million in funds and in-kind contributions are available or likely will become available to launch the R & D Incubator activities (see below). These include:

- Direct contributions from U.S. and Canadian ports totaling approximately $100,000
- A $400,000 earmark in 2005 DOT appropriations to the University of Wisconsin to launch tests and a pilot-scale test pad
- A $500,000 earmark in 2006 DOT appropriations to the University of Wisconsin as above
- A more than $200,000 Sea Grant award to the Northeast-Midwest Institute to conduct preliminary shipboard tests to refine the shipboard testing protocols
- $50,000 from the Great Lakes Maritime Research Institute for engineering assistance
- $100,000 from the St. Lawrence Seaway Development/Management corporations in the United States and Canada for a mobile laboratory
- An in-kind contribution of a MARAD barge as a test platform (worth more than $600,000)
- Direct collaboration with FedNav Ltd. treatment trials scheduled for summer 2006
- $1 million awarded from NOAA over four years to assist in operation of the testing facility

This funding, combined with additional contributions from ports, government agencies, and private-sector sources, will provide the necessary impetus to deliver treatment solutions—including their development, installation, and use—for Seaway-sized ships in advance of the anticipated federal and international time frame.

Coordination with Federal Programs and Agencies

The GSI will be carefully designed to add value to ongoing regulatory and voluntary programs to prevent ship-mediated introductions of invasive species. As Seaway-sized ships ply around the globe, the GSI mission is to help solve international maritime commerce issues, not just those of the Great Lakes. Accordingly, the U.S. Coast Guard, with a regulatory program governing ballast discharge, will be closely consulted on the design and implementation of shipboard treatment evaluations of the GSI. The GSI goal will be to maintain such high quality in its evaluations that the efforts may be deemed tantamount to—or, at the Coast Guard's discretion, a part of—the Coast Guard's Shipboard Technology Evaluation Program (STEP). The Canadian Coast Guard and the IMO also will be consulted and kept informed.

Box 8: The National Fish and Wildlife Foundation: A Brief Overview

What is NFWF?

The National Fish and Wildlife Foundation is a private, nonprofit, 501(c)(3) tax-exempt organization, established by Congress in 1984 and dedicated to the conservation of fish, wildlife, and plants, and the habitat on which they depend. Its goals are to promote healthy populations of fish, wildlife, and plants by generating new commerce for conservation. The foundation meets these goals by creating partnerships between the public and private sectors and strategically invests in conservation and the sustainable use of natural resources.

What NFWF does

Matching Grants – The foundation identifies conservation needs, reviews proposed projects, fosters cooperative partnerships, and commits a combination of federal and nonfederal funds to on-the-ground conservation projects. The foundation commits funds in the form of matching grants to ensure that they are leveraged.

Building Partnerships – The foundation creates partnerships among federal, state, and local governments, corporations, private foundations, individuals, and nonprofit organizations. Creating partnerships facilitates the strategic identification of conservation issues and promotes efficiency and cooperation in the delivery of solutions through matching grants.

Leveraging Funds – Matching grants are partially supported by Congressionally appropriated dollars that must be matched by a ratio of one to one. However, the foundation strives to maximize dollars invested in conservation and currently averages more than a 2:1 return on funds entrusted to the foundation. For every dollar that Congress provides to the foundation, nearly $3 in on-the-ground conservation takes place. Since its founding in 1984, NFWF has supported over 6,400 grants and leveraged $261 million in federal funds for more than $786 million in on-the-ground conservation.

Recommendation

Due to its expertise in managing, leveraging, and disbursing funds, as well as its expertise in fostering and developing effective partnerships between public and private entities, NFWF would make an excellent choice to help coordinate and implement the Great Ships Initiative.

Source: The National Fish and Wildlife Foundation Web site, www.nfwf.org

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Appendix A:
A Note on Additional Vectors of Introduction and Spread of Invasive Species into the Great Lakes

Visits by transoceanic vessels are the leading primary vector by which many non-native organisms travel to the Great Lakes-St. Lawrence Seaway system (GLSLSS) from abroad. However, it is not the only such primary vector. Aquaculture, bait trade, aquarium use and recreational boats in transoceanic expeditions, also account for new introductions of non-native aquatic species. In addition, once established in the system, other aspects of the maritime transportation system including domestic vessel trade and connecting waterways, join salty vessels as vectors of organism spread. These and other secondary vectors accelerate the impact of introduced species, and thwart control efforts. Figure 1 illustrates the non-ballast vectors responsible for the primary and secondary spread of many notorious invading organisms within the Great Lakes

While the top priority of the Great Ships Initiative (GSI) should be attenuating the primary vector of ocean-going maritime trade, state and federal policy is also urgently needed to interdict other primary vectors and stop secondary spread of invasive organisms. The nature and extent of these maritime industry-related, and non-maritime industry-related alternative vectors of introduction and secondary spread relevant to the GLSLSS are summarized below.

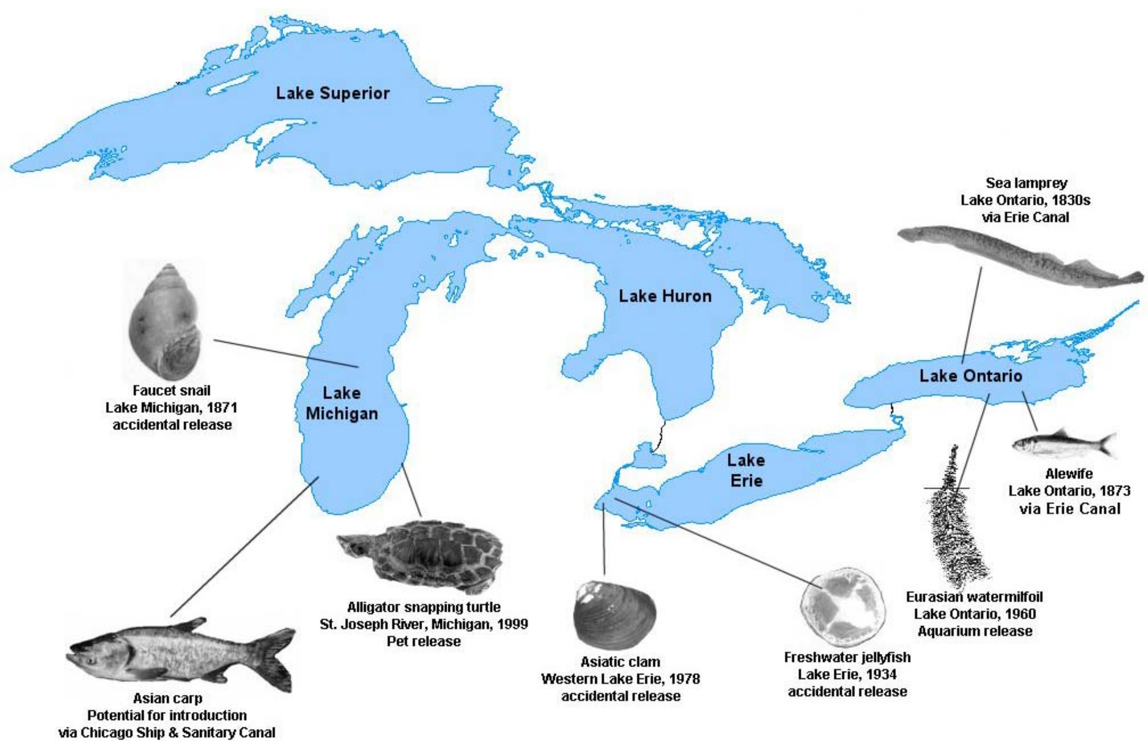

Fig. 1. Map showing first sightings of presumed invaders transported to the Great Lakes by vectors other than ballast water (source: USGS, 2004)

Maritime-Related Vectors of Secondary Spread

U.S.-Flagged Lakers

Fleet and Vessels

The U.S.-flagged laker fleet comprises approximately 60 vessels, the majority of which are self-propelled, self-unloading bulk carriers, although there is a small number of tankers, cement carriers, tugs, and barges in service. U.S.-flagged lakers are by far the largest vessels on the Great Lakes, with many vessels in the fleet more than 300 m long. Their size prevents them from transiting the Welland Canal, so that U.S. lakers trade exclusively in the upper four Great Lakes.

Because they do not ply saltwater, U.S. lakers can have very long useful service lives. Most of the lakers in operation today began service in the 1960s or 1970s, while the younger vessels entered the fleet in the early 1980s. It is not uncommon for lakers to serve for 50 years. Because of this longevity, many lakers undergo refurbishment during their life cycle. For example, the vessel *Alpena,* currently operated by Inland Lakes Management, was constructed as a conventional bulk carrier in 1942, but converted to a cement carrier in 1989.

Cargoes

The U.S.-flagged laker fleet transports three primary types of cargo around the upper four Great Lakes: iron ore, coal, and limestone. In 2002, the fleet transported over 147 million metric tons of cargo—a figure on par with the annual tonnage carried by the fleet over the last 10 years (fig. 2)—including 53 million metric tons of iron ore for use in domestic steel production, 38 million metric tons of coal for use by steel manufacturers and electric utilities, and 33 million metric tons of limestone for use by diverse customers including the steel, construction, chemical, and paper industries (LCA, 2003). With the exception of 2002, both the iron ore and limestone floats have been steadily declining in recent years, while the coal float holds steady (fig. 3).

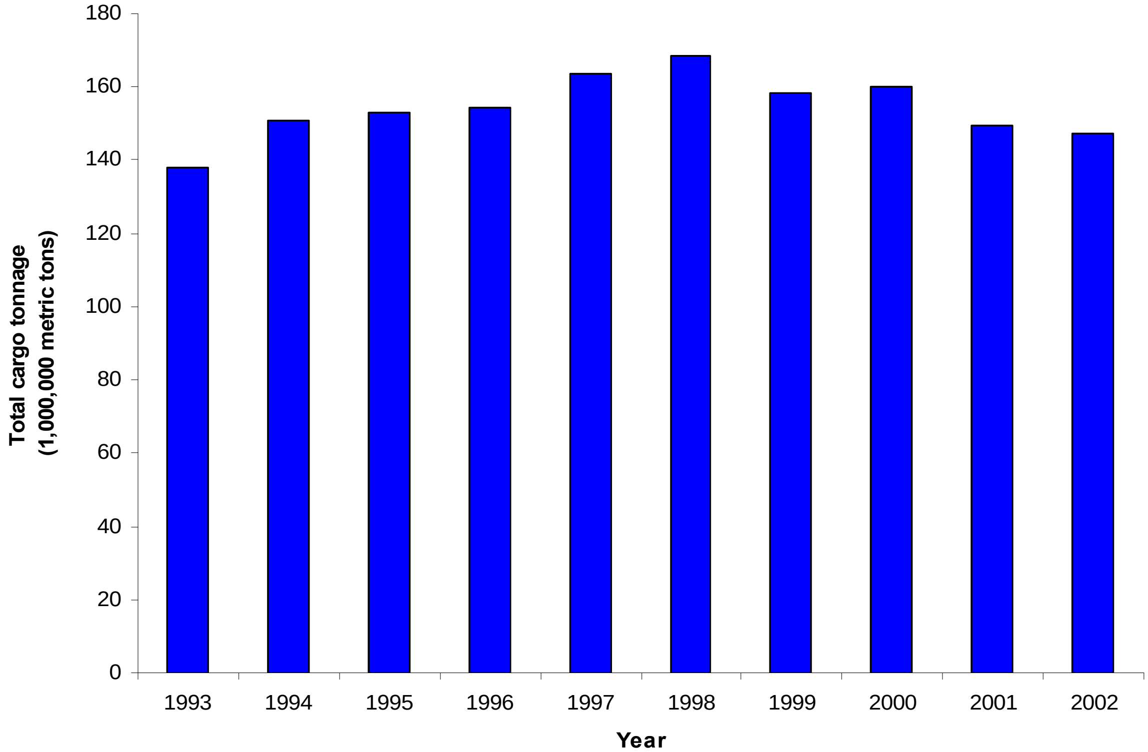

Fig. 2. Total tonnage of cargo (in millions of metric tons) carried by the U.S.-flagged lakers, 1993—2002 (LCA, 2003)

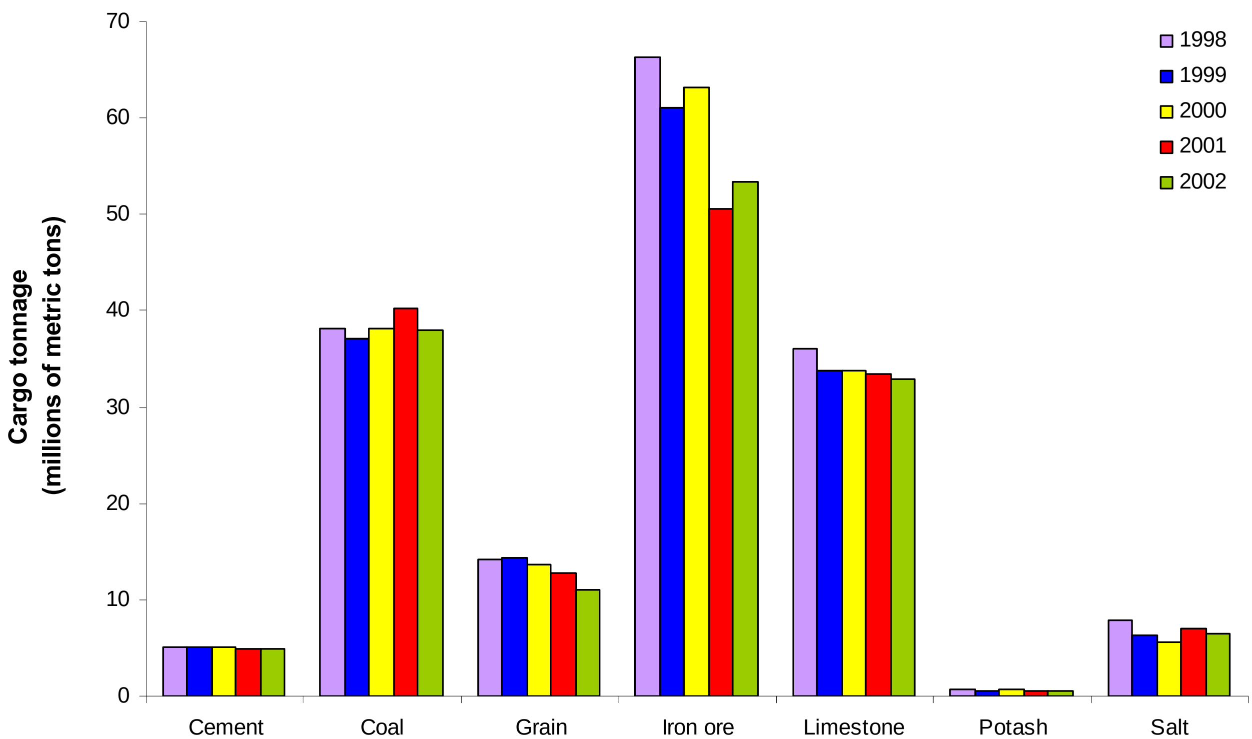

Fig. 3. Tonnage of cargo (in millions of metric tons) carried by the U.S-flagged lakers by major cargo category, 1998–2002 (source: LCA, 2003)

Vessel Movement Patterns

The primary pattern of cargo movement for U.S.-flagged laker vessels is to carry iron ore and coal from northern Michigan and Minnesota south to major industrial cities in lower Michigan and Ohio. Vessels tend to return north in ballast, although there is some backhaul of other cargoes including cement, salt, grain, sand, and various liquid-bulk products. Some ships, generally the small and mid-sized vessels, may also engage in a triangular trade whereby they undertake a number of short hauls with cargo or ballast before returning to Lake Superior for an iron ore or coal cargo. Figures 4 through 6 illustrate the typical voyage patterns laker vessels follow in transporting these commodities.

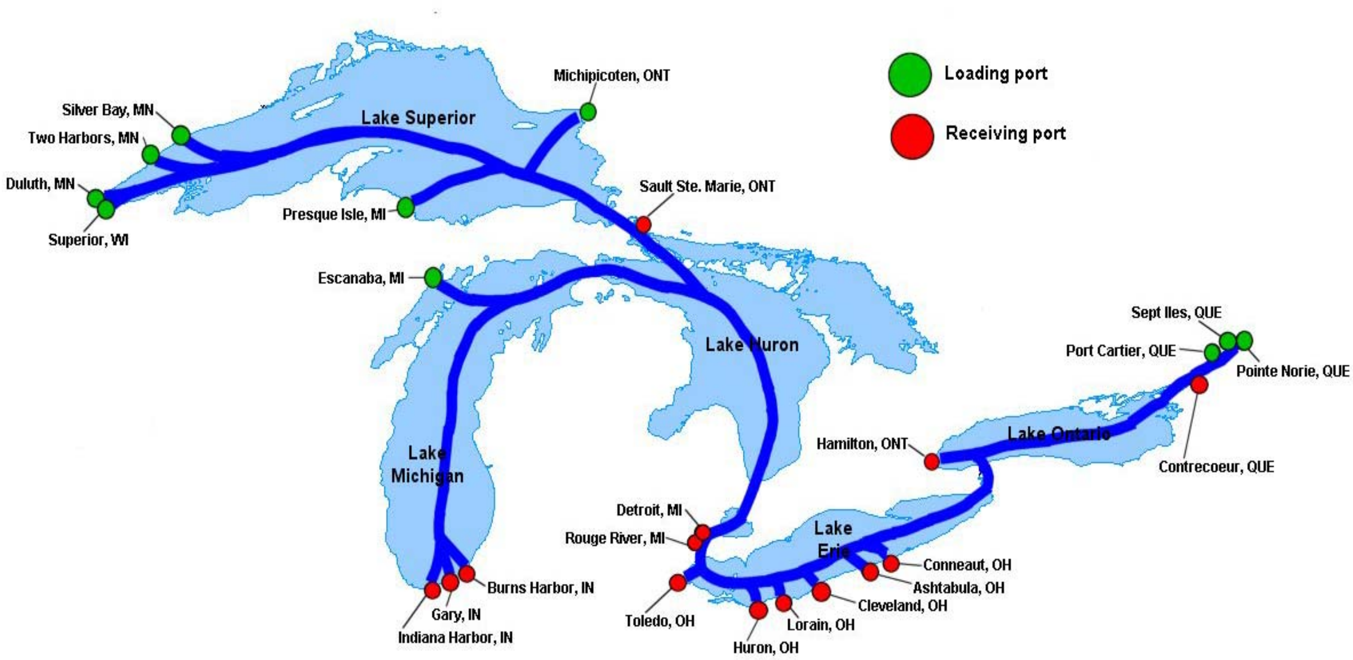

Fig. 4. Generalized trade pattern of U.S.- and Canadian-flagged laker vessels transporting iron ore throughout the Great Lakes

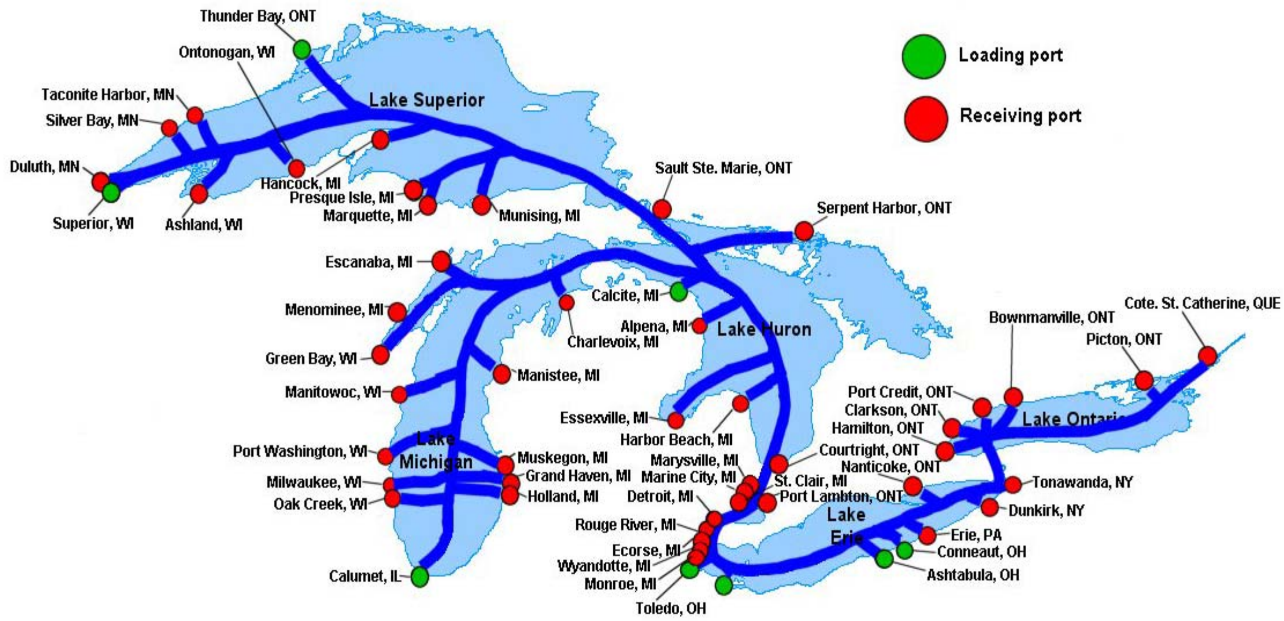

Fig. 5. Generalized trade pattern of U.S.- and Canadian-flagged laker vessels transporting coal throughout the Great Lakes

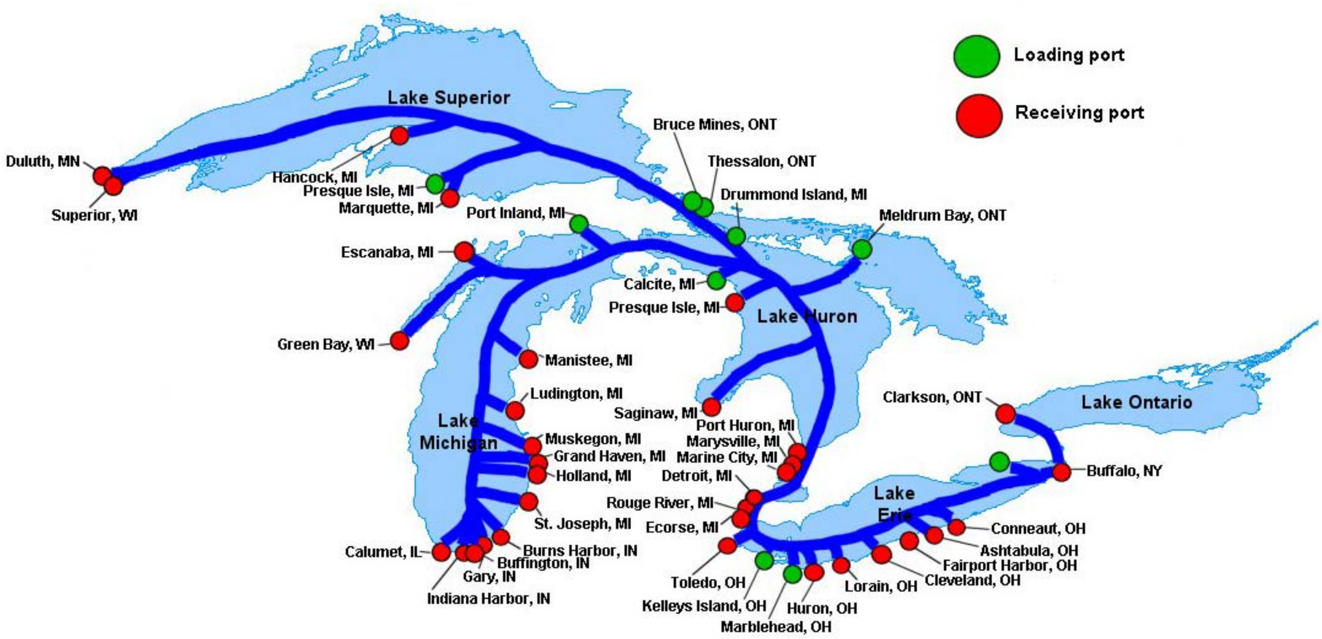

Fig. 6. Generalized trade pattern of U.S.- and Canadian-flagged laker vessels transporting limestone throughout the Great Lakes

Owners and Operators

Unlike the transoceanic vessels operating on the GLSLSS, there is little ambiguity between U.S. laker-vessel owners and operators. This is primarily because the Jones Act—a U.S. law that requires cargo moving between two U.S. ports to be carried in vessels that are U.S.-owned and U.S.-built and employ U.S. citizens—offers little benefit for vessels to be owned and operated by different companies. Of the 14 companies currently operating U.S.-flagged vessels in the Great Lakes (table 1), only one—the *MV Southdown Challenger*—has a different owner and operator, and this is due to the acquisition of the vessel's previous owner by an offshore company.

Table 1. Companies that currently operate U.S.-flagged lakers on the Great Lakes

Ship operator	Type of vessel	No. of vessels	Average gross registered tonnage
American Steamship Company	Dry bulk carrier	11	20,793
Central Marine Logistics	Dry bulk carrier	2	13,328
Cleveland Tankers Ship Management	Tankers	1	5,854
Grand River Navigation Company, Inc.	Dry bulk carrier	2	8,211
	Barge	1	13,500
	Tug	1	180
Great Lakes Associates, Inc.	Dry bulk carrier	1	11,076
Great Lakes Fleet, Inc.	Dry bulk carrier	8	20,632
HMC Ship Management Operators, Ltd.	Cement carrier	1	6,967
Inland Lakes Management, Inc.	Cement carrier	3	7,260
Interlake Steamship Company	Dry bulk carrier	8	22,126
ISG-Burns Harbor, Inc.	Dry bulk carrier	2	34,291
Oglebay Norton Marine Services Co.	Dry bulk carrier	11	15,918
Pere Marquette Shipping Company	Barge	1	3,413
	Tug	1	569
Upper Lakes Towing Company, Inc.	Barge	1	14,356
	Tug	1	841
VanEnkevort Tug & Barge Inc.	Barge	1	15,823
	Tug	1	1,179

Canadian-Flagged Lakers

Fleet and Vessels

The Canadian-flagged laker fleet comprises approximately 80 vessels operated by eight companies. Most of these vessels are self-unloading bulk carriers, though there are also a small number of tankers, cement carriers, and general cargo carriers. Canadian lakers are much smaller than U.S-flagged lakers, averaging around 220 meters in length. Because of their smaller size, Canadian lakers are able to visit ports throughout the five Great Lakes. Some vessels are also small enough to transit the St. Lawrence Seaway and thus visit Canadian ports outside the Great Lakes system, undertaking an important function in connecting the heavy industries on the south shores of Ontario with the eastern coast of Canada.

The age and condition of the Canadian laker fleet is similar to that of the U.S.-flagged laker fleet, with many of the vessels constructed during the 1960s and 1970s and some newer vessels built in the 1980s. The service life for this fleet is approximately 45 years—slightly shorter than that of vessels in the U.S. fleet, owing to their occasional exposure to saltwater.

Cargoes

In general, cargoes carried by Canadian lakers are similar to those carried by U.S. lakers, with iron ore, coal, and limestone making up nearly two-thirds of the fleet's total float. Other cargoes include tanker products, grain, salt, miscellaneous bulk, and cement. Approximately 60 percent of Canadian-laker traffic is involved in north-south trade with U.S. ports in the Great Lakes; the remaining 40 percent involves trade outside the Great Lakes to Canada's eastern seaboard (CSA, 2003).

In 2002, the Canadian-flagged laker fleet carried more than 66 million metric tons of cargo—a figure on par with the annual tonnage carried by the fleet over the last 10 years (fig. 7)—including 15 million metric tons of iron ore, 17 million metric tons of coal, 8 million metric tons of limestone, and 6 million metric tons of grain (CSA, 2003). In recent years coal, for use in power and steel production, has replaced iron ore as the leading cargo transported by the fleet (CSA, 2003). The 15 million metric tons of iron ore transported in 2002 represented the smallest iron ore float in 11 years (fig. 8).

Fig. 7. **Total tonnage of cargo (in millions of metric tons) carried by the Canadian-flagged laker fleet, 1992–2002 (source: CSA, 2003)**

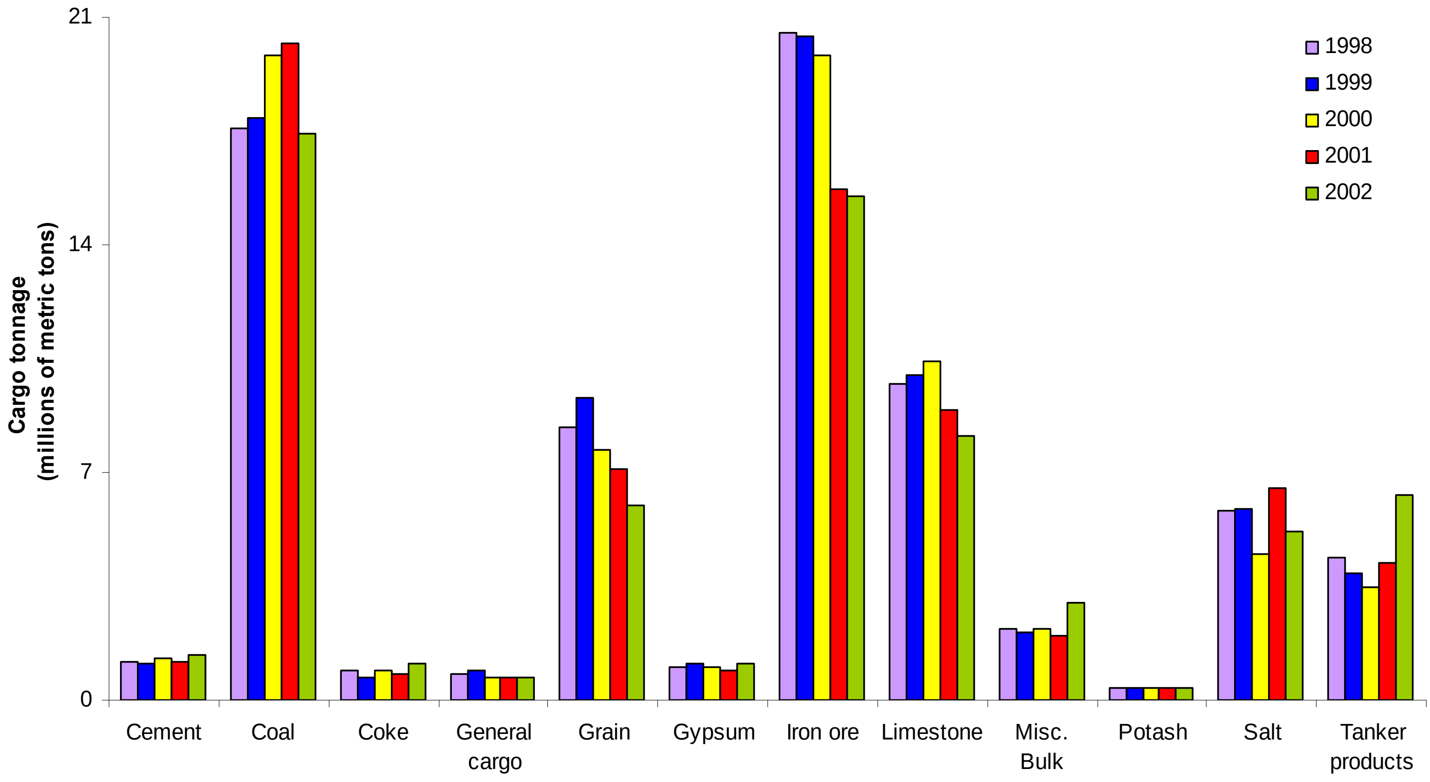

Fig. 8. **Tonnage of cargo (in millions of metric tons) carried by the Canadian-flagged laker fleet by major cargo category, 1998–2002 (source: CSA, 2003)**

Vessel Movement Patterns

The primary transit pattern for Canadian lakers in the Great Lakes is much different from the movement of the U.S.-flagged laker fleet. Canadian lakers are generally involved in triangular trading rather than direct trading, transporting coal and grain from ports on western Lake Superior to ports on Lake Ontario and along the St. Lawrence Seaway, and then moving to the gulf ports of Sept Isles and Port Cartier in ballast to load iron ore. The iron ore is carried to Hamilton and U.S. ports in Lake Erie for steel production. The vessels then travel back to Lake Superior in ballast to reload cargos of coal and grain. Figures 4-6 and 9 illustrate the typical voyage patterns Canadian lakers follow in transporting these commodities.

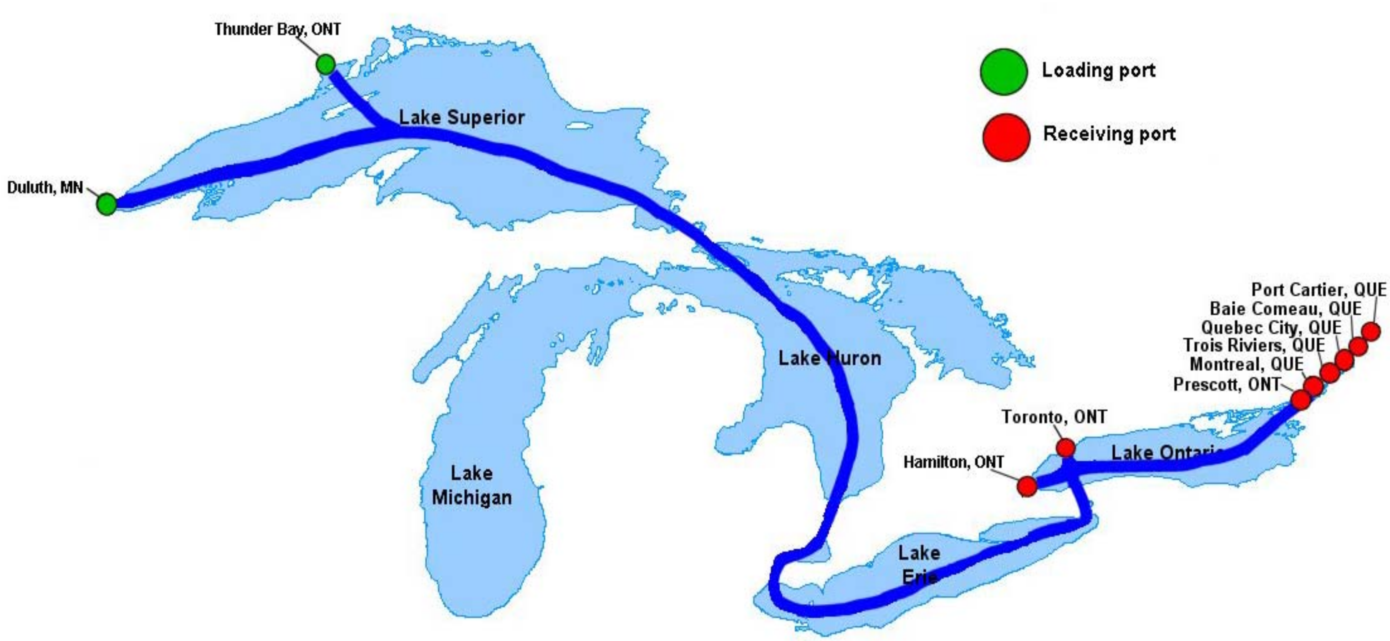

Fig. 9. Generalized trade pattern of Canadian-flagged laker vessels transporting grain throughout the Great Lakes

Owners and Operators

As with the U.S.-flagged fleet, there is little benefit for Canadian vessels to be owned and operated by different companies. The Canada Shipping Act requires that vessels involved in trade between Canadian ports use Canadian crew and be owned by Canadian companies. Although no regulation requires that the ship be built in Canada, any ship built elsewhere is subject to an import tariff equal to 25 percent of the vessel's value. Recently, however, several partnerships between major Canadian shipping companies have been created. For example, Algoma Central Corporation and Upper Lakes Group, Inc. have combined to form Seaway Marine Transport, which is responsible for the commercial management of the two companies' fleets, including 21 self-unloading vessels and 13 gearless bulk cargo vessels (table 2).

Table 2. Companies that operate Canadian-flagged vessels on the Great Lakes-St. Lawrence Seaway system

Ship operator	Type of vessel	No. of vessels	Average gross registered tonnage
Algoma Central Corp.	Bulk carrier	19	19,132
	Tanker	5	7,993
Canada Steamship Lines, Inc.	Bulk carrier	16	21,516
	Cement carrier	1	6,729
	Ore carrier	1	33,792
Desgagnes Tankers	Tanker	4	7,298
Lower Lakes Towing Ltd.	Bulk carrier	4	11,250
Purvis Marine Ltd.	General cargo carrier	1	3,280
Transport Desgagnes, Inc.	Bulk carrier	1	4,433
	General cargo carrier	6	6,179
	Tanker	3	6,262
Transport Nanuck	General cargo carrier	1	6,037
Upper Lakes Group, Inc.	Bulk carrier	17	8,756
	Cement carrier	1	6,792

U.S.-Flagged Barges

The Illinois Waterway is another passage for cargo leaving and entering the Great Lakes region. According to the U.S. Army Corps of Engineers Waterborne Commerce Statistics, 40.7 million metric tons of commodities were moved on the river in 2003. That was a typical year; from 1994 through 2003, the total annual tonnage was always 39 million–43 million metric tons. In 2003, as in other years, over half of the cargo (more than 21 million metric tons) moved down river to the Mississippi River. This down-river movement was dominated by food and farm commodities (including grain), averaging approximately 16 million or 17 million metric per year.

Fleet and Vessels

There are over 27,000 commercial barges in operation in the United States (American Waterways Association, 2005). This total encompasses vessels that ply all of the nation's rivers and interior waterways; the number of barges that travel routes relevant to the Great Lakes is smaller—approximately 6,000—but still significant. A 2003 U.S. Army Corps of Engineers inventory identified approximately 3,000 barges operated by towing and barge operators on the Mississippi and Illinois Rivers and their tributaries.

A typical barge that operates on the Mississippi and Illinois River systems measures 59 meters long by 10.7 meters wide and can carry just over 1,300 metric tons of cargo. They are designed to carry bulk cargo either on open decks or in holds or tanks within the barge's hull. Most of these barges are not self-propelled, requiring a tow or pushboat to move them. Multiple barges are typically arranged into "tows," with tows of 15 barges common on the Illinois waterway and even longer on the Mississippi River.

Cargoes

Barges are used to transport many of the same bulk commodities carried by the larger, self-propelled bulk cargo vessels of the laker and Salty fleets. The most common barge cargos on the Illinois and Mississippi River system are grain, petroleum products, chemicals, and coal. In 2002, just over 39 million metric tons of cargo was transported on the Illinois Waterway, which is in line with the average for recent years (Army Corps of Engineers, 2002b). Nearly half of this, or 17 million metric tons, was downbound shipments of grain and other farm products heading to ports along the Mississippi River. The most significant upbound commodities in 2002 were 2.8 million metric tons of chemical products, 2.4 million metric tons of petroleum products, and 2.2 million metric tons of manufactured goods (split evenly between limestone and cement, and iron and steel products).

Vessel Movement Patterns

Barge traffic flows year round in both directions on the Mississippi River and Illinois Waterway. In general, grain is shipped from ports along the Upper Mississippi River and Illinois Waterway south to Gulf of Mexico ports for shipment overseas. Other commodities, such as chemicals and iron and steel products, tend to be transported upbound on the Mississippi River and Illinois Waterway. Petroleum products tend to move in both directions, with significant amounts both shipped and received by ports all along the Mississippi River and Illinois Waterway.

These river barges are not specifically designed to operate in the open-water environment of the Great Lakes. As a result, relatively few barges travel from the Chicago Ship and Sanitary Canal onto or across Lake Michigan, with most of the barge traffic in the San-Ship Canal performing intracanal operations (GLRC, 2005). However, some barges do operate in southern Lake Michigan, typically staying close to shore and traveling between the ports of Chicago, Calumet Harbor, Gary, Indiana Harbor, and Burns Harbor (fig. 10). The Coast Guard has created special rules to allow river barges to travel to the ports of Milwaukee and Muskegon, further north along Lake Michigan's coastline. Approximately 1,600 transits between the western rivers and Lake Michigan occur annually. With three or four barges per tow, this equates to an approximate total of between 4,000 and 6,400 barges per year (U.S. Coast Guard, pers. comm.).

Fig. 10. Generalized trade pattern of domestic barges traveling between the Illinois Waterway and Lake Michigan ports

Owners and Operators

As with the U.S. laker fleet, Jones Act requirements provide little incentive for barges to be owned and operated by different companies. Due to the large number (over 27,000) of barges operating within the United States, there are a large number of companies that own and operate barges. These companies range in size, from relatively small operations that own a handful of barges to large transportation firms that may own and operate many hundreds of barges. Some companies operate their barges for charter and other barge companies may be subsidiaries of much larger companies, as in the case of barge operators associated with ADM and General Dynamics Corp. Table 3 provides an overview of some of the companies that operate barges on the Mississippi River and Illinois Waterway. According to the U.S. Army Corps of Engineers, there are approximately 35 such barge companies (Army Corps of Engineers, 2003).

Table 3. Companies that operate U.S.-flagged barges on the Mississippi River and Illinois Waterway

Barge Operator	Type of Barge	Number of Barges
ADM	Dry Covered Barge	15
AGP Memco LLC	Dry Covered Barge	630
	Dry Open Barge	840
Alberici, J.S. Const. Co., Inc.	Deck Barge	12
	Other Dry Cargo Barge	6
Ameren, UE	Dry Covered Barge	41
American Marine Constructors	Deck Barge	3
Apex Towing Co.	Double Hull Tank Barge	5
Artco Fleeting Services	Deck Barge	1
Baxter, R.R. and Baxter, Jameson	Dry Covered Barge	8
Blessey Marine Services, Inc.	Dry Covered Barge	2
	Double Hull Tank Barge	79
Cemex, S.A. DE C.V.	Dry Covered Barge	1
Deluca, David T.	Dry Covered Barge	2
Durocher Marine	Deck Barge	9
	Other Dry Barge	1
Economy Boat Store	Single Hull Tank Barge	5
	Double Hull Tank Barge	1
	Other Tank Barge	1
Egan Marine Corp.	Deck Barge	2
	Double Hull Tank Barge	9
	Other Tank Barge	3
Eneix, Lloyd H.	Dry Covered Barge	1
Florida Marine Transporters, Inc.	Single Hull Tank Barge	11
	Double Hull Tank Barge	6
	Other Tank Barge	41
Garvey Marine Inc.	Dry Open Barge	6
	Deck Barge	2
	Double Hull Tank Barge	1
Gillen, Edward E. Co.	Deck Barge	12
Hamm's Harbor Service and Fleeting	Dry Covered Barge	22
	Dry Open Barge	10
	Deck Barge	2
Hannah Marine Corp.	Dry Covered Barge	1
	Double Hull Tank Barge	16
Holly Marine Towing	Dry Covered Barge	2
	Deck Barge	7

Illinois Marine Towing, Inc.	Dry Covered Barge	45
	Dry Open Barge	11
Kadinger Marine Service	Deck Barge	1
	Other Dry Cargo Barge	1
Kirby Inland Marine, LP	Single Hull Tank Barge	65
	Double Hull Tank Barge	707
	Other Tank Barge	65
Le Beouf Bros. Towing, LLC	Single Hull Tank Barge	11
	Double Hull Tank Barge	31
	Other Tank Barge	1
Lower Illinois Towing Co.	Deck Barge	1
Material Service Corp.	Dry Covered Barge	1
	Dry Open Barge	1
	Deck Barge	84
Matteson, L.W. Inc.	Deck Barge	16
Metal Management Midwest, Inc.	Dry Open Barge	1
Midwest Generation, LLC	Dry Open Barge	25
Midwest Marine Management	Dry Covered Barge	50
Powley Sand and Gravel	Dry Covered Barge	6
Riverdocks, Inc.	Dry Covered	6
	Deck Barges	2
SCF Barge Line II, Inc.	Dry Covered Barge	2
	Dry Open Barge	1
SCF Towboat III	Dry Covered Barge	6

Artificial Waterways

In some cases, introductions of invasive species have occurred via the artificial waterways and canals that allow vessels to transit between water bodies. Eleven of the invasive species established in the Great Lakes basin reached the lakes through a canal. Of these, four (sea lamprey, purple loosestrife, alewife, and white perch) are considered to have had substantial impacts on the Great Lakes ecosystem (Mills *et al.*, 1993).

The sea lamprey is the most notable example of an invasive species introduction via canal. This species entered Lake Ontario through the Erie Canal in the 1830s. The subsequent opening of the Welland Canal allowed sea lamprey to spread to Lake Erie by 1921, and eventually spread to all of the Great Lakes (Mills *et al.*, 1993). Once in the lakes, the lamprey severely affected native fish populations, leading directly to the collapse of the region's lake trout fishery. To this day, lamprey-control programs cost millions of dollars each year.

The most recent of these introductions occurred in the late 1950s, but canals and artificial waterways remain a potential route for additional introductions. One of the greatest invasion threats is the potential for Asian carp to reach Lake Michigan via the Chicago Ship and Sanitary Canal. These carp pose a significant threat to the Great Lakes and would be expected to compete with valuable sport and commercial fish. Once introduced, they would likely become a dominant species in the ecosystem (GLFC, 2004).

Relevance to Invasions

Due to their typical vessel voyage patterns, the U.S. and Canadian laker fleets are not significant sources of new nonindigenous species to the Great Lakes. Because the U.S. laker fleet never operates outside of the Great Lakes, U.S. lakers are never in a position to take on foreign ballast water. While some Canadian lakers travel beyond the Seaway, they typically operate around Canada's Atlantic coast. Little, if any, of their ballast water comes from across the ocean. However, thanks to the large volume of ballast water they transport around the Great Lakes annually, the U.S. and Canadian laker fleets may play a role in spreading and dispersing species already introduced and established in the lakes (Aquatic Sciences, Inc., 1996; Reeves, 1999).

Similarly, barges may pose a risk for spreading previously introduced species. Although the overwhelming majority of barges that operate on the inland waterways and Great Lakes do not carry ballast water, a subset of tank and heavy-lift barges may ballast for stability when empty (U.S. Coast Guard, pers. comm.). However, the amount of ballast water transferred by these vessels is unknown, and the likelihood of barge ballast transporting viable aquatic invasive species remains unexplored. While the risk posed by barge ballast water may remain undetermined, hull fouling on barges appears to have been a problem in the past and could continue to act as a dispersal mechanism for some invasive species. It has been theorized that the movement of barge traffic was a major factor in the rapid spread of zebra mussels from the Great Lakes throughout the United States (USGS, 2004). In this case, barges traveling from the Great Lakes along the Mississippi Rivers and other inland waterways inadvertently transferred zebra mussels attached to their hulls. Furthermore, the canals and artificial waterways that barges travel can also act as a conduit for invasive species transfer, as in the case of the round goby spreading from the Great Lakes to the Mississippi River basin via the Chicago Ship and Sanitary Canal (Great Lakes Regional Collaboration, 2005).

The laker fleets have attempted to proactively address this potential for spreading organisms. Beginning in 1993, the laker fleets developed and implemented a Voluntary Ballast Water Management Program (VBWMP) to slow the spread of the Eurasian Ruffe, which had been introduced to Duluth/Superior Harbor in the late 1980s. It requires vessels to either not take on ballast in Duluth/Superior Harbor, or, when ballasting is operationally required, to exchange ballast water in an area of Lake Superior where Ruffe are unlikely to survive (U.S. Fish and Wildlife Service, 1996). To date, this program has been successful, as the Ruffe infestation remains mostly confined to Lake Superior's western end, with exceptions around Alpena, Little Bay de Noc, and Big Bay de Noc, Michigan.

The laker fleets have built on these early efforts to develop a series of voluntary management practices to reduce species transfer. These include:

- Developing programs similar to the VBWMP for harbors where U.S. or Canadian authorities determine a nuisance species has become established
- Conducting annual inspections to assess sediment accumulation and removing sediment, if necessary
- Developing sediment removal policies and plans
- When practical and safe, having vessels take only minimum required ballast to safely depart dock and then complete ballasting in deeper water
- Cooperating with scientific research into sampling, analysis, and ballast-treatment technologies

Non-Maritime Related Vectors of Introduction and Spread

Aquarium/Pet trade

Release from home aquaria has resulted in the introduction of invasive species throughout the United States. The aquatic weed *Hydrilla*, cultivated as a freshwater aquarium plant, has been accidentally released at several points in the United States. Plants from home aquaria or cultivation facilities were likely responsible for infestations starting in Tampa Bay, Florida, and near Washington, DC. *Hydrilla* has since spread throughout the Southeast and as far north as Massachusetts. Introduction of *Hydrilla* on the West Coast likely resulted from importation of other ornamental aquatic plants. A handful of species has also been introduced to the Great Lakes via accidental release from home aquaria—mainly snail species that were accidentally released between the 1900s and 1930s. Since the 1970s, however, the bluespotted sunfish, Asiatic clam, and a parasitic copepod have also been introduced (Mills *et al*., 1993).

Recent years have seen a number of "close calls" with species released from aquaria. In 2000, *Caulerpa taxifolia*—a highly invasive seaweed popular in aquaria—was discovered in a lagoon in California. Two years later, snakehead fish were intentionally released into a Maryland pond.

Fisheries and Aquaculture

In the Great Lakes, deliberate introduction and stocking of aquatic species, particularly fish, occurred throughout the latter half of the 19th century and the first half of the 20th century. Eight fish species have been introduced or stocked, which have had both positive and negative impacts. In some cases, these stocked species support commercial and recreational fisheries. However, examples such as common carp and Pacific salmon have impacted native fish and wildfowl through competition, predation, and habitat destruction (Mills *et al*., 1993).

In addition to the introduction or stocking of species in the wild, the introduction of species for aquaculture is also a potential vector for invasive species. The Asian carp discussed above were originally imported to the Mississippi River basin to control algae in aquaculture facilities. During flooding in the early 1990s, they escaped into the Mississippi River and have been moving north since, altering fish and shellfish communities and posing a looming threat to the Great Lakes ecosystem.

Another potential impact of fishery and aquaculture introductions is the coincident introduction of parasites and disease. Three fish pathogens—*Furunculosis, Glugea hertiwgi*, and whirling disease—have been reported in the Great Lakes. *G. hertwigi* was responsible for high mortalities of Lake Erie and Lake Ontario rainbow smelt during the 1960s. *Furunculosis* and whirling disease affect salmon and trout, most commonly in fish hatcheries and aquaculture settings (Mills *et al*., 1993).

Recreational Vessels

While ballast water from large commercial vessels is the most significant source of introductions, there are a number of secondary vectors as well, including the numerous recreational vessels owned and operated by private citizens. Recreational vessels that come into contact with invasive species can hasten the spread of organisms or introduce them to bodies of water. This is of particular concern for small boats that can be transported over land via trailer, as well as recreational vessels that travel directly between two bodies of water. For example, some 35,000 recreational vessels travel between Lake Michigan and the Chicago Ship and Sanitary Canal (on the Illinois Waterway) annually—each one a potential vector for aquatic invasive species (Army Corps of Engineers, 2002c).

Research

Laboratories and universities throughout the basin make use of many different aquatic species in conducting research and experiments, creating the risk of accidental release and establishment of species. This risk is made more serious by the relative lack of regulatory constraints on research organisms, as well as the overall lack of information about the potential consequences of accidental release (Carlton, 2001).

Appendix B: Ballast Volumes and Numbers of Organisms Discharged into the GLSLSS by Transoceanic Ships Under Various Scenarios

Total Foreign Ballast Volumes

Based on best available data and a number of assumptions,[6] the total amount of ballast water discharged by the transoceanic Salty fleet in the GLSLSS is estimated to be approximately 5.8 million cubic meters per year (table 1), equal to an average discharge of more than 18,879 cubic meters per day. In comparison, the U.S-flagged laker fleet discharges volumes an order of magnitude greater—some 227,400 cubic meters into the Great Lakes each day (Ryan, 2001)—and the Canadian-flagged laker fleet discharges more than twice the transoceanic fleet—an average of 57,500 cubic meters into the GLSLSS each day (D. Reid, pers. comm.).

Although these figures provide an estimate of the volumes of ballast water that vessels, including those entering the system from outside the EEZ, discharge into the GLSLSS, they greatly exceed the volumes of *foreign* ballast water (which could contain non-native organisms) that is discharged into the system. The reason for this discrepancy is that virtually all ships entering the GLSLSS after operating outside the EEZ either purge their tanks of near coastal water in the high seas through conducting a "ballast water exchange" (BWE) pursuant to federal law (see below) or they are empty of pumpable ballast water and full of cargo. Neither practice (BWE or removal of pumpable ballast water) completely removes near coastal organisms from ballast tanks. Rather, the foreign ballast water that ships in both conditions ultimately discharge into the GLSLSS is heavily diluted either by open ocean water or GLSLSS water.

In light of these considerations, what volume of foreign ballast water is in fact carried to and discharged into the GLSLSS by merchant ships? Approximately 15 percent of transoceanic vessel visits to the Great Lakes system from overseas are in the ballasted condition, containing water that has been diluted in the high seas through BWE (St. Lawrence Seaway Development Authority, 2003; fig. 1). Of these, Johengen *et al*. (2005) reported that each vessel can have as much as 25,500 cubic meters or as little as 1,500 cubic meters of ballast water on board, with over 50 percent of vessels having capacities greater than 10,000 cubic meters. Using 10,000 cubic meters as metric for the average amount of ballast water salty vessels carry into the GLSLSS, approximately 460,000 cubic meters of ballast water was discharged in the GLSLSS in 2002 alone by the 46 vessels that had conducted BWE (table 1). Similar studies by Parsons *et al*. (1997) and Locke *et al*. (1993) have estimated that 716,462 and 719,565 cubic meters of ballast water, respectively, was discharged into the GLSLSS by transoceanic vessels that conducted BWE prior to entering the system in a one year period.

[6] Vessel visit data provided by St. Lawrence Seaway Development Authority (2003). Average foreign ballast volume per vessel and BWE efficiency estimates provided by Johengen *et al*. (2005).

Assuming that BWE delivers a 86–98 percent efficiency at purging the harbor water from foreign ports and replacing it with high-seas water, as reported by Johengen *et al*. (2005), the portion of this 460,000 cubic meter volume that is foreign ballast water falls somewhere in the range of 9,200 to 64,400 cubic meters (table 1).

The remaining 85 percent of transoceanic vessels arrive fully loaded with cargo with only unpumpable ballast residuals in ballast tanks (St. Lawrence Seaway Development Authority, 2003; fig. 1). After their cargo is discharged, Great Lakes water mixes with the residual, unpumpable ballast water already present in the tanks, only to be discharged at upper-lakes ports where the vessel takes on cargo for its outgoing voyage, primarily Duluth-Superior Harbor and Thunder Bay (Bailey *et al*., 2003). Based on best available data and a number of assumptions, 5.8 million cubic meters of this mixed ballast water is discharged into the lakes annually by transoceanic vessels (table 1). At the most, approximately 106,000 cubic meters of this volume is the original foreign ballast water, equivalent to 350 cubic meters discharged into the lakes per day (table 1).

Recently the U.S. Coast Guard issued voluntary guidelines urging ships in the NOBOB condition to undertake a partial exchange in the open ocean. If ships follow this guidance, the volume of foreign ballast discharged by these ships will further decrease.

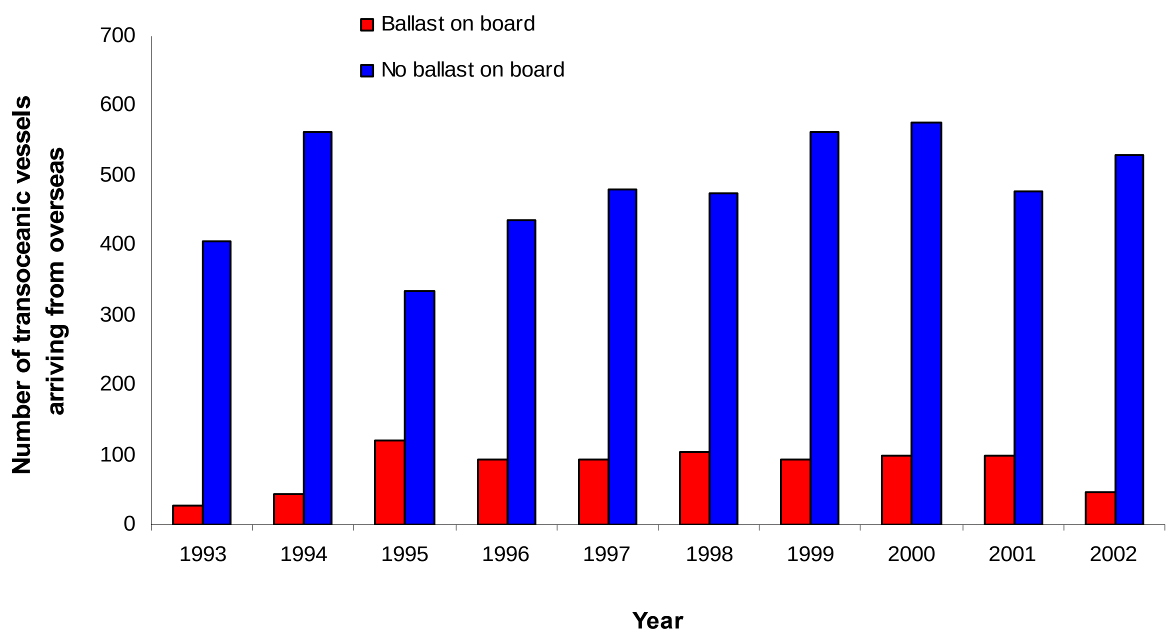

Fig. 1. Number of overseas-flagged transoceanic vessels that entered the Great Lakes-St. Lawrence Seaway system declaring "ballast on board" and "no ballast on board," 1993–2002 (source: St. Lawrence Seaway Development Authority, 2003)

Table 1. Estimates of foreign ballast water volume discharged in the GLSLSS by transoceanic ships in 2002 (in cubic meters) given a range of BWE efficiency assumptions.

	Ballasted (BOB) vessels	Unballasted (NOBOB) vessels	TOTAL
Number of vessel visits in 2002	46	531	577
Average foreign ballast volume per vessel (m^3)	10,000	200	566,200
Ballast from foreign ports discharged in GLSLSS assuming 86% BWE efficiency (m^3)	64,400	106,200 (no BWE requirements)	170,600
Ballast from foreign ports discharged in GLSLSS assuming 98% BWE efficiency (m^3)	9,200	106,200 (no BWE requirements)	115,400
Ballast from foreign ports discharged in GLSLSS assuming 100% BWE efficiency (m^3)	0	106,200 (no BWE requirements)	106,200
Ballast from high seas discharged in GLSLSS assuming 86% BWE efficiency (m^3)	395,600	0	395,600
Ballast from high seas discharged in GLSLSS assuming 98% BWE efficiency (m^3)	450,800	0	450,800
Ballast from high seas discharged in GLSLSS assuming 100% BWE efficiency (m^3)	460,000	0	460,000
Ballast from foreign ports combined with GLSLSS ballast discharged in GLSLSS (m^3)	0	5,203,800	5,203,800
Total amount of ballast water discharged by the transoceanic fleet in the GLSLSS (m^3)	460,000	5,310,000	5,770,000

Overall Rate of Foreign Ballast-Entrained Organisms

Assuming that organism densities in ships arriving to the Great Lakes are similar to those in ships plying globally, a typical Salty entering the Great Lakes could carry an average of 464 zooplankton per cubic meter, 2.9×10^8 phytoplankton per cubic meter, and 8.3×10^{11} bacteria per cubic meter in its ballast water—based on the ICES review of worldwide ballast water studies to determine the range of organism concentrations observed in ships' ballast water (IMO MEPC 49/2/21, 2003). Applying these ICES metrics to the 2002 estimates of transoceanic vessel visits to the GLSLSS provided by the St. Lawrence Seaway Development Corporation (2003) and Johengen *et al*.'s (2005) estimates of the average volume of foreign ballast per vessels—and assuming that BWE is only 86 percent efficient (Johengen *et al*., 2005) and organism densities in residual ballast are identical to those in fully ballasted ships—the number of organisms from foreign ports discharged into the GLSLSS in 2002 can be calculated at 79 million zooplankton, 49 trillion phytoplankton, and 14 quadrillion bacteria (table 2). Similarly, the total amount of organisms contained in ballast water discharged by the transoceanic fleet in the GLSLSS (including that originating from foreign ports, the high seas, and Great Lakes lower ports) in 2002 can be estimated at 2.7 billion zooplankton, 1.7 quadrillion phytoplankton, and 4.7 quintillion bacteria (table 2).

A recent study by Verling *et al*. (2005) that looked at zooplankton survivorship across various voyage durations and routes found that the mean density of zooplankton for a transatlantic voyage was 39,800 organisms per cubic meter at the start of the voyage, and 613 organisms per cubic meter at the end of the voyage. Applying this end-of-voyage estimate to the same data and assumptions used to generate table 2, the number of organisms from foreign ports discharged into the system in 2002 can be calculated at 104 million zooplankton. Similarly, the total amount of organisms contained in ballast water discharged by the transoceanic fleet in the GLSLSS (including that originating from foreign ports, the high seas and Great Lakes lower ports) in 2002 can be estimated at 3.6 billion zooplankton.

Table 2. Estimates of total organisms discharged in the GLSLSS by transoceanic ships in 2002[7]

	Ballasted (BOB) vessels	Unballasted (NOBOB) vessels	ESTIMATED TOTAL
Number of vessel visits in 2002	46	531	577
Average foreign ballast volume per vessel (m^3)	10,000	200	981
ZOOPLANKTON			
Zooplankton from foreign ports discharged in GLSLSS assuming 86% BWE efficiency (#)	29,881,600	49,276,800 (no BWE requirements)	79,158,400
Zooplankton from high seas discharged in GLSLSS assuming 86% BWE efficiency (#)	183,558,400	0	183,558,400

[7] Vessel visit data provided by St. Lawrence Seaway Development Authority (2003). Average foreign ballast volumes per vessel and BWE efficiency estimates provided by Johengen *et al*. (2005). Organism quantities based on ICES review which states that on average 1 cubic meter of ballast water contains 464 plankton ≥50 micrometers in minimum dimension (zooplankton), 2.9 X 10^8 plankton <50 micrometres and ≥10 micrometers in minimum dimension (phytoplankton), and 8.3 X 1011 bacteria per cubic meter (IMO MEPC 49/2/21, 2003). Also, organism densities in ships arriving to the Great Lakes are assumed to be similar to those in ships plying globally, and organism densities in residual ballast are assumed to be identical to those in fully ballasted ships.

Zooplankton from foreign ports combined with GLSLSS zooplankton discharged in GLSLSS (#)	0	2,414,563,200	2,414,563,200
Total amount of zooplankton discharged by the transoceanic fleet in the GLSLSS ((#)	213,440,000	2,463,840,000	2,677,280,000
PHYTOPLANKTON			
Phytoplankton from foreign ports discharged in GLSLSS assuming 86% BWE efficiency (#)	1.87×10^{13}	3.08×10^{13} (no BWE requirements)	4.95×10^{13}
Phytoplankton from high seas discharged in GLSLSS assuming 86% BWE efficiency (#)	1.15×10^{14}	0	1.15×10^{14}
Phytoplankton from foreign ports combined with GLSLSS phytoplankton discharged in GLSLSS (#)	0	1.51×10^{15}	1.51×10^{15}
Total amount of phytoplankton discharged by the transoceanic fleet in the GLSLSS (#)	1.34×10^{14}	1.54×10^{15}	1.67×10^{15}
BACTERIA			
Bacteria from foreign ports discharged in GLSLSS assuming 86% BWE efficiency (#)	5.31×10^{16}	8.81×10^{16} (no BWE requirements)	1.41×10^{17}
Bacteria from high seas discharged in GLSLSS assuming 86% BWE efficiency (#)	3.28×10^{17}	0	3.28×10^{17}
Bacteria from foreign ports combined with GLSLSS bacteria discharged in GLSLSS (#)	0	4.32×10^{18}	4.32×10^{18}
Total amount of bacteria discharged by the transoceanic fleet in the GLSLSS (#)	3.81×10^{17}	4.41×10^{18}	4.66×10^{18}

Quantities of Organisms from Foreign Ports Discharged into the GLSLSS by Transoceanic Vessels Relative to Current National Law, and the Proposed Global Convention

Federal law requires vessels entering the Great Lakes from outside the EEZ with ballast water on board to undertake ballast water exchange (BWE) to purge tanks of near coastal water. Johengen *et al*. (2005) found BWE to be 86 to 98 percent effective at replacing coastal water with open-ocean water in practice. However, the government has only recently issued voluntary best management practices for managing residual water and sediment in the ballast tanks of the approximately 85 percent of transoceanic vessels that declare NOBOB, arriving in the lakes with a full complement of cargo (St. Lawrence Seaway Development Authority, 2003).

Globally, the IMO's International Convention for the Control and Management of Ships' Ballast Water and Sediments will require ships to manage their ballast water through BWE or BWT. The convention will require ships to perform BWE with an efficiency of at least 95 percent volumetric exchange. Ships undertaking BWT will be required to discharge less than 10 viable organisms per cubic meter greater than or equal to 50 micrometers in minimum dimension, and less than 10 viable organisms per milliliter less than 50 micrometers in minimum dimension and greater than or equal to 10 micrometers in minimum dimension (equivalent to 9×10^6 per cubic meter). The convention also includes discharge standards for indicator microbes, including *Vibrio cholerae*, *Escherichia coli* and *Enterococci*.

Based on best available data and a number of assumptions,[8] table 3 provides estimates of the quantities of organisms (plankton only) from foreign ports discharged in the Great Lakes by transoceanic vessels following BWE, and also the quantities likely to be discharged in the lakes following application of the international convention. The adoption of the international convention's BWE standard could reduce the number of plankton greater than or equal to 50 micrometers discharged into the GLSLSS from foreign ports by 20 million (table 3). However, compared to BWE, the adoption of the convention's BWT standard will produce a tenfold decrease in the discharge of this larger plankton into the lakes (table 3).

For smaller plankton of less than 50 micrometers in minimum dimension and greater than or equal to 10 micrometers in minimum dimension, adoption of the international convention's BWE and BWT standards could result in little change in the quantity of organisms from foreign ports being discharged into the GLSLSS (table 3).

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[6] 2002 Vessel visit data provided by St. Lawrence Seaway Development Authority (2003). Average foreign ballast volumes per vessel and BWE efficiency estimate of 86 percent, relative to federal law, provided by Johengen *et al*. (2005). Analysis assumes that each cubic meter of ballast water contains 464 plankton $\geq$ 50 micrometers in minimum dimension, and 2.9×10^8 plankton < 50 micrometers in minimum dimension and greater than or equal to 10 micrometers in minimum dimension, based on ICES review (IMO MEPC 49/2/21). Analysis also assumes that vessels declaring NOBOB are not required to manage their ballast water relative to BWE; that organism densities in ships arriving to the Great Lakes are similar to those in ships plying globally; and that organism densities in residual ballast are identical to those in fully ballasted ships.

Table 3. Estimates of the quantities of organisms (plankton only) from foreign ports discharged in the Great Lakes by transoceanic vessels relative to current federal law, the proposed international convention, and no ballast management requirements, based on best available data and a number of assumptions[6]

	Ballasted (BOB) vessels	Unballasted (NOBOB) vessels	TOTAL
Number of vessel visits (2002)	46	531	577
Average foreign ballast volume per vessel (m^3)	10,000	200	981
Total foreign ballast volume (m^3)	460,000	106,200	566,200
PLANKTON ≥ 50 MICRONS IN MINIMUM DIAMETER			
Quantity of plankton given no ballast management (#)	213,440,000	49,276,800	262,716,800
Quantity of plankton given management using BWE that is 86% effective (federal law) (#)	29,881,600	49,276,800	79,158,400
Quantity of plankton given management using BWE that is 95% effective (IMO) (#)	10,672,000	49,276,800	59,948,800
Quantity of plankton given management using BWT to IMO standard (#)	4,140,000	955,800	5,095,800
PLANKTON < 50 AND ≥ 10 MICRONS IN MINIMUM DIAMETER			
Quantity of plankton given no ballast management (#)	1.33×10^{14}	3.08×10^{13}	1.36×10^{14}
Quantity of plankton given management using BWE that is 86% effective (federal law) (#)	1.87×10^{13}	3.08×10^{13}	4.95×10^{13}
Quantity of plankton given management using BWE that is 95% effective (IMO) (#)	6.67×10^{12}	3.08×10^{13}	3.75×10^{13}
Quantity of plankton given management using BWT to IMO standard (#)	4.14×10^{12}	9.56×10^{11}	5.09×10^{12}

NORTHEAST
MIDWEST
INSTITUTE

50 F St., NW. Suite 950
Washington DC 20001
Hwww.nemw.org