TRANSPORTATION RESEARCH BOARD

SPECIAL REPORT 291

GREAT LAKES SHIPPING, TRADE, AND AQUATIC INVASIVE SPECIES

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

TRANSPORTATION RESEARCH BOARD
SPECIAL REPORT 291

GREAT LAKES SHIPPING, TRADE, AND AQUATIC INVASIVE SPECIES

Committee on the St. Lawrence Seaway: Options to Eliminate Introduction of Nonindigenous Species into the Great Lakes, Phase 2

Transportation Research Board

Water Science and Technology Board

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

Transportation Research Board
Washington, D.C.
2008
www.TRB.org

Transportation Research Board Special Report 291

Subscriber Categories
I planning, administration, and environment
VIII freight transportation (multimodal)
IX marine transportation

Transportation Research Board publications are available by ordering individual publications directly from the TRB Business Office, through the Internet at www.TRB.org or national-academies.org/trb, or by annual subscription through organizational or individual affiliation with TRB. Affiliates and library subscribers are eligible for substantial discounts. For further information, contact the Transportation Research Board Business Office, 500 Fifth Street, NW, Washington, DC 20001 (telephone 202-334-3213; fax 202-334-2519; or e-mail TRBsales@nas.edu).

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competencies and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to the procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

This report was sponsored by the Great Lakes Protection Fund.

Cover design by Beth Schlenoff, Beth Schlenoff Design.

Library of Congress Cataloging-in-Publication Data

National Research Council (U.S.). Committee on the St. Lawrence Seaway: Options to Eliminate Introduction of Nonindigenous Species into the Great Lakes, Phase 2.
Great Lakes shipping, trade, and aquatic invasive species / Committee on the St. Lawrence Seaway: Options to Eliminate Introduction of Nonindigenous Species into the Great Lakes, Phase 2, Transportation Research Board, Division on Earth and Life Studies, National Research Council of the National Academies.
p. cm.—(Transportation Research Board special report ; 291)
Includes bibliographical references and index.
1. Nonindigenous aquatic pests—Control—Great Lakes (North America)
2. Discharge of ballast water—Environmental aspects—Great Lakes (North America)
3. Animal introduction—Great Lakes (North America)—Prevention. 4. Ballast water—Purification—Great Lakes (North America) I. Title.
TD427.A68N38 2008
363.7'80977—dc22

2008025878

ISBN 978-0-309-11313-7

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. On the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Ralph J. Cicerone is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Charles M. Vest is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, on its own initiative, to identify issues of medical care, research, and education. Dr. Harvey V. Fineberg is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both the Academies and the Institute of Medicine. Dr. Ralph J. Cicerone and Dr. Charles M. Vest are chair and vice chair, respectively, of the National Research Council.

The **Transportation Research Board** is one of six major divisions of the National Research Council. The mission of the Transportation Research Board is to provide leadership in transportation innovation and progress through research and information exchange, conducted within a setting that is objective, interdisciplinary, and multimodal. The Board's varied activities annually engage about 7,000 engineers, scientists, and other transportation researchers and practitioners from the public and private sectors and academia, all of whom contribute their expertise in the public interest. The program is supported by state transportation departments, federal agencies including the component administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation. **www.TRB.org**

www.national-academies.org

Marine Board

Martha R. Grabowski, LeMoyne College, Cazenovia, New York, *Chair*
Malcolm MacKinnon III, MSCL, LLC, Alexandria, Virginia, *Vice Chair*
Kenneth E. Arnold, K Arnold Consulting, Inc., Houston, Texas
Michael S. Bruno, Stevens Institute of Technology, Hoboken, New Jersey
Charles R. Cushing, C. R. Cushing and Co., Inc., New York
Larry L. Daggett, Waterway Simulation Technology, Inc., Vicksburg, Mississippi
Robert A. Dalrymple, Johns Hopkins University, Baltimore, Maryland
Paul S. Fischbeck, Carnegie Mellon University, Pittsburgh, Pennsylvania
Stephen E. Flynn, Council on Foreign Relations, New York
Judith Hill Harris, Department of Transportation, Portland, Maine
John R. Headland, Moffatt & Nichol Engineers, New York
William E. Jenkins, SeaRiver Maritime, Inc., Houston, Texas
Robert E. Johnston, OSG Ship Management, Inc., New York
Ronald K. Kiss, Consultant, Rockville, Maryland
Robert C. North, North Star Maritime, Inc., Queenstown, Maryland
Patrick E. O'Connor, BP America, Inc., Houston, Texas
Robert W. Portiss, Tulsa Port of Catoosa, Catoosa, Oklahoma
Jerry R. Schubel, Aquarium of the Pacific, Long Beach, California
Richard H. Vortmann, RHV Co., LLC, San Diego, California
John W. Waggoner, Hornblower Marine Services, New Albany, Indiana

Transportation Research Board 2008 Executive Committee Officers

Debra L. Miller, Secretary, Kansas Department of Transportation, *Chair*
Adib K. Kanafani, Cahill Professor of Civil Engineering, University of California, Berkeley, *Vice Chair*
C. Michael Walton, Ernest H. Cockrell Centennial Chair in Engineering, University of Texas, Austin (Past Chair, 1991), *Division Chair for NRC Oversight*
Robert E. Skinner, Jr., Transportation Research Board, *Executive Director*

Division on Earth and Life Studies
Water Science and Technology Board

Committee on the St. Lawrence Seaway: Options to Eliminate Introduction of Nonindigenous Species into the Great Lakes, Phase 2

Jerry R. Schubel, *Chair*, Aquarium of the Pacific, Long Beach, California
Richard M. Anderson, Duke University, Durham, North Carolina
Stephen W. Fuller, Texas A&M University, College Station
Trevor D. Heaver, University of British Columbia, Vancouver, Canada (emeritus)
Geoffrey J. D. Hewings, University of Illinois, Urbana–Champaign
Philip T. Jenkins, Philip T. Jenkins and Associates, Ltd., Fonthill, Ontario, Canada
Hugh J. MacIsaac, University of Windsor, Ontario, Canada
Steven W. Popper, Rand Corporation, Santa Monica, California
Frank H. Quinn, Consultant, Tecumseh, Michigan
Thomas D. Waite, Florida Institute of Technology, Melbourne
M. Gordon Wolman, Johns Hopkins University, Baltimore, Maryland
Joy B. Zedler, University of Wisconsin, Madison
Ann P. Zimmerman, University of Toronto, Ontario, Canada

National Research Council Staff
Jill Wilson, Study Director, Transportation Research Board
Stephen R. Godwin, Director, Studies and Special Programs, Transportation Research Board
Lauren Alexander, Senior Program Officer, Water Science and Technology Board, Division on Earth and Life Studies
Amelia B. Mathis, Administrative Assistant, Transportation Research Board

Preface

On June 26, 1959, Queen Elizabeth II and President Eisenhower officially opened the St. Lawrence Seaway, a series of locks and canals providing a navigation route into the North American heartland for deep-draft vessels coming from the Atlantic Ocean and beyond. Almost 50 years later, the seaway, which is managed and operated jointly by Canada and the United States, provides a route into and out of the Great Lakes for cargoes such as grain, iron ore, and steel. Between 1997 and 2006, an average of 33.5 million metric tons (tonnes) of cargo moved each year through the Montreal–Lake Ontario section of the seaway, which links the lower St. Lawrence River and Lake Ontario.

When the seaway was constructed, it was seen as offering important economic benefits for Canada and the United States through enhanced navigation and associated trade, as well as the generation of much-needed electricity by the associated Moses–Saunders hydroelectric power station. An additional effect of opening up a route into the Great Lakes for international shipping did not attract attention until much later. The rapid spread throughout the Great Lakes of the European zebra mussel, discovered in Lake St. Clair in 1988, drew public attention to the fact that the seaway provides a route into the North American heartland not only for ships but also for potentially troublesome stowaways—namely, aquatic invasive species (AIS) inadvertently taken aboard in ballast water at previous ports of call.

In addition to the zebra mussel, invaders such as the Eurasian ruffe, round goby, and quagga mussel are all thought to have entered the Great Lakes in the ballast water of ships. Held in a variety of tanks or holds, ballast water provides the stability required for safe ship operations under a variety of conditions and is routinely loaded or discharged at various points during a voyage. When discharged, organisms loaded with ballast water at previous ports of call may be dispersed into new environments where, under favorable conditions, they establish new populations. Research has shown the ballast water of ships engaged in international trade to be a major vector for transferring species from locations such as the Baltic, Black, and North Seas across the Atlantic Ocean to the freshwater ecosystem of the Great Lakes.

The economic and environmental impacts of AIS in the Great Lakes have been, and continue to be, severe. The cost of removing zebra mussels from piping in power generation plants, public and private drinking water plants, and industrial facilities; navigation lock and dam structures; and marinas has been tentatively estimated at over US$1 billion since 1989, and some put the estimate as high as US$5 billion. In addition, the zebra mussel's rapid reproduction, coupled with its consumption of microscopic plants and animals, has modified the aquatic food web and led to a suite of indirect effects, including increased water clarity and the accompanying growth of rooted aquatic vegetation in shallow areas of the lakes and nuisance algae along shorelines.

Efforts have been under way since 1989 to prevent further introductions into the Great Lakes of AIS carried in ships' ballast water. These efforts have focused primarily on the steps ships can take to reduce the risk of introductions, notably replacing (exchanging) their freshwater ballast with ocean water before entering the Great Lakes. Ballast water exchange (BWE) removes organisms from a ship's ballast tanks by dilution and exposes freshwater organisms in the tanks to salt water, thereby killing many of them. Canadian and U.S. regulations require vessels in international trade entering the Great Lakes to manage their ballast water, and BWE is one of the options for vessels carrying ballast. Despite this requirement, reports of new AIS discovered in the Great Lakes continue. Recent estimates put the total number of such species, including algae, fish, invertebrates, and plants, at more than 180. Shipping is by no means the only mechanism by which AIS enter the Great Lakes. Deliberate releases, aquaculture, home aquaria, water gardens, and recreational boating have all been implicated in reported AIS introductions. However, the major role of shipping through the seaway as a vector for such introductions is not disputed.

Against this backdrop, the Great Lakes Protection Fund (GLPF) asked the Transportation Research Board (TRB) and the Division on Earth and Life Studies (DELS) of the National Academies to convene an expert committee to develop a detailed plan for eliciting a wide range of transportation options and concepts for the Great Lakes region that would (*a*) promote global commerce and (*b*) eliminate the introduction of additional nonindigenous species and pathogens into the Great Lakes due to oceangoing vessels transiting the St. Lawrence Seaway. The project began as an effort to plan and conduct a design competition to develop innovative solutions to the problem of AIS introductions into the Great Lakes by commercial shipping. At the end of the first phase, however, both GLPF and the National Academies concluded that a design competition would not be the best strategy to identify such solutions. Phase 2 became a more traditional project to identify, develop, and recommend potential solutions.

In Phase 1 of the project, TRB and DELS convened a 13-member committee that met twice, first in Washington, D.C., in May 2004 and then in Montreal, Quebec, Canada, in September 2004. In conjunction with the second meeting, a group of committee members visited the Port of Montreal and the St. Lawrence Seaway Management Corporation's St. Lambert Lock facility. At its meetings, the committee heard presentations from experts in invasion biology, ballast water management, and freight transportation and from stakeholders, including representatives of the St. Lawrence Seaway and the shipping industry. The committee also discussed lessons learned from design competitions in other fields (architecture, town planning, and aeronautics and astronautics) with experts who had planned and administered such competitions. In December 2004, the Phase 1 committee delivered its proposal for a design competition to GLPF.

In light of concerns about the feasibility of a design competition, GLPF, the chair of the Phase 1 committee, and National Academies staff explored alternative approaches to generating options for meeting the two project criteria. Subsequently, in late 2005, GLPF asked TRB and DELS to convene a second expert committee, which was charged with identifying and exploring options for the Great Lakes region that would meet two criteria: (*a*) enhance the potential for global trade in the Great Lakes region and (*b*) eliminate further introductions of nonindigenous aquatic species into the Great Lakes by vessels transiting the St. Lawrence Seaway. These criteria are similar to those considered in Phase 1, but not identical. Most notably, the requirement to eliminate further AIS introductions targets *all* vessels transiting the seaway, rather than exclusively oceangoing vessels engaged in international trade. In addition, pathogens, which are very different in nature from most of the AIS studied thus far, are not included explicitly. As in Phase 1, the criterion relating to global trade is a broad mandate without specific directives.

The committee was to commission papers, hold a symposium at which these papers would be presented and discussed, and develop a range of practical and technically feasible options that would meet both project criteria.

In accordance with usual National Research Council (NRC) procedures, TRB and DELS assembled a Phase 2 study committee of 13 members under the leadership of Jerry R. Schubel, President and Chief Executive Officer of the Aquarium of the Pacific in Long Beach, California.[1] Committee members have expertise in transportation and logistics, marine transportation operations, ballast water treatment, invasion biology, ecology and ecosystem management, environmental systems analysis, Great Lakes science, the Great Lakes regional economy, public policy, and decision analysis.

The committee held five meetings between May 2006 and July 2007 (see Appendix A). It also commissioned a series of eight ex-

[1] Dr. Schubel also chaired the Phase 1 committee, and four Phase 1 committee members (Captain Jenkins and Drs. MacIsaac, Waite, and Wolman) also served in Phase 2.

pert papers (see Appendix B) to inform its discussions. Preliminary findings and conclusions from seven of these papers were discussed by committee members and guests at the committee meeting held in Irvine, California, in February 2007. The authors then completed their drafts, which were reviewed by committee members in advance of a 1-day public symposium, held in Toronto, Ontario, in May 2007 in conjunction with the committee's fourth meeting. After presenting their major findings and conclusions at the symposium, the authors finalized their papers. The paper by Drs. Kelly and Kazumi on retroactive evaluation of the International Maritime Organization's ballast water standards was commissioned, prepared by the authors, and reviewed by committee members between the fourth and fifth meetings. After the fifth meeting, additional committee comments on the draft paper were shared with the authors, who then finalized their paper.

All eight commissioned papers are being made available in electronic form in conjunction with this report. The reader is cautioned that the interpretations and conclusions contained in the papers are those of the authors and are not necessarily endorsed by the committee.

After its fifth and final meeting in July 2007, the committee worked by correspondence to refine its recommendations and develop its report.

ACKNOWLEDGMENTS

Funding from GLPF for the present study and for the preliminary Phase 1 effort is gratefully acknowledged. Thanks go also to the members of the Phase 1 committee: Jerry R. Schubel, Chair, Aquarium of the Pacific, Long Beach, California; Stephen B. Brandt, National Oceanic and Atmospheric Administration Great Lakes Environmental Research Laboratory, Ann Arbor, Michigan; Jerry E. Fruin, University of Minnesota, St. Paul; J. Richard Hodgson, Dalhousie University, Halifax, Nova Scotia; Philip T. Jenkins, Philip T. Jenkins and Associates, Ltd., Fonthill, Ontario; Catherine T. Lawson, State University of New York at Albany; Kenneth J.

Leonard, Wisconsin Department of Transportation, Madison; Walter R. Lynn, Cornell University, Ithaca, New York; Hugh J. MacIsaac, University of Windsor, Ontario; Henry A. Olson, Matson Navigation Company, Inc., Oakland, California; Evelyn A. Thomchick, Pennsylvania State University, University Park; Thomas D. Waite, University of Miami, Coral Gables, Florida, and National Science Foundation, Arlington, Virginia;[2] and M. Gordon Wolman, Johns Hopkins University, Baltimore, Maryland. The outcomes of their information-gathering activities and discussions laid a robust foundation on which to build during Phase 2. The contributions of all those who participated in the Phase 1 committee's activities are also recognized, as is financial support from the International Joint Commission, U.S. Section, for the visits to the Port of Montreal and the St. Lambert Lock and for a preliminary study of freight flows in the Great Lakes region by David Kriger of iTRANS Consulting in Ottawa, Ontario. Thanks go to Jeffrey A. Hutchings of Dalhousie University, who attended the Phase 1 committee meeting in Montreal on behalf of the Royal Society of Canada.

The Phase 2 committee thanks all those individuals and organizations who participated in the information-gathering sessions of its meetings, including the representatives of the Hamilton Port Authority and the St. Lawrence Seaway Management Corporation's Welland Canal facility who hosted the committee's site visits (see Appendix A). The interest and encouragement of Russ Van Herik, Executive Director of GLPF, and of David Rankin, GLPF's Vice President and Director of Programs, are also gratefully acknowledged.

Particular appreciation is expressed to the authors of the commissioned papers: J. Richard Hodgson, Hodgson and Associates, Halifax, Nova Scotia; Junko Kazumi, University of Miami, Florida; David W. Kelly, formerly at the University of Windsor, Ontario, and now with Landcare Research, Dunedin, New Zealand; John Lawson, Lawson Economics Research, Inc., Ottawa, Ontario;

[2] Dr. Waite is now with the Florida Institute of Technology, Melbourne.

Frank Millerd, Wilfrid Laurier University, Waterloo, Ontario; Richard D. Stewart, University of Wisconsin, Superior; and M. Jake Vander Zanden, University of Wisconsin, Madison (see Appendix B). Their expert papers and their participation in committee discussions contributed greatly to the overall effort.

The committee recognizes the contributions of all those who participated in the symposium in Toronto in May 2007 (see the list of participants in Appendix C). The willingness of participants to share their perspectives with the committee and to engage in discussion of various candidate actions for meeting the two project criteria proved valuable in informing the committee's deliberations. In addition, special thanks are due to Ivan Lantz of the Shipping Federation of Canada for providing the committee with information on international seaway shipping and related issues; to Jennifer Nalbone of Great Lakes United, whose AIS Listserv was a valuable resource in helping set the context for the project; and to Chris Wiley of Fisheries and Oceans Canada and Transport Canada for verifying factual details of current ballast water management regulations.

Jill Wilson managed the study under the supervision of Stephen R. Godwin, Director of TRB's Studies and Special Programs Division, and with support from Lauren Alexander of DELS. Dr. Wilson also drafted major portions of the final report under the committee's guidance. Amelia Mathis was responsible for meeting logistics and assisted with communications with committee members.

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise in accordance with procedures approved by the NRC's Report Review Committee. The purpose of this review is to provide candid and critical comments that will assist the institution in making the report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process.

NRC thanks the following individuals for their review of this report: Craig Alig, Ferrate Treatment Technologies, LLC, Orlando, Florida; Kenneth Eldred, Ken Eldred Engineering, East Boothbay, Maine; Jeremy Firestone, University of Delaware, Newark; Jerry Fruin, University of Minnesota, St. Paul; Chad Hewitt, Australian Maritime College, Rosebud, Victoria; Michael Hubbard, Transport Canada (retired), Ottawa, Ontario; Gail Krantzberg, McMaster University, Hamilton, Ontario; Walter Lynn, Cornell University, Ithaca, New York; and Gregory Ruiz, Smithsonian Environmental Research Center, Edgewater, Maryland. Although the reviewers provided many constructive comments and suggestions, they were not asked to endorse the committee's findings, conclusions, or recommendations, nor did they see the final draft before its release. The review of this report was overseen by George M. Hornberger, University of Virginia, Charlottesville, and C. Michael Walton, University of Texas at Austin. Appointed by NRC, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of the report rests solely with the authoring committee and the institution.

Suzanne Schneider, Associate Executive Director, TRB, managed the report review process. The report was edited and prepared for publication by Norman Solomon, Senior Editor; the prepublication files for posting to the TRB website were formatted and prepared by Jennifer J. Weeks, Editorial Services Specialist; and the book design and production were coordinated by Juanita Green, Production Manager, under the supervision of Javy Awan, Director of Publications, TRB.

Acronyms

AIS	aquatic invasive species
BOB	ballast on board
BWE	ballast water exchange
BWM	ballast water management
BWWG	Ballast Water Working Group
CWA	(U.S.) Clean Water Act
DWT	deadweight tonnage
EEZ	exclusive economic zone
EPA	(U.S.) Environmental Protection Agency
GLFC	Great Lakes Fishery Commission
GLPF	Great Lakes Protection Fund
GLSLS	Great Lakes St. Lawrence Seaway
IJC	International Joint Commission
IMO	International Maritime Organization
MDEQ	Michigan Department of Environmental Quality
MLO	Montreal–Lake Ontario
NANPCA	Nonindigenous Aquatic Nuisance Prevention and Control Act
NOBOB	no ballast on board
SLSDC	St. Lawrence Seaway Development Corporation
SLSMC	St. Lawrence Seaway Management Corporation
VHS	viral hemorrhagic septicemia

Contents

Summary **1**

1 Introduction **7**

AIS and Seaway Shipping 9
Charge to the Committee 12
Committee's Approach 12
Organization of the Report 14

2 The St. Lawrence Seaway **17**

Historical Overview 19
Management, Operations, and Financing 21
Infrastructure 24
Traffic 27
A Changing Future 35
Concluding Remarks 39

3 Aquatic Invasive Species in the Great Lakes **43**

Historical Overview 43
Invasion Vectors and Pathways 44
Impacts of AIS 47
Examining Trends in Invasion History 52
Future AIS Introductions 56
Concluding Remarks 58

4 The Ballast Water Vector **63**

Vessels Transiting the Seaway 63
Fleet and Vessel Characteristics 65
Vessel Operations 69
Current Measures to Prevent AIS Introductions into the Great Lakes 76
Concluding Remarks 84

5 Identifying and Exploring Options for the Great Lakes Region: The Committee's Approach **87**

Identifying Candidate Actions 88
Candidate Actions to Enhance the Potential for Global Trade 91
Candidate Actions to Eliminate Further AIS Introductions 102
Options That Meet Both Criteria? 118

6 Committee's Conclusions and Recommended Option for the Great Lakes Region **122**

Compromise Options 123
Committee's Rationale 124
Closure of the Seaway to Transoceanic Shipping 126
Committee's Recommended Option 134
Ballast Water Management Technologies 138
Surveillance and Control Program 152
An Adaptive Process 156
Strengths and Weaknesses 160
Managing the Waters of the Great Lakes—A Vision for the Future 166
Key Points 168

Appendices

A Committee Meetings and Other Activities 172
B Commissioned Papers and Authors 177
C Public Meeting Agenda and Participants 179
D Economic Benefits of Transoceanic Shipping Through the St. Lawrence Seaway 186

Study Committee Biographical Information **193**

Summary

The Laurentian Great Lakes are the largest unfrozen reservoir of freshwater on earth, accounting for almost one-fifth of the world's fresh surface water. They are vital to the economy of the Great Lakes region and to the quality of life of its residents, providing drinking water for more than 33 million people in Canada and the United States, supplying hydroelectric power, supporting industries, providing waterborne transportation, and offering a variety of recreational opportunities.

Human activities have, however, imposed stresses on the Great Lakes basin's ecological integrity, and one of these stresses—the introduction of nonindigenous species of animals and plants—is the focus of this report. The opening of the St. Lawrence Seaway in 1959 provided a route into the Great Lakes not only for international maritime trade but also for aquatic invasive species (AIS)[1] carried in the ballast water needed by ships to operate safely. Ships' ballast water is not the only vector by which AIS enter the Great Lakes, but it has accounted for 55 to 70 percent of reported AIS introductions since 1959, including that of the zebra mussel (*Dreissena polymorpha*).

In this context, the committee, which was convened at the request of the Great Lakes Protection Fund, was charged with identifying and exploring options for the Great Lakes region that would meet two criteria: (*a*) enhance the potential for global trade in the

---

[1] In accordance with common usage, the term "AIS" is used throughout this report to describe nonindigenous aquatic species.

Great Lakes region and (*b*) eliminate further introductions of AIS into the Great Lakes by vessels transiting the St. Lawrence Seaway.

The options recommended by the committee were to be practical and technically feasible, in addition to meeting the two project criteria.

Because of the number, diversity, and distribution of vectors and routes by which AIS can enter the Great Lakes, the committee views elimination of all new AIS introductions as virtually impossible. However, shipping through the seaway is easier to control than some other invasion vectors and routes because the geographic chokepoint at the seaway entrance provides a unique opportunity to inspect and control vessels entering the Great Lakes, the number of vessels involved is relatively small (approximately 300 annually), and the shipping industry is already highly regulated.

After examining various candidate actions, the committee concluded that the only way to eliminate all further AIS introductions into the Great Lakes by vessels transiting the seaway would be to close the waterway to *all* vessel traffic. Such action would, however, be incompatible with efforts to enhance the Great Lakes region's potential for global trade. It also appears impractical from a political perspective. Thus, the committee's task became one of identifying compromise actions that would reduce—but not eliminate—further ship-vectored AIS introductions into the Great Lakes. Two very different alternatives were identified: (*a*) use ballast water management technologies (ballast water exchange, saltwater flushing, and ballast water treatment) to kill or remove organisms in ships' ballast water or (*b*) close the seaway to the "riskiest" component of traffic from an AIS perspective, namely, transoceanic vessels engaged in trade with countries outside of Canada and the United States.

Although closing the seaway to transoceanic shipping would reduce substantially the risk of AIS introductions by vessels using the waterway, this action could not, in the committee's judgment, be implemented in a timely fashion. Moreover, economic principles indicate that eliminating a transportation option would increase the cost of moving goods and therefore would not enhance trade. Other disadvantages could include adverse environmental impacts associated with alternative transportation modes and routes and reprisals by trading partners of the United States and Canada. In contrast, mandatory use of ballast water management technologies by all categories of vessel known to pose a risk could lead to a marked reduction in AIS introductions by vessels using the seaway and could be implemented almost immediately. In the committee's judgment, such a measure would achieve a high level of protection against further ship-vectored AIS introductions without the disadvantages of closing the seaway to transoceanic shipping, if it was supported by effective procedures for vessel monitoring and for enforcing ballast water management regulations and by an AIS surveillance and control program for the Great Lakes.

The committee recommends, therefore, that access to the Great Lakes through the seaway be restricted to vessels taking protective measures aimed at ensuring that they do not harbor living aquatic organisms. Such measures should form the core of a comprehensive technology-based AIS control program incorporating the following features:

- A uniform set of effective and enforceable standards for the Great Lakes;
- Monitoring for compliance with the standards, strict enforcement mechanisms, and remediation options for arriving vessels that do not immediately meet standards for entry;
- Surveillance of the Great Lakes ecosystem for early detection of new AIS from any source;
- Rapid response capability for containment, control, and possible subsequent eradication following the discovery of any new AIS; and
- Feedback mechanisms to update and improve the control program over time.

The committee recommends nine actions necessary to implement the proposed control program. In the committee's view, many of these actions could be implemented within the next 2 to 3 years if Canada and the United States have the necessary political will. To establish a solid foundation for the control program, the following four actions should be taken as a matter of urgency.

Transport Canada and the U.S. Coast Guard should ensure that all vessels entering the Great Lakes after operating in coastal areas of eastern North America take protective measures similar to those required for transoceanic vessels, notably ballast water exchange for ballasted vessels and salt-water flushing for vessels declaring no ballast on board.[2]

The United States should follow Canada's lead and take immediate action to adopt and implement ballast water exchange and performance standards for the Great Lakes that are identical to those specified in the International Maritime Organization's International Convention for the Control and Management of Ships' Ballast Water and Sediments.

A binational science-based surveillance program should be established to monitor for the presence of new AIS in the Great Lakes. The program should involve dedicated lake teams, as well as academic researchers, resource managers, and local citizens groups, and should leverage existing monitoring activities wherever possible.

An adaptive process should be established to ensure that policy measures designed to prevent further AIS introductions into the Great Lakes are updated in a timely and periodic fashion to reflect practical experience and knowledge gained through research. The organization responsible for this process should have a binational mandate; adequate resources to conduct its work; and the ability to draw on the advice of scientific and policy experts in Canada, the United States, and elsewhere as needed. It should also be widely perceived as independent and free from conflicts of interest.

---

[2] For the purposes of the present report, coastal vessels are defined as those that operate within the exclusive economic zone (i.e., not more than 200 nautical miles from shore) before entering the Great Lakes St. Lawrence Seaway system.

The requirement to eliminate further AIS introductions is absolute and narrow and addresses one invasion vector and route (shipping on the St. Lawrence Seaway). In contrast, the requirement to enhance the potential for global trade is a broad mandate without specific directives. A region's potential for global trade is influenced by a multitude of forces, both within the region and outside it. Although the committee received and examined many suggestions, it has not recommended any actions aimed solely at enhancing the Great Lakes region's potential for global trade. It noted, however, that the development of efficient transportation infrastructure and services is one of many strategies for stimulating economic growth and ensuing trade. Uncertainty about future ballast water management regulations for the Great Lakes may well be hindering investment in the transportation system. Thus, timely implementation of the committee's recommendations with regard to ballast water management and associated standards could help reduce regulatory uncertainties and the associated barrier to the development of trade-enhancing transportation infrastructure and services. In the committee's judgment, the recommended suite of actions comes closer to achieving the two project criteria than any other options it identified.

1
Introduction

The Laurentian Great Lakes—Superior, Michigan, Huron, Erie, and Ontario—are the world's largest reservoir of freshwater, with the exception of the Antarctic and Greenland ice caps. Comprising almost one-fifth of the global supply of freshwater, the Great Lakes cover a total area of 94,000 square miles (244,000 km^2) with a shoreline of approximately 10,500 miles (17,000 km).

Unlike the polar ice caps, the Great Lakes provide drinking water for the more than 33 million people living in the 300,000 square miles (750,000 km^2) of watershed. They are also vital to the economy of the region, supplying hydroelectric power, supporting industries and commercial enterprises, and providing waterborne transportation for both people and goods. The Great Lakes' commercial and sport fishery, for example, is valued at $4 billion (Great Lakes Information Network n.d.), and the region supports a multibillion-dollar recreational and tourism industry. The Great Lakes are also fundamental to the region's culture and history. The basin's water and other resources have played a major role in the history and development of both Canada and the United States, and the basin is now home to one-fourth of the Canadian population and more than one-tenth of the U.S. population (U.S. Environmental Protection Agency and Government of Canada 1995).

Perhaps not surprisingly, human activities have imposed numerous stresses on the Great Lakes basin's ecological integrity. These stresses include cultural eutrophication, an accelerated process of nutrient and sediment concentration in a body of water caused by excessive human activity; toxic contaminants, such as heavy metals and synthetic organic chemicals; overfishing; habitat destruction;

and the introduction of nonnative species of animals and plants. Billions of dollars and uncounted hours have been spent in addressing these and other stresses and their impacts on the Great Lakes ecosystem.

Given that the Great Lakes form a single system of interconnected lakes and rivers, it is widely acknowledged that many of the stresses imposed on the system by human activity can only be addressed effectively on a systemwide basis (see, for example, U.S. Environmental Protection Agency and Government of Canada 1995). The Great Lakes system of governance, however, is fragmented among the agencies, offices, and organizations of two federal governments; eight states; two provinces; and myriad municipalities, local governments, and aboriginal peoples. As a result, it has been suggested that the institutional capacity to halt either new or reemerging stresses is lacking (International Joint Commission 2003).

This report focuses on one of the many stresses imposed on the Great Lakes by human activity: the introduction of aquatic invasive species (AIS) through maritime trade. Also referred to as introduced, alien, exotic, nonnative, or nonindigenous, an invasive species, which may be aquatic or terrestrial, is defined as one transported by human activity into a region where it did not occur in historical time and where it is now established in the wild. Not all introduced species are invasive, in the sense of being harmful, very abundant, or spreading rapidly. However, the term "AIS" has been widely adopted by the press, politicians, and the public, and for that reason it is used throughout this report, except in quoting sources that use alternative terminology.

Recent reports estimate the number of AIS in the Great Lakes at more than 180, including algae, fish, invertebrates, and plants (Ricciardi 2006). There are many agents, or vectors, by which such species enter the Great Lakes, including commercial shipping, recreational boating, angling or bait fishing, aquaculture, commercial and home aquaria, water gardens, canals, and rivers. The focus of this report is commercial shipping, and in particular vessels transiting the St. Lawrence Seaway.

AIS AND SEAWAY SHIPPING

Following the discovery of the zebra mussel (*Dreissena polymorpha*) in Lake St. Clair[1] in 1988, the highly visible effects of this species' invasion of the Great Lakes drew public attention to an age-old phenomenon, namely, the unintentional carriage of organisms to new locations by ships. The zebra mussel was by no means the first AIS to enter the Great Lakes on board a ship, but its explosive population growth resulted in clogged water pipes, drains, and vents and damage to docks, boats, power generation facilities, and water treatment plants. In addition, large numbers of zebra mussels washed ashore and rotted on Great Lakes beaches, leaving a foul odor and sharp-edged shells. There is considerable uncertainty about the economic impact of the zebra mussel invasion, but the costs of zebra mussel cleanup during the period since 1989 are estimated to be at least US$1 billion.[2]

The AIS problem is not unique to the Great Lakes. More than 50 AIS have been reported in San Francisco Bay since 1970, for example. Further afield, Australian ports have been invaded by the North Pacific sea star (*Asterias amurensis*) from Japan, and a carnivorous North American comb jellyfish has invaded and contributed to massive fisheries losses in the Black and Caspian Seas (NRC 1996; Shiganova et al. 2001; Kideys 2002). However, the Great Lakes differ from many other regions experiencing ship-mediated AIS introductions because of their freshwater ecosystem and the distinctive patterns of maritime trade to, from, and within the Great Lakes St. Lawrence Seaway (GLSLS) system.[3]

The opening of the St. Lawrence Seaway in 1959 is widely recognized as having provided a route into the Great Lakes not only for trade but also for ship-vectored introductions of AIS. While a trade corridor along the St. Lawrence River and into the Great

[1] Lake St. Clair, together with the St. Clair and Detroit Rivers, connects Lake Huron and Lake Erie.

[2] Zebra Mussel Economic Impacts, 1989–2006. Presentation to the committee by Chuck O'Neill, Cornell University/New York Sea Grant, May 24, 2006.

[3] The GLSLS system stretches from Anticosti Island in the Gulf of St. Lawrence to the western shore of Lake Superior.

Lakes has been in use since the earliest days of European settlement in North America, the modern seaway, built to facilitate international maritime trade into the North American heartland, allows deep-draft oceangoing vessels from all over the world to enter the Great Lakes carrying not only freight but also aquatic species loaded along with ballast water at previous ports of call. This ballast water is used to increase a vessel's draft, change its trim, regulate its stability, and maintain stress loads within acceptable limits, and it is essential for safe operations (NRC 1996).

During the 20 years since the discovery of the zebra mussel in Lake St. Clair, research has led to a greater understanding of the mechanisms by which AIS enter the Great Lakes, both in ships' ballast water and by other means. Ballasting practices that pose a risk of introducing AIS have been identified, with particular emphasis on the trade patterns of transoceanic vessels entering the Great Lakes from outside of the Canadian and U.S. exclusive economic zones. The geographic origins of many of the AIS found in the Great Lakes have been identified, as have a number of "high-risk" species likely to invade in the future. While forecasts of future invaders are far from infallible, a mysid shrimp native to the Black Sea (*Hemimysis anomala*) was identified as having a high risk of introduction into the Great Lakes several years before its discovery in Lakes Michigan and Ontario in 2006 (Ricciardi and Rasmussen 1998; Grigorovich et al. 2003). Research on the science of AIS introductions into the Great Lakes has been accompanied by efforts to develop science-based ballast water management practices and technologies that can be used by ships to prevent such introductions and by the promulgation of regulations requiring certain ships entering the Great Lakes to undertake ballast water management measures.

Despite these various efforts, reports of new AIS introductions into the Great Lakes continue.[4] Recent invaders include the mysid shrimp, *Hemimysis anomala,* and an amphipod, *Gammarus tigrinus.*

[4] As discussed in Chapter 3, there may be a considerable time lag between the introduction of a new AIS and reports of its discovery.

Of course, not all AIS are introduced into the Great Lakes by vessels transiting the St. Lawrence Seaway. Nonetheless, such vessels have historically been a major source of AIS introductions since the waterway opened in 1959. Hence, seaway shipping continues to be a focal point for many of the efforts aimed at eliminating further AIS introductions into the Great Lakes.

Canada and the United States have not been alone in their efforts to understand and prevent ship-vectored AIS introductions. For example, in 2001, Australia introduced mandatory ballast water management requirements to reduce the risk of introducing harmful aquatic organisms into the nation's marine environment through ships' ballast water (Australian Quarantine and Inspection Service 2007). And in 2004, after more than 10 years of preparatory work, the International Maritime Organization (IMO) adopted the International Convention for the Control and Management of Ships' Ballast Water and Sediments (IMO 2004). This convention, which has yet to be ratified by the necessary quorum of the world's maritime nations, aims to "prevent, minimize and ultimately eliminate the risks to the environment, human health, property and resources arising from the transfer of harmful aquatic organisms and pathogens via ships' ballast water" (Gollasch et al. 2007, 586).

The ballast water control and management regulations contained in the Canada Shipping Act of 2006 include ballast water standards identical to those proposed in the IMO convention. The United States has yet to update its invasive species legislation, which was first enacted in 1990 and reauthorized in 1996, although draft legislation is currently before Congress. Frustration at the delays in passing U.S. federal legislation aimed at preventing further AIS introductions appears to be an important factor driving some groups to act on their own or in concert with others. The state of Michigan has established its own ballast water legislation, and other Great Lakes states are considering following suit. A coalition of environmental groups has called for a moratorium on oceangoing vessels using the seaway until Congress establishes effective ballast water discharge standards, and others are seeking to have ballast water discharges regulated under the U.S. Clean Water Act.

CHARGE TO THE COMMITTEE

In the above context, the Great Lakes Protection Fund asked the Transportation Research Board and the Water Science and Technology Board of the National Academies to convene an expert committee to identify and explore options for the Great Lakes region that would meet two criteria: (*a*) enhance the potential for global trade in the Great Lakes region and (*b*) eliminate further introductions of nonindigenous aquatic species into the Great Lakes by vessels transiting the St. Lawrence Seaway.[5]

The committee was tasked with developing a range of practical and technically feasible options that would meet these criteria. In its final report, the committee was to comment on the strengths and weaknesses of the options identified and suggest approaches that appear most promising for more detailed evaluation and possible implementation.

COMMITTEE'S APPROACH

Consideration of the two project criteria led the committee to observe that the requirements to enhance the potential for trade and eliminate further AIS introductions are very different in both nature and scope. The subject of economic development and ensuing trade is broad in scope, and a region's potential for global trade is influenced by a multitude of forces, both within the region and outside it. The requirement to enhance the Great Lakes region's potential for global trade is a broad mandate without specific directives. In contrast, the requirement to eliminate further AIS introductions is an absolute and narrow requirement addressing a specific vector (shipping) and a single route (the St. Lawrence Seaway).

Identifying options that meet both project criteria simultaneously proved to be a key component of the committee's task and involved assessing the extent to which efforts to enhance the Great

[5] The committee's task statement uses the term "nonindigenous aquatic species" in place of "AIS."

Lakes region's potential for global trade are likely to be influenced by efforts to eliminate further ship-vectored AIS introductions. For example, imposing additional regulatory requirements on vessels entering the seaway could adversely affect trade by excluding those vessels unwilling or unable to comply. Nonetheless, the influence of such policies may not be major. A government with numerous protective tariffs and quotas, for example, would find it difficult to enhance global trade, regardless of its policies for preventing AIS introductions.

With these observations in mind, the committee undertook a series of activities to gather the data necessary to inform its development of future options for the Great Lakes region. It held two initial information-gathering meetings, one in Washington, D.C., in May 2006 and one in Toronto, Ontario, in August 2006 (see Appendix A). At these meetings, a series of invited presentations from experts and stakeholders helped establish what actions are currently being undertaken to prevent further ship-vectored AIS introductions into the Great Lakes and enhance the region's potential for global trade. In conjunction with its August 2006 meeting in Toronto, the committee visited two locations on the GLSLS system, the Welland Canal and the Port of Hamilton.

Armed with the information gathered from these meetings and site visits and from its background reading, the committee commissioned a series of expert papers on topics relating to the two project criteria (see Appendix B). Some of the papers focused on clarifying the current state of knowledge, while others explored opportunities to catalyze changes aimed at enhancing the Great Lakes region's potential for global trade while preventing further AIS introductions by vessels transiting the seaway. At its third meeting, held in Irvine, California, in February 2007, the committee met with the authors of the commissioned papers to review their progress, discuss the major messages of their draft papers, and provide guidance for completing the drafts.

The first day of the committee's fourth meeting, which was held in Toronto in May 2007, was devoted to a public meeting, Aquatic Invaders and Global Trade: Options for the Great Lakes Region.

The primary purpose of the meeting was for the committee to gain a better understanding of stakeholder views about possible approaches to meeting the two project criteria. To this end, participants were invited to suggest solutions and to comment on a variety of actions that might be taken. The 34 meeting guests represented Canadian and U.S. federal and provincial or state government agencies, environmental groups, private-sector organizations (including the shipping industry and developers of ballast water treatment technologies), and academia (see Appendix C). To help inform the discussions, the authors of the commissioned papers spoke briefly about their work.

The remainder of the fourth meeting and most of the fifth and final committee meeting, which was held in Washington, D.C., in July 2007, were devoted to committee deliberations and development of the conclusions and recommendations of this report.

ORGANIZATION OF THE REPORT

The next chapter provides a brief historical overview of the St. Lawrence Seaway and discusses the waterway's management, operations, and financing. Historical trends in seaway traffic are summarized, and some of the factors likely to influence the waterway's future role within the larger Great Lakes transportation system are identified. After a brief overview of the history of AIS introductions in the Great Lakes, Chapter 3 summarizes the role of ships' ballast water in introducing AIS and examines briefly the impacts of AIS introductions with reference to both high-profile and less studied invaders. The difficulties in interpreting historical trends in such introductions are then discussed in the context of efforts to assess the effectiveness of prevention measures. Chapter 4 identifies the categories of vessel using the seaway and discusses each briefly. The ballast water management requirements for vessels entering the GLSLS system are then summarized. Chapter 5 describes the committee's approach to identifying and exploring options for the Great Lakes region that would meet the two project criteria. Candidate actions for meeting each criterion are examined, and ways of combining these actions to meet both criteria simultaneously are then considered. The final chapter discusses the committee's conclusions about two alternative options for the Great Lakes region. It then describes the committee's recommended option and the actions necessary to implement this option.

REFERENCES

Abbreviations

IMO	International Maritime Organization
NRC	National Research Council

Australian Quarantine and Inspection Service. 2007. Australian Ballast Water Management Requirements, Version 3, June 1. www.daff.gov.au/__data/assets/pdf_file/0020/104807/Australian_BW_Requirements.pdf.

Gollasch, G., M. David, M. Voigt, E. Dragsund, C. Hewitt, and Y. Fukuyo. 2007. Critical Review of the IMO International Convention on the Management of Ships' Ballast Water and Sediments. *Harmful Algae,* Vol. 6, pp. 585–600.

Great Lakes Information Network. n.d. Great Lakes Fish and Fishing. www.great-lakes.net/teach/envt/fish/fish_1.html.

Grigorovich, I. A., R. I. Colautti, E. L. Mills, K. Holeck, A. G. Ballert, and H. J. MacIsaac. 2003. Ballast-Mediated Animal Introductions in the Laurentian Great Lakes: Retrospective and Prospective Analyses. *Canadian Journal of Fisheries and Aquatic Sciences,* Vol. 60, pp. 740–756.

IMO. 2004. *International Convention for the Control and Management of Ships' Ballast Water and Sediments.* London, United Kingdom.

International Joint Commission. 2003. Priorities 2001–2003: Priorities and Progress Under the Great Lakes Water Quality Agreement. Science Advisory Board, Chapter 5. www.ijc.org/php/publications/pdf/ID1568.pdf.

Kideys, A. E. 2002. Fall and Rise of the Black Sea Ecosystem. *Science,* Vol. 297, pp. 1482–1484.

NRC. 1996. *Stemming the Tide: Controlling Introductions of Nonindigenous Species by Ships' Ballast Water.* National Academy Press, Washington D.C.

Ricciardi, A. 2006. Patterns of Invasion in the Laurentian Great Lakes in Relation to Changes in Vector Activity. *Diversity and Distributions,* Vol. 12, pp. 425–433.

Ricciardi, A., and J. B. Rasmussen. 1998. Predicting the Identity and Impact of Future Biological Invaders: A Priority for Aquatic Resource Management. *Canadian Journal of Fisheries and Aquatic Sciences,* Vol. 55, pp. 1759–1765.

Shiganova, T. A., A. M. Kamakin, O. P. Zhukova, V. B. Ushivtsev, A. B. Dulimov, and E. I. Musaeva. 2001. The Invader into the Caspian Sea Ctenophore *Mnemiopsis* and Its Initial Effect on the Pelagic Ecosystem. *Oceanology,* Vol. 41, pp. 517–524.

U.S. Environmental Protection Agency and Government of Canada. 1995. *The Great Lakes: An Environmental Atlas and Resource Book* (3rd ed.). www.epa.gov/glnpo/atlas/index.html.

2

The St. Lawrence Seaway

The Great Lakes St. Lawrence Seaway (GLSLS) system is a binational waterway operated jointly by the United States and Canada. Encompassing the St. Lawrence River and the five major Laurentian Great Lakes (Ontario, Erie, Huron, Michigan, and Superior), the inland waters that make up the GLSLS system stretch westward over 2,300 miles (3,700 km) from Anticosti Island in the Gulf of St. Lawrence to the western shore of Lake Superior (see Figure 2-1).

The St. Lawrence Seaway proper, within the meaning of the legislation providing for its construction and maintenance, extends from Montreal to Lake Erie and is made up of two sections:

- The Montreal–Lake Ontario (MLO) section, located partially in Canadian waters and partially in international boundary waters, includes a series of seven locks (five Canadian, two U.S.) and connects Montreal, Quebec, and Lake Ontario. It enables ships to navigate the 190 miles (304 km) between the lower St. Lawrence River [elevation 20 feet (6 m)] and Lake Ontario [elevation 243 feet (75 m)].
- The Welland Canal, located in Canadian waters, includes a series of eight locks (all Canadian) and connects Lake Ontario and Lake Erie [elevation 569 feet (175 m)], a distance of 36 miles (58 km).

The MLO section, which opened in 1959, was the last link to be completed in the series of channels and canals allowing deep-draft vessels to move between the Atlantic Ocean and ports on the Great Lakes.

To provide context for the committee's identification and exploration of options for the Great Lakes region, this chapter gives a

FIGURE 2-1 GLSLS system.
(SOURCE: St. Lawrence Seaway Development Corporation.)

short historical overview of the St. Lawrence Seaway, from early efforts to develop a transportation route and trade corridor along the St. Lawrence River into the Great Lakes to the culmination of these efforts in the 1959 opening of the modern seaway. A summary of the waterway's management, operations, and financing includes brief comments on the roles and perspectives of the seaway's Canadian and U.S. partners. The infrastructure of the seaway itself and of associated ports and industrial facilities is then discussed. The section on seaway traffic comments on historical trends, notes the difficulties encountered in forecasting future traffic levels, and seeks to put the seaway in the broader context of the Great Lakes transportation system as a whole by identifying alternative (competing) routes and modes for international commerce. The chapter concludes with a brief discussion of two areas—global climate and world maritime trade—where anticipated changes could well affect the numbers and types of vessels using the seaway in the future.

HISTORICAL OVERVIEW

The Great Lakes have provided a means of transporting people and goods since humans first settled in the Great Lakes basin. The lakes and tributaries provided transportation by canoe for the native peoples, and trade among groups flourished. European settlement in North America during the 16th and 17th centuries was accompanied by efforts to develop a travel route and trade corridor along the St. Lawrence River and into the Great Lakes, and a trading post was established at Duluth at the head of Lake Superior as early as 1679.

During the 18th and early 19th centuries, the St. Lawrence River was the principal inland route for people, supplies, arms, and commercial goods, even though major shipping could travel no further west than Montreal. Despite the need to portage past obstacles such as the Lachine Rapids and Niagara Falls, the river was far easier to travel than rugged inland routes. Over time, various rapids were bypassed by channeling or dredging, and by the middle of the 19th century a continuous water route—including the first Welland Canal—linked Lake Erie to the Atlantic Ocean. The waterway was rudimentary, however, and its depth and lock dimensions precluded the shipment of heavy bulk cargoes aboard large vessels. The system closed frequently because of bad weather and was generally inoperable for 5 months over the winter. The railroads began to expand into the Great Lakes basin during the 1840s, providing an alternative means of transporting large amounts of freight year-round between the Atlantic Ocean and the continental interior; by the 1850s the Erie Canal was losing much of its traffic to the railroads.

During the second half of the 19th century, rapid industrial expansion and population growth in the continental interior resulted in greatly increased requirements to move goods, notably wheat and iron ore. Construction of the transcontinental Canadian Pacific Railway in the 1880s opened up the possibility of transporting grain by rail from the prairies to Port Arthur (now part of Thunder Bay) for shipment down the Great Lakes. Also during this period, modernization of the St. Lawrence waterway continued through a variety of lock and canal construction projects, and in 1895 the governments of the United States and Canada appointed a Deep Waterways Commission to study the feasibility of a seaway. The commission reported in favor of the project (U.S. Congress 1897), and its report was followed in 1905 by the establishment of the International Waterways Commission, created to advise the governments of both countries about water levels and flows in the Great Lakes, especially in relation to the generation of electricity by hydropower. The Boundary Waters Treaty between the United States and Canada was signed in 1909 and provided for the creation of the International Joint Commission (IJC),[1] which conducted a series of engineering studies and proposed the construction of the

[1] IJC has the authority to resolve disputes over the use of water resources that cross the international boundary. The commission is currently responsible for the regulation of the water level in Lake Ontario, which governs the flow of water in the St. Lawrence River.

St. Lawrence Seaway. However, two world wars and strong opposition from the railroads and other industrial interests prevented the start of any joint seaway construction projects to allow ocean vessels to enter the Great Lakes for another 45 years.

Finally, in the early 1950s, the pressing needs for both power generation and improved navigation led to the creation of the seaway.[2] In 1951, the Canadian Parliament approved legislation authorizing construction of a Canadian Seaway and associated hydroelectric power generation facilities. The proposed dams in the International Rapids section of the St. Lawrence River would not only create a navigation pool upstream of the dams to allow sufficient draft for shipping but also offer the opportunity to generate more than 12 billion kilowatt-hours of electricity annually. In 1954, the U.S. Congress passed the Wiley–Dondero Seaway Act authorizing the U.S. government to work jointly with the government of Canada to create a deepwater navigation channel in the St. Lawrence River between Montreal and Ogdensburg, New York, and associated hydroelectric generation facilities. Construction work commenced later that year. The Moses–Saunders hydroelectric generating station commenced operations in 1958, and the seaway was officially opened for navigation by Queen Elizabeth II and President Eisenhower on June 26, 1959.

MANAGEMENT, OPERATIONS, AND FINANCING

Canadian and U.S. legislation authorizing construction of the seaway also created organizations to manage and operate the waterway, namely, the Canadian St. Lawrence Seaway Authority (SLSA) and the U.S. St. Lawrence Seaway Development Corporation (SLSDC). Both organizations have undergone changes in the years since their

[2] Significant changes in elevation in various sections make the St. Lawrence River ideal for electric power generation. The first hydroelectric power generation facilities were built by private firms in the late 1800s. In contrast to the power generation facilities associated with the current seaway, these were modest projects that used only a small fraction of the water flow.

creation. SLSDC is now an operating administration of the U.S. Department of Transportation, subject to the policy direction and supervision of the Secretary of Transportation, and since 1986 has been an appropriated rather than a self-financing agency. On the Canadian side, the 1998 Canada Marine Act replaced SLSA by a private, not-for-profit entity, the St. Lawrence Seaway Management Corporation (SLSMC), which operates and maintains the Canadian Seaway infrastructure, while the Canadian government retains ownership of the infrastructure and acts as regulator.

The Canadian and U.S. seaway corporations jointly operate and maintain the GLSLS system[3] and provide traffic control assistance to vessels using the waterway. The two organizations also undertake trade development functions aimed at enhancing use of the GLSLS system, which is increasingly referred to in promotional literature as Highway/Autoroute H2O.

The total cost of the St. Lawrence Seaway navigation project was US$470.3 million, of which Canada paid $336.5 million (72 percent) and the United States $133.8 million (28 percent). When the seaway opened in 1959, a system of tolls based on estimates of future traffic was established by agreement between the two countries. The purpose of the system was to obtain directly from users the revenues required to cover the costs of operation and maintenance, as well as interest on loans and repayment of capital over a 50-year period (Ghonima 1984). This objective was not met, and the operating deficit for the system escalated rapidly during the 1970s, despite some of the highest traffic volumes in the seaway's history. A revised toll system, agreed on by the two governments in 1978, allowed for the phase-in of higher tolls, and further revisions were implemented during the early 1980s.

Tolls were eliminated on the U.S. portion of the seaway in 1986 when the U.S. Congress created the Harbor Maintenance Tax

[3] The U.S. Army Corps of Engineers (USACE) is involved in maintenance of the GLSLS system through its broad responsibilities for inland waterway transportation in the United States. USACE facilitates the movement of vessels by activities such as deepening, widening, and straightening navigation channels, and it evaluates, plans, and constructs improvements to inland harbors and channels.

(HMT) to generate revenue for operation and maintenance of the nation's navigation infrastructure. The HMT is an ad valorem (value) tax assessed on cargo moved by ship between U.S. ports and to U.S. ports from overseas, and it is paid by the owner of the cargo. HMT receipts are placed in the Harbor Maintenance Trust Fund. Expenditures from this fund are determined by the congressional budget and appropriations process and include annual appropriations to SLSDC that are used to meet operation and maintenance expenses for the seaway.[4]

Canada continues to charge seaway tolls, which are a major source of revenue for SLSMC. For the period April 1, 2006, through March 31, 2007, the corporation's total revenue was C$85.2 million, of which C$80.3 million (94 percent) was from seaway tolls. The current toll structure is a composite charge that depends on cargo tonnage and type, as well as on the vessel's gross registered tonnage. For vessels using the Welland Canal, there is also a lockage charge for each lock transited. Cargo tolls are generally higher for higher-value commodities. Thus, for the 2007 navigation season, the tolls per metric ton (tonne) for coal and grain were approximately C$0.6, while those for general cargo and steel slab were C$2.4 and C$2.2, respectively.

While the seaway is managed and operated jointly by Canada and the United States, there are important differences between the two partners in terms of the seaway's geography and financing. As already noted, Canada had a greater financial stake in the original navigation project, paying 72 percent of the total cost. In addition, 13 of the 15 seaway locks are operated by the Canadian SLSMC and two by the U.S. SLSDC. As a result, Canada makes a much larger financial contribution than does the United States to seaway operations. In 2006, SLSMC's operating expenses were C$63.7 million, while those of SLSDC were US$19.3 million. Furthermore, while the GLSLS system serves both the United

[4] Proposals in the Bush administration's FY 2006 and FY 2007 budgets to reinstate tolls on the U.S. portion of the seaway met strong opposition from Great Lakes ports and many others in the region's maritime industry.

States and Canada, the St. Lawrence Seaway itself, comprising the MLO section and the Welland Canal, is used primarily by foreign- and Canadian-flagged vessels. The majority of the U.S.-flagged vessels operating on the GLSLS system are too large to transit the Welland Canal, and their operations are limited to the upper Great Lakes (see Chapter 4).

INFRASTRUCTURE

Navigation System

The seaway channels and canals were built throughout to a project depth below chart datum[5] of 27 feet (8.2 m), and the locks were built to a usable length of 766 feet (233.5 m) and a width of 80 feet (24.4 m). Thus, after the completion of the MLO section in 1959, vessels capable of carrying 25,000 tons or more of cargo were able to enter the Great Lakes for the first time.[6] Over the past 15 years, technological developments and more sophisticated modeling techniques have led to increases in allowable vessel draft and length, thereby enabling vessels to carry more cargo (possibly up to 30,000 tons per voyage).[7] Today, the seaway locks can accommodate vessels up to 740 feet (225.5 m) long and up to 78 feet (23.8 m) wide and loaded to a draft not exceeding 26 feet 6 inches (8.2 m).

Maintenance of the seaway infrastructure, including system improvements, is conducted during the annual winter closure between December and March. SLSMC's annual asset renewal expenses, which represent the cost of maintenance and major repairs of locks, canal bridges, buildings, and other infrastructure

[5] The chart datum is the level of water from which charted depths displayed on nautical charts are measured.

[6] Construction of the current Welland Canal started in 1913 but was interrupted by World War I. When the current canal opened in 1932, it allowed for the passage of vessels larger than those existing on the Great Lakes at the time.

[7] See, for example, Transport Canada 2001.

assets, have increased steadily from C$16.9 million for 1998–1999 to C$35.5 million for 2006–2007. The Canadian government has been providing general Canadian Treasury funds to SLSMC for its capital improvement projects and has more than doubled SLSMC capital and maintenance funding over the past few years (SLSDC n.d.). SLSDC's annual operating expenses for maintenance and engineering have been relatively constant over the past 10 years, averaging approximately US$3.6 million.[8] SLSDC has developed a 10-year U.S. Seaway Asset Renewal Program Capital Investment Plan for its navigation infrastructure and facilities, and project and equipment costs are estimated at US$86 million for the period FY 2009–FY 2013 (SLSDC n.d.).

As the seaway system ages, planning for future operation, maintenance, repair, and rehabilitation is becoming increasingly important. The MLO section is almost 50 years old, and the eight locks of the Welland Canal date from 1932.[9] Thus, in 2003, the governments of Canada and the United States initiated a joint study to evaluate the infrastructure needs of the GLSLS system, including the St. Lawrence Seaway proper and the Soo Locks, which allow transit of vessels between Lake Superior and Lake Huron. The GLSLS study, published in late 2007 (Transport Canada et al.) assessed the ongoing maintenance and long-term capital requirements needed through 2050 to ensure the continuing reliability of the system. The study report does not give a "bottom line" cost estimate, but the information provided indicates that structural maintenance costs for the MLO section, the Welland Canal, and the Soo Locks over the next four decades could exceed US$2 billion (in 2007 nominal dollars).

[8] Data on asset renewal and maintenance and engineering expenses are taken from the Annual Reports of SLSMC and SLSDC, which are available on the GLSLS system website (www.greatlakes-seaway.com/). The two seaway corporations use different budget categories to report their various expenses, so the data cited should be interpreted as indicative of the relative contributions of the Canadian SLSMC and the U.S. SLSDC to maintenance and renewal of the seaway infrastructure rather than as rigorous comparisons.

[9] A 7-year program to rehabilitate the Welland Canal, funded by the Canadian federal government, was undertaken in the late 1980s and early 1990s.

Ports and Industrial Facilities

In addition to the infrastructure of the seaway itself, port facilities and a network of industrial capacity, including land-based transportation services, have grown up around the GLSLS system. As noted in a recent report, these facilities embody significant capital investment by industry, Great Lakes states and provinces, and the Canadian and U.S. federal governments (Cangelosi and Mays 2006). As the report's authors observe, port facilities may be large and generalized to a range of cargoes or small and specialized to a specific cargo, or even a specific carrier. Those with nearby manufacturing facilities may have major rail connections to move semifinished or finished products to the next point on the supply chain.

Some ports in the GLSLS system specialize in transshipment—the transfer of goods from one vessel to another or to another mode of transportation—and are equipped accordingly. For example, transshipment elevators that handle both Canadian and U.S. grain exports are situated along the St. Lawrence River in Montreal, Sorel, Quebec City, Trois Rivieres, Baie Comeau, and Port Cartier. These elevators are capable of receiving, storing, and loading all types of export grain, and even of transferring parcels between one ship and another. Import and export cargoes also move by road or rail between transshipment ports on the St. Lawrence River and inland destinations. For example, the Port of Montreal, which has extensive rail links to destinations throughout North America, is a major center for transshipment of containerized cargo between ocean vessels and rail.

Transshipment does not necessarily require specialized port facilities, however. The self-unloading ship was developed and perfected by the domestic Great Lakes shipping industry as a means of delivering bulk cargoes to clients with little or no infrastructure for receiving or handling ships. Conveyors serviced by hoppers under each cargo compartment transfer the cargo to an additional conveyor on a long boom, thus allowing these highly maneuverable ships to place an entire cargo, or parcels of cargo, in one location without the assistance of stevedores or shore equipment.

TRAFFIC

Historical Trends

Traffic data collected by the seaway corporations show that the amount of cargo shipped through the seaway each year has varied considerably since the waterway opened to deep-draft vessels in 1959 (Figure 2-2). For this report, the focus is on vessels transiting the seaway that may be carrying aquatic invasive species (AIS) into the Great Lakes. Thus, the traffic data of particular interest are those for the MLO section, which capture information on all vessels passing through the geographic pinch point at the entrance to the seaway. (The different categories of vessel transiting the seaway are discussed in Chapter 4.) The cargo tonnage moving through the Welland Canal is generally higher than that moving through the MLO section, as Figure 2-2 illustrates, because of the large amount of interlake traffic carrying relatively low-value bulk commodities (see Chapter 4).

Traffic on the seaway grew rapidly in its first 7 years and continued to grow, with some fluctuations, until the late 1970s. This 20-year period of growth was followed by an overall downward trend ending in 1993, when traffic levels were the lowest since 1963. A number of factors caused this decline, including a prolonged economic recession affecting the U.S. steel, automotive, and related industries in the Great Lakes region; reduced demand for grain from traditional markets in Western Europe, notably the former Soviet Union; and increased movement of Canadian grain by rail to developing west coast ports serving the growing Asian market. Between 1994 and 2000, seaway traffic saw a modest recovery, largely as a result of a surge in steel traffic reflecting the overall strength of the U.S. economy. In recent years, traffic volumes have continued to fluctuate as a result of varying charter rates for ocean vessels, restructuring in the steel industry, and slowing industrial production in the Great Lakes region.[10]

[10] A detailed analysis of trends in seaway traffic from 1959 to 2001 has been conducted by TAF Consultants (2002).

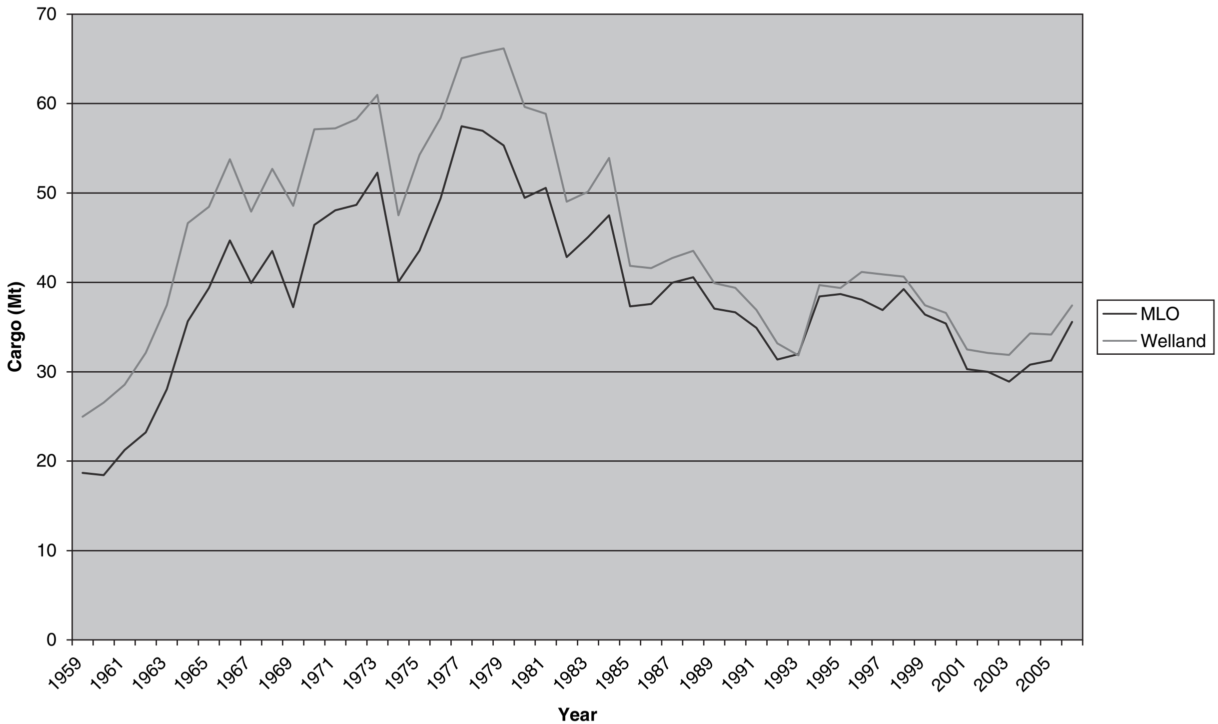

FIGURE 2-2 Seaway traffic, 1959–2006.
(SOURCE: St. Lawrence Seaway Traffic Reports, available at www.greatlakes-seaway.com/.)

The availability of both inbound and outbound cargoes is also an important factor affecting current levels of seaway traffic. In the early days of the seaway, it was not unusual for vessels with no cargo on board to enter the GLSLS system destined for ports on Lake Superior, where they would load export cargoes of grain. Since the early 1990s, however, requirements for commercial viability have dictated that vessels using the GLSLS system carry cargo on both inbound and outbound voyages (Jenkins 2007). To this end, vessel owners and operators have sought to exploit the complementary nature of the seaway steel and grain trades, notably in the case of transoceanic vessels trading with countries outside of North America (see Chapter 4). Taylor and Roach (2007, 5) note that "the front haul movement of steel and other products into the Great Lakes may be a key determinant of how much outbound grain moves by [transoceanic] vessels, since these vessels present an opportunity for an attractively priced backhaul movement of grain."

Forecasts

Taylor and Roach (2005) offer a brief review of long-run traffic forecasts for the St. Lawrence Seaway. Four studies are cited that made forecasts for traffic on the MLO section for 2000. On average, the forecast tonnage was found to be more than twice the actual tonnage, with individual forecasts ranging from 1.8 to 2.8 times the actual values. Thus, these forecasts have missed their mark by a wide margin. An additional study forecast 2010 tonnage on the MLO section of the seaway at 130 million tonnes (Mt), a level that appears unlikely to be achieved, given that it is about 4 times the average traffic for the most recent 5-year period. Taylor and Roach do not identify the reasons behind the overly optimistic traffic forecasts other than to note the possible influence of high seaway traffic volumes in the mid-to-late 1970s and errors in forecasting grain tonnages on the MLO section of the seaway.

The observation that past efforts to forecast future commerce via the St. Lawrence Seaway have fallen short is not surprising.

Accurate long-run forecasts of international trade patterns are extremely difficult to establish despite the best efforts of economists, geographers, demographers, and other social scientists armed with a variety of mathematical and statistical tools. History shows that the comparative advantage of a trading region and its transportation links to international markets are affected by a multitude of dynamic economic and political forces, which do not often lend themselves to numerical extrapolation.

The sources of the substantial errors in St. Lawrence Seaway traffic forecasts have not been specifically identified, although a multitude of political and economic forces and the dynamic environment in which they operate are often cited (see, for example, TAF Consultants 2002). Factors affecting levels of seaway traffic include the decline in automotive and steel industries in the Great Lakes region; a decline in European demand for North American grain as a result of the European Union's (EU's) agricultural policies, technology, and preferential trade agreements;[11] a decline in grain exports from Canada and the United States to the former Soviet states following the Soviet Union's collapse; a geographic redistribution of international trading patterns, and in particular the growth of trade with Asia; a comparative decline in real overland transport rates on competing routes; the worldwide shift to containerization; government policies; and a myriad of other forces that are difficult to forecast.[12]

A recent forecast of future seaway traffic appears more conservative than some of the earlier forecasts examined by Taylor and

[11] Grain production in Western Europe has climbed steadily over the past 40 years because of a combination of new technology, high prices, and income support provided by the EU's Common Agricultural Policy. As a result, the EU has been a grain exporter for more than two decades.

[12] The difficulties encountered in attempting to forecast future traffic on a specific trade corridor are not unique to the St. Lawrence Seaway. A report on inland navigation system planning for the upper Mississippi River and Illinois Waterway cites difficulties encountered by USACE in forecasting waterway traffic to determine feasibility of improved navigation infrastructures and new waterway construction (NRC 2001). Examples include an effort to forecast future traffic on the upper Mississippi River system (Lock 26 at St. Louis, Missouri) and studies that focus on feasibility of the Tennessee–Tombigbee waterway project. In particular, forecasts in 1975 and 1982 of traffic at Lock 26 (St. Louis) in 1999 are about 60 percent greater than actual traffic, and actual tonnage on the constructed Tennessee–Tombigbee project is only 20 percent of forecast tonnage.

Roach, although it still anticipates that traffic in bulk commodities through the GLSLS system will "increase gradually through to the year 2030 and grow steadily for the 20 years thereafter" (Transport Canada et al. 2007, 47). Even the pessimistic scenario assumes that traffic through the MLO section will grow, albeit at an average annual rate of only 0.1 percent, and will reach an annual tonnage of 33 Mt by 2050. Under the most likely scenario, the average annual growth rate is estimated to be 0.7 percent, with annual tonnage through the MLO section reaching 42 Mt by 2050.[13] The forecast methodology is described as quantitative and qualitative econometric analysis, but few details are provided.

A possible alternative approach to exploring the future role of the seaway and its importance for the Great Lakes regional economy could consider, perhaps in a scenario form, likely "futures" and their realization in terms of trade and economic interdependence in the region. For example, it may be useful to examine the general question of how the geography of production and trade may evolve in the region over the next several decades. More specific questions to be considered could include the following:

- Will the region's increasing dependence on trade external to North America change the volume and composition of what is shipped into the region via the seaway? For example, will the move to greater containerization of international trade focus on a relatively small number of megaports, with a concomitant increased dependence on road and rail for movement of goods to interior destinations?
- Will North American export trade (physical as opposed to trade in services or information) move to greater reliance on nonmanufactured products (e.g., agricultural products, wood, minerals), thus generating increased possibilities for the use of the seaway, or will these exports be "diverted" to increasing domestic use in response to changes in relative prices and technology (e.g., increased use of grains for ethanol production)?

[13] For the 5-year period 2002–2006, annual tonnage through the MLO section averaged 32 Mt.

Such scenario analysis was beyond the scope of the committee's charge but may be of interest in informing further examinations of the GLSLS system's future, particularly given the historical difficulties in developing reliable traffic forecasts.

Alternatives to the Seaway

The seaway has played, and continues to play, a key role in certain markets—notably the shipment of grain, iron ore, coal, and steel—where the constraints imposed by the seasonality of the navigation season and the relatively long transit times can be accommodated. Nonetheless, the seaway is only one component of the Great Lakes region's complex multimodal freight transportation system. Within this system, alternative routes and modes compete for the various commodities moving within or through the region between supply and demand centers in North America and overseas. Consideration of modal competitive dynamics suggests that, in general, rail rather than truck is the most viable alternative to waterborne transportation for many of the relatively low-value bulk commodities moving on the seaway (see Table 2-1). For international movements of such commodities, a number of competing routes and modes to the seaway are available, as illustrated by the examples in Box 2-1. The relative advantages and disadvantages of these competing routes and modes change over time in response to a host of dynamic forces, including the state of the Canadian and U.S. economies, the strength of the Canadian dollar and U.S. dollar relative to each other and to other currencies, fuel prices and associated transportation costs for different modes, and congestion at ports and other locations on the transportation network.

In practice, the amounts and directions of commodity movements (trade) on the Great Lakes region's transportation network are influenced by a multitude of economic and political forces at both domestic and international levels. For example, a report prepared for Transport Canada examined seaway competitiveness versus the Mississippi and rail options for the movements of grains (TAF Consultants 2002). The competitiveness of the GLSLS

TABLE 2-1 Typical Characteristics of Shipments Moved by Different Transportation Modes

Shipment Characteristic	Transportation Mode		
	Water	Rail	Truck
Volume of cargo	Very large	Large to single carloads	Medium to less than truckloads
Inventory	High	Medium	Low
Product value	Low	Low to medium	Medium to high
Distance	Variable, determined by water links	Medium to long	Short to long
Relative transit time sensitivity	Low	Medium	High
Transportation cost sensitivity	Critical factor	Important factor	Secondary factor

NOTE: Table 2-1 has been adapted from a presentation to the Committee on the St. Lawrence Seaway, Phase 1, by Yves Lemieux of Canadian National and Malcolm Cairns of Canadian Pacific Railway in Montreal, Quebec, on September 28, 2004.

system for moving Canadian grain was found to depend on multiple factors, including world grain demand, Canadian grain supply, the available capacity of the western Canadian seaboard outlet,[14] and the ability of the seaway to compete with alternative transportation systems in terms of total transportation costs and charges. The Canadian and U.S. governments subsidize the seaway through their provision of capital and maintenance funding, and these subsidies affect the waterway's competitiveness vis-à-vis other transportation modes. As already discussed, forecasting future traffic on one or more specific trade corridors is challenging and generally unsatisfactory. Thus, while there are alternatives to the seaway for moving goods, the future competitive position of the seaway versus the various alternatives is difficult to assess with any degree of certainty.

[14] The seaway provides an overflow route for Canadian grain exports in the event of delays at west coast ports due to capacity constraints or other factors.

BOX 2-1

Competing Routes and Modes to the Seaway for International Commerce in the Great Lakes–Seaway Hinterland

An alternative Canadian routing to the seaway could involve export movements from hinterland locations (e.g., Ontario, Manitoba) via land-based transport, most likely railroads, to east coast Canadian (e.g., Quebec, Montreal) or Hudson Bay ports for transport by ship to international markets. Similarly, ship-transported Canadian imports may bypass the seaway by entering east coast or Hudson Bay ports for land-based shipment to interior locations. Much of Canada's increasing trade with Asia is bypassing the seaway via railroads that link interior Canadian regions and west coast ports. Finally, selected regions in Canada may find it feasible to access international markets through U.S. Gulf ports via a Canadian railroad (Canadian National) or U.S. inland waterways. For example, if the Canadian dollar continues to strengthen against the U.S. dollar, such routings could become increasingly attractive to Canadian grain exporters because of the reduced logistics costs incurred at U.S. Gulf ports.

Several alternative routes allow U.S. commerce in the Great Lakes–Seaway hinterland to bypass the seaway. Interior U.S. locations may route international commerce through U.S. east coast or Gulf ports rather than the seaway. Often the commerce transshipping at Gulf ports moves via inland waterways and railroads while commerce to east coast ports is generally transported by railroads. For example, U.S. trade with regions in eastern Canada (e.g., Labrador) can move by ship through the seaway or bypass this artery by moving directly to east coast U.S. ports for subsequent transport to interior locations by rail. As with Canada, the expanding trade with Asia is largely through west coast ports but facilitated by rail links with interior U.S. locations.

A CHANGING FUTURE

As the seaway is about to enter its sixth decade of service, it faces a variety of challenges and opportunities, some related to its aging infrastructure and others to environmental, economic, and social changes since its opening in 1959. The committee's information-gathering activities (see Appendix A) indicated that exploration of many of these challenges and opportunities is already being undertaken by a variety of organizations, most notably the two seaway corporations. These activities are referenced as appropriate throughout this report. The following paragraphs provide brief comments on two areas of change that the committee judged important in the context of its efforts to identify and explore options for the Great Lakes region that will meet the two project criteria. Changes in global climate and in world maritime trade could affect both the numbers and the types of vessels using the seaway in the future and could, therefore, affect efforts to enhance the Great Lakes region's potential for global trade and to eliminate further AIS introductions by vessels transiting the seaway.

Global Climate Change[15]

A number of studies completed over the past 20 years have investigated the anticipated effects on the hydrology and lake levels of the GLSLS system as a result of climate change associated with increased concentrations of greenhouse gases in the atmosphere. Using increasingly complex general circulation models and emissions scenarios, these studies estimated changes in air and water temperatures, precipitation, runoff, and lake evaporation. These parameter estimates were then input into lake-level routing models and ice formation models to assess impacts on ice cover, water levels, and flows. With one exception, all of the models resulted in lower lake levels and a large reduction in ice cover, both of which would affect navigation.

[15] The following discussion draws extensively on an expert paper commissioned by the committee on global climate change and international Great Lakes shipping (Millerd 2007).

The depths of the Great Lakes are such that navigation on the open lakes would not be affected by the lower water levels associated with climate change. However, navigation in shoal areas, in connecting channels between the lakes (the St. Mary's, Detroit, and St. Clair Rivers), in sections of the St. Lawrence Seaway, and in harbors would become problematic if water levels decline as predicted by the models. As shown in Table 2-2, anticipated average water levels in the Port of Montreal would decrease, and the difference between minimum and maximum levels would increase. The maximum allowable vessel draft in the seaway locks and navigation channels would also decrease, with the result that additional trips would be needed to carry the same amount of cargo. For a lake vessel moving grain out of the lakes to the lower St. Lawrence River of the Gulf of St. Lawrence, it has been estimated that a reduction in draft of 1 m would reduce the cargo-carrying capacity by 17 percent (Millerd 2007).

The seaway is closed every winter because ice conditions make use of the locks difficult and winter navigation in restricted channels presents environmental problems. As a result of milder winters, however, there has been a gradual increase in the length of the seaway navigation season since the 1980s. Hence, for the 5 years from 1982 to 1986, the average open period for the MLO section was 269 days. For the 5 years from 2002 to 2006, it was 279 days,

TABLE 2-2 St. Lawrence River at Montreal Jetty 1 Quarter-Monthly Mean Level Statistics for Climate Change (Base Case and Different Scenarios Simulated with Plan 1958D with Deviations)

	Base Case (m)	Warm and Dry (m)	Not as Warm and Dry (m)	Warm and Wet (m)	Not as Warm and Wet (m)
Average	6.80	5.74	6.10	5.98	6.65
Maximum	9.21	8.78	9.14	9.19	9.16
Minimum	5.01	4.31	4.45	4. 41	4.92
Difference, max – min	4.20	4.47	4.69	4.78	4.24

SOURCE: Fay and Fan 2006.

an increase of 10 days. And in 2006, the MLO section was open for a record 283 days.

The reduced ice cover associated with climate change may offer the possibility of further extending the seaway navigation season, although there are no current plans to do so. The conditions allowing for opening of the navigation season would occur earlier, and conditions requiring closing the locks would occur later. Thus, the adverse effects of lower water levels on navigation could be offset to some extent by a longer navigation season.

A longer navigation season could, however, complicate maintenance and replacement schedules. Some period of closure is required every year for regular maintenance and inspection because the majority of lock sites throughout the system possess only one lock chamber and no parallel or auxiliary chambers (Transport Canada et al. 2007). Thus, in the absence of lock "twinning," it is not possible to conduct all the necessary maintenance while the system is operational. As already noted, the winter shutdown of the seaway provides an opportunity to conduct lock maintenance and mechanical overhauls and to replace machinery and other parts while there is no shipping using the system. Maintenance engineers suggest that this regular annual maintenance could be done in 1 month, providing no major problem is encountered. Every 3 to 5 years, however, lock machinery requires major maintenance, replacement, and upgrading, and resurfacing of lock walls may be necessary, requiring at least 2 months. Thus, for many years a maintenance closure of 1 month would suffice, but every third to fifth year a longer closed period would be required. Maintenance procedures and schedules would have to be rearranged and more outside contractors may need to be hired to accommodate the shorter periods of closure. The increased maintenance requirements associated with aging of the locks could also complicate efforts to extend the navigation season.

As the preceding paragraphs indicate, the direct effects of global climate change on seaway navigation are expected to be mixed, with the adverse impacts of lower water levels offset to some extent by a longer shipping season. However, policies aimed at reducing transportation-related greenhouse gas emissions could favor waterborne freight transportation over competing surface modes. An expert paper commissioned by the committee (Lawson 2007) indicates that ships are generally more "environmentally friendly" than trains and trucks in terms of greenhouse gas emissions, although data limitations preclude detailed quantitative comparisons.

In addition to long-term changes associated with global climate change, cyclical variations in water levels in the Great Lakes affect navigation from time to time.

Changes in World Maritime Trade

As already discussed, steps have been taken to maximize the amounts of cargo carried by vessels transiting the seaway by increasing the allowable vessel draft and length. Nonetheless, an analysis conducted in 2001 showed that, while 70 percent of vessels in the world fleet can be accommodated by the seaway locks, these seaway-size vessels represent only 13 percent of world vessel capacity (USACE 2002). In particular, less than 2 percent of the world's bulk fleet by capacity and less than 5 percent of its container fleet can use the seaway. Furthermore, larger vessels are under construction or entering service, indicating that the percentage of the world fleet able to transit the seaway is likely to decline in the foreseeable future.

The continued rapid growth of containerization is widely acknowledged as a key factor likely to influence future world maritime trade. The advent of the cargo container and of small and large ships designed to carry nothing but containers has been a major step in expediting the transoceanic movement of general cargo and has introduced a new connotation to "transshipment." It has led to the establishment of transshipment hubs, strategically located in sheltered deepwater locations adjacent to major trade routes, where container shipments are consolidated by destination. Designed to minimize the costs of transporting goods between shipper and consignee, these hub ports service feeder containerships that move containers in a local area, larger containerships on dedicated transoceanic routes, and the megacontainerships that continually circumnavigate the globe. Hub ports aim to limit the number of port calls and overall port time for the ships they service and to receive, sort, and reship containers so that they reach their intended destination by the fastest possible route. Such facilities are in operation, are under construction, or are being promoted around the world in locations such as Tanjung Pelepas, Malaysia; Singapore; Colombo, Sri Lanka; Manzanillo, Panama; Freeport, Bahamas; Kingston, Jamaica; the Malta Freeport; Sydney, Nova Scotia; and Scapa Flow, Scotland.

New waterborne feeder services throughout the GLSLS system could serve the existing containerport in Halifax, Nova Scotia, or a possible new hub port for container transshipment in Sydney, Nova Scotia. It has been suggested, for example, that ships built for the purpose could move containers to the Lake Ontario port of Hamilton, where they would be distributed throughout the Great Lakes basin.[16] Questions remain about the effects of relatively long transit times and seasonal closure on the demand for container shipping on the GLSLS system (see Chapter 5). Nonetheless, the fact that future container feeder services are being explored indicates that efforts to prevent further AIS introductions into the Great Lakes by vessels transiting the seaway need to recognize the possibility that the mix of vessels using the seaway may be different from that of today. The ports of origin of these vessels may also be different, with an increase in the proportion of traffic from coastal areas of eastern North America providing feeder services into the Great Lakes.

CONCLUDING REMARKS

The binational GLSLS system, which includes the St. Lawrence Seaway, stretches over 2,300 miles (3,700 km) from the Gulf of St. Lawrence to the western shores of Lake Superior. The 1959

[16] Opportunities for container shipping on the GLSLS system are discussed in the recent GLSLS study (Transport Canada et al. 2007).

opening of the MLO section of the seaway was the final step in establishing a navigation system that allows deep-draft ocean vessels to move between the Atlantic Ocean and Great Lakes ports. In the almost 50 years since its opening, the MLO section has handled 1.9 billion tonnes of cargo. Although traffic volumes in recent years have been about half the peak levels of the 1970s and early 1980s, the seaway continues to play a key role in the shipment of grain, iron ore, and steel. Seaway trade is particularly important for Canada, which paid more than 70 percent of the total cost of the original seaway navigation project and continues to play a greater role than its U.S. partner in financing and operating the waterway.

Forecasting future seaway traffic has historically proven problematic because of the multitude of economic and political forces affecting trade, both within the Great Lakes region and beyond. In addition, the seaway is only one component of the larger Great Lakes transportation system, which offers a variety of alternative routes and modes for moving cargoes.

As the seaway enters its sixth decade of service, its future role within the Great Lakes transportation system is unclear. This observation does not imply that the waterway has no future role, but rather that this role remains difficult to anticipate because of the numerous uncertainties. On the one hand, the seaway infrastructure is in need of major renovation to ensure its continuing reliability, and the waterway's locks can accommodate only a decreasing fraction of world vessel capacity as the growth of container shipping leads to the building of ever-larger vessels. On the other hand, the seaway offers an alternative to increasingly congested land-based routes, particularly for cargo movements where the relatively long transit times and seasonality of the navigation season can be accommodated. Furthermore, the growth of hub ports for container shipping on North America's eastern seaboard may provide opportunities to develop feeder services into the Great Lakes through the seaway. The overall influence of global climate change on seaway navigation is also uncertain, with the possibility that the adverse effects of lower water levels may be offset to some extent by a longer navigation season.

REFERENCES

Abbreviations

NRC	National Research Council
SLSDC	St. Lawrence Seaway Development Corporation
USACE	U.S. Army Corps of Engineers

Cangelosi, A., and N. Mays. 2006. *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.* Northeast-Midwest Institute, Washington, D.C. www.nemw.org/scopingreport.pdf.

Fay, D., and Y. Fan. 2006. Hydrologic Scenarios for the Evaluation of Lake Ontario Regulation Plans. Presented at 59th Canadian Water Resources Association Conference, Toronto, Ontario, Canada, June 4–7.

Ghonima, H. 1984. The Seaway Economic Planning System–Computer Model Program (SEPS-CMP): An Essential Planning Tool. Presented at the Annual Conference of the Canadian Transportation Research Forum, Jasper, Alberta, Canada, May.

Jenkins, P. T. 2007. *Brine as a Treatment Solution for the Control of Aquatic Nuisance Species Introductions into the Great Lakes by NOBOB Vessels.* Prepared for Transport Canada Marine Safety by Philip T. Jenkins and Associates, Ltd., Fonthill, Ontario, Canada.

Lawson, J. 2007. *The Environmental Footprint of Surface Freight Transportation.* Lawson Economics Research, Inc., Ottawa, Ontario, Canada, June.

Millerd, F. 2007. *Global Climate Change and Great Lakes International Shipping.* Wilfrid Laurier University, Waterloo, Ontario, Canada, May.

NRC. 2001. *Inland Navigation System Planning: The Upper Mississippi River–Illinois Waterway.* National Academy Press, Washington, D.C.

SLSDC. n.d. U.S. St. Lawrence Seaway Asset Renewal Program Capital Investment Plan FY 2009–2013. www.greatlakes-seaway.com/en/home.html.

TAF Consultants. 2002. *Seaway Competitiveness Versus the Mississippi and Rail Options for the Movements of Grains.* Prepared for Transport Canada. May 15.

Taylor, J. C., and J. L. Roach. 2005. *Ocean Shipping in the Great Lakes: Transportation Cost Increases That Would Result from a Cessation of Ocean Vessel Shipping.* Grand Valley State University, Grand Rapids, Mich., Aug. www.gvsu.edu/cms3/assets/C6D78A67-0AEF-0264-A38619EC6FB0793A/OceanShippingReport091105.pdf.

Taylor, J. C., and J. L. Roach. 2007. *Ocean Shipping in the Great Lakes: An Analysis of Issues, Phase 2.* Grand Valley State University, Grand Rapids, Mich., Oct. www.gvsu.edu/business/index.cfm?id=11971F16-DBAF-2179-96B0680A95CC6F83.

Transport Canada. 2001. *Maximization of Ship Draft in the St. Lawrence.* Report TP 13888. www.tc.gc.ca/TDC/projects/marine/a/9883.htm.

Transport Canada, U.S. Army Corps of Engineers, U.S. Department of Transportation, St. Lawrence Seaway Management Corporation, Saint Lawrence Seaway Development Corporation, Environment Canada, and U.S. Fish and Wildlife Service. 2007. *Great Lakes St. Lawrence Seaway Study*. Final Report. www.glsls-study.com/Supporting%20documents/GLSLS%20finalreport%20Fall%202007.pdf.

USACE. 2002. *Reconnaissance Report: Great Lakes Navigation System Review.* June.

U.S. Congress. 1897. *Report of the United States Deep Waterways Commission.* House Document 192, 54th Congress, 2nd session.

BIBLIOGRAPHY ON SEAWAY HISTORY

American Great Lakes Ports Association. St. Lawrence Seaway Tolls. www.greatlakesports.org/tolls.html.

American Presidency Project. Letter from Harry S. Truman to Committee Chairmen on the St. Lawrence Seaway and Power Project, April 19, 1952. www.presidency.ucsb.edu/ws/print.php?pid=14087.

Environment Canada. The St. Lawrence Seaway—Great Lakes Waterway. www.ec.gc.ca/soer-ree/English/SOER/1996report/Doc/1-6-6-4-4-2-1.cfm.

Great Lakes St. Lawrence Seaway System. Seaway History. www.greatlakes-seaway.com/en/aboutus/seaway_history.html.

Infrastructure Canada. History of the St. Lawrence Seaway. www.infrastructure.gc.ca/research-recherche/result/alt_formats/pdf/hm05_e.pdf.

McConville, D. J. 1995. Seaway to Nowhere. *American Heritage of Invention and Technology,* Vol. 11, No. 2, Fall, pp. 34–44.

U.S. Environmental Protection Agency and Government of Canada. 1995. *The Great Lakes: An Environmental Atlas and Resource Book* (3rd ed.). www.epa.gov/glnpo/atlas/index.html.

3

Aquatic Invasive Species in the Great Lakes

This chapter provides an overview of aquatic invasive species (AIS) in the Laurentian Great Lakes to set the context for the committee's examination of ways to eliminate further introductions of AIS by vessels transiting the St. Lawrence Seaway. After a brief historical overview, invasion vectors and pathways are discussed, with emphasis on the ballast water vector, which has played a predominant role in ship-mediated AIS introductions into the Great Lakes since the opening of the modern seaway in 1959. The impacts of AIS are considered, with particular reference to the zebra mussel, one of the high-profile invaders. Other AIS that have attracted less study, and in many cases less public attention, are also discussed. Historical trends in AIS introductions are important in assessing the effectiveness of measures taken to prevent such introductions, and the challenges in interpreting observed trends are examined. Brief remarks about future AIS introductions are made, and the chapter concludes with a summary of key points pertaining to the committee's task.

HISTORICAL OVERVIEW

The Laurentian Great Lakes have an extensive history of human-mediated introductions of AIS, both intentional and unintentional, beginning almost 200 years ago. Precise numbers of introductions are hard to determine, given the challenges of finding and identifying some new species and verifying their nonnative status, as well as uncertainties associated with sampling. As discussed later, confusion may also result over the inclusion or exclusion of microscopic organisms such as viruses, bacteria, parasites, or protozoans (Drake et al. 2007). The number of reported AIS established in the Great Lakes has, however, increased substantially from the early 19th century to modern times, with current estimates ranging from a low of 136 to more than 180 species of nonnative algae, fish, invertebrates, and plants (U.S. Geological Survey n.d.; Ricciardi 2006).

During the period of human-mediated biological invasions, a number of transitions have occurred with respect to both the types of AIS that have established and the mechanisms by which they entered the Great Lakes. Fish and plants were the most common invaders before the 20th century, with most introductions resulting from human releases (Mills et al. 1993). Algae and invertebrates became more common invaders after transoceanic shipping converted to use of liquid ballast around 1900. Shipping appears to have become the dominant means by which AIS have been transported into the Great Lakes during much of the 20th century, and notably since the opening of the St. Lawrence Seaway in 1959. The origins are less certain for invasive plants that now dominate coastal wetlands in highly urbanized areas, such as Lake Michigan's lower Green Bay.

INVASION VECTORS AND PATHWAYS

In invasion biology, a vector is defined as the physical means or agent by which a species is transported. There are multiple vectors by which AIS gain access to the Great Lakes, including commercial shipping, recreational boating, angling or bait fishing, aquaculture, commercial and home aquaria, water gardens, canals, and rivers.

For the purposes of this report, an invasion pathway is defined as the geographic path over which a species is transported from its origin (donor area) to its destination (target area). An analysis commissioned by the committee examined pathways of introduction for AIS reported as being established in the Great Lakes since the opening of the St. Lawrence Seaway in 1959 (Kelly 2007). Information on the most probable geographic sources of species and the vector assignments showed Eurasia to be the dominant source, accounting for 67 percent of established AIS, followed by North America with 14 percent; 15 percent had unknown or widespread origins, and Australasia and Africa each contributed a single species.

Committee's Charge

The committee was asked to identify and explore options for eliminating "further introductions of nonindigenous aquatic species into the Great Lakes by vessels transiting the St. Lawrence Seaway." Thus, its charge was limited to one specific invasion route into the Great Lakes (the St. Lawrence Seaway) and addressed only nonindigenous *aquatic* species (i.e., AIS) and not terrestrial invasive species. Most AIS that have drawn attention in recent decades inhabit benthic or pelagic areas of the Great Lakes, although the system has been invaded by and remains vulnerable to invasions by wetland species such as hybrid cattail (*Typha x glauca*). In addition, the committee's charge was restricted to one group of vectors by which AIS enter the Great Lakes, namely, those associated with shipping (vessels).

There are many dispersal vectors for the transport of organisms on board ships, but the most important is widely acknowledged to be ballast water, which is needed for vessels to operate safely (NRC 1996). As discussed in Chapter 4, the mechanisms by which AIS enter the Great Lakes in ships' ballast water have been extensively investigated. Hull fouling is another vector by which vessels can transport AIS, although this vector is thought to have played a minor role compared with ballast water in introducing AIS into the Great Lakes (see later).

Importance of the Ballast Water Vector

To help set the context for its work, the committee commissioned the aforementioned analysis of AIS reported as being established in the Great Lakes since the opening of the St. Lawrence Seaway in

1959 (Kelly 2007). By means of a series of criteria to determine introduced status, 59 species were identified as nonindigenous, with an additional 21 species (mainly algae) classified as cryptogenic (not clearly introduced or native). Ships' ballast water was the leading vector for approximately 55 percent of species identified as nonindigenous.[1] Deliberate releases, unauthorized introductions, range extensions, hull fouling, and recreational boating were all of lesser importance, each representing less than 10 percent of species. A clear vector could not be established for 11 percent of the confirmed AIS. Other less conservative analyses suggest that ships' ballast water may account for as much as 65 or 70 percent of the total documented inventory of AIS in the Great Lakes (Ricciardi 2006; Holeck et al. 2004). In summary, the evidence points to ships' ballast water as the leading vector for recorded introductions of AIS into the Great Lakes since the opening of the seaway, with other vectors collectively accounting for the remaining 30 to 45 percent of introductions. Hence, eliminating further AIS introductions by vessels transiting the seaway, as specified in the committee's charge, would be expected to have an important impact on the AIS problem. However, data on the relative importance of different invasion vectors suggest that this action would not prevent all further AIS introductions into the Great Lakes.

Hull Fouling Vector

Ballast water, as well as residual ballast water and sediment, has been well characterized for transoceanic vessels entering the Great Lakes.[2] In contrast, there is a dearth of information with regard to the risk of AIS introductions posed by hull fouling on such vessels. Marine-to-marine introductions on hulls of ships have occurred for hundreds of years, and studies conducted in marine

[1] The analysis showed Europe to be the source of 94 percent of ballast-mediated invasions, including 15 species from western and central Europe, 12 from the Ponto-Caspian region, and three from the Baltic Sea.

[2] As discussed in Chapter 4, transoceanic vessels (i.e., those engaged in international trade) are the major—but not the only—source of ship-vectored AIS introductions into the Great Lakes.

and estuarine habitats have demonstrated that hull fouling is as, or more, important than ballast water to the introduction of non-indigenous species (see, for example, Gollasch 2002). However, ecologists have perceived the Great Lakes as less at risk of introductions via the hull fouling vector owing to the required transfer of fouling species from a freshwater course (the vessel's port of origin), across an inhospitable saline medium (the Atlantic Ocean), to a freshwater destination (the Great Lakes). To date, only one study has explored the role of the hull fouling vector for the Great Lakes. Drake and Lodge (2007) examined a single ship that required dry-docking on Lake Ontario for emergency repairs. This vessel had just been purchased "as is" after extended stays in Algeria and Chile before entering the Great Lakes and was not, therefore, representative of Great Lakes vessels in general. A large number of species (29) were found encrusted on a small surface area of the vessel hull, suggesting that the total number of hull fouling species could be as many as 200. However, further analyses of the species found on the hull determined that only eight are not presently reported in the Great Lakes and, of these, only two appear capable of survival in freshwater.[3] Additional examinations of exterior surfaces (e.g., hulls and rudders) of vessels entering the Great Lakes will be needed to help determine whether hull fouling is an important mechanism for AIS introductions. Absent a solid body of evidence indicating the importance of the hull fouling vector, the committee's analysis of options for preventing further introductions of AIS by vessels transiting the St. Lawrence Seaway focused on ballast water as the predominant vector associated with shipping into the Great Lakes.

IMPACTS OF AIS

Judgments about the impacts of AIS are frequently anecdotal and qualitative, and the impacts of many species have not been studied explicitly. However, available data demonstrate clearly that some

[3] Personal communication from Sarah Bailey, Fisheries and Oceans Canada, to Hugh MacIsaac, committee member, January 2008.

AIS have had severe economic or ecological influences in the Great Lakes. The most problematic invasive species include alewife, common carp, Eurasian ruffe, Eurasian water milfoil, purple loosestrife, zebra and quagga mussels, rainbow smelt, round goby, rusty crayfish, sea lamprey, and spiny and fishhook waterfleas (U.S. Geological Survey n.d.). These species alone have contributed to extirpations and some extinctions of native taxa, along with severe alterations in local food webs. In addition, invasive plants in Great Lakes coastal wetlands, such as *Typha* and *Phalaris arundinacea,* have resulted in the exclusion of many native species and declines in plant species richness and evenness of distribution.

The following section summarizes the impacts of one of the Great Lakes' highest-profile invaders—the zebra mussel. Other AIS that have attracted less study are then discussed, with particular reference to plants and to viruses and bacteria.

Zebra Mussel

The zebra mussel (*Dreissena polymorpha*) has been one of the most successful Great Lakes invaders. Most estimates of the costs of ship-vectored introductions of AIS into the Great Lakes have focused on this species and on the costs of cleaning infrastructure dependent on raw lake water, such as power generation plants, public and private drinking water plants, industrial facilities, navigation lock and dam structures, marinas, and golf courses. One expert reported to the committee that the total cost of zebra mussel cleanup during the period 1989–2004 has been tentatively estimated at \$1 billion to \$1.5 billion.[4] Other reports put the estimate as high as \$5 billion for cleanup since the discovery of the zebra mussel in 1988 (Lovell and Stone 2005).

In addition to its economic impacts, the zebra mussel has had both direct and indirect effects on the Great Lakes ecosystem. Zebra mussels are efficient filter feeders, competing directly with indige-

[4] Zebra Mussel Economic Impacts, 1989–2006. Presentation to the committee by Chuck O'Neill, Cornell University/New York Sea Grant, May 24, 2006.

nous mussel species for food and space. Zebra mussel numbers, particularly in Lake Erie, have reached such levels that concentrations of particulate matter in the lake (much of it phytoplankton, also the basis of the pelagic food web) have fallen below levels predicted by phosphorus availability. Redirection of algal biomass to benthic from pelagic food webs has implications for both rates of nutrient recycling and the efficiency with which energy makes its way up the food web to support the fishery. The "benthification" of the Great Lakes by dreissenid mussels portends greater energy and resources for many benthic species of animals and plants and less for planktonic species (Hecky et al. 2004).

The invasion of the Great Lakes by the zebra mussel, and by the quagga mussel, has also had indirect effects. Reductions in suspended particles have increased water clarity, allowing deeper penetrations of light into the water column. This, in turn, fosters growth of nuisance, attached algae (*Cladophora glomerata*) along shorelines. Rooted aquatic vegetation has increased dramatically in shallow areas of the lakes. These changes are facilitating numerous benthic invertebrates, including the rapid spread of a "Ponto-Caspian" associate of the zebra mussel, the benthic amphipod *Echinogammarus ischnus* (Vanderploeg et al. 2002). In addition, because the biomass of zebra mussel populations is orders of magnitude higher than that of native mussel populations, they have an important impact on contaminant dynamics in invaded lakes. As suspension feeders, zebra mussels bio-accumulate metals and organic contaminants, and the transfer of these contaminants up the food chain to waterfowl and fish that eat mussels has the potential to change contaminant cycling in the system significantly (see, for example, Mazak et al. 1997).

The zebra mussel was almost certainly introduced into the Great Lakes in freshwater ballast discharged by vessels engaged in international trade (see Chapter 4). Since its discovery in Lake St. Clair in 1988, the zebra mussel has spread throughout the Great Lakes, into hundreds of small inland lakes and rivers in most of the states and provinces bordering the Great Lakes, and into the Mississippi River, and it can now be found all the way down to New Orleans.

In January 2008, the species was found in San Justo Reservoir in San Benito County, California. This rapid expansion has highlighted concerns about the spread of invaders as a result of the interconnectivity of waters through canals, boat traffic, and recreational practices.

Less Studied AIS

While invaders such as the zebra mussel are unlikely to go unnoticed because of their abundance, size, and readily observable and widespread impacts, the same cannot be said of all AIS. For example, analyses of beach sand revealed introduced species of benthic copepods and testate rhizopods, species that are both inconspicuous and low impact (Horvath et al. 2001; Nicholls and MacIsaac 2004). Moreover, interest in and study of AIS have not historically been even across taxa, as illustrated by the following discussion of plants and of viruses and bacteria.

Plants

Gollasch et al. (2007) report that the first biological study to infer ballast water as a vector for nonindigenous species introductions concerned phytoplankton.[5] In the 100 years since that first study, however, research on shipping as a vector for AIS has shifted substantially toward animals. Where data on plants are available, the primary emphasis has been on macrophytes, with some attention to benthic algal species, such as the widely publicized spread of the macroalgae *Caulerpa taxifolia* in the Mediterranean, rather than microscopic pelagic phytoplankton. In the Great Lakes, the introduced diatom *Thallossiosira baltica* evaded detection from 1988 until 1994, even though it was a dominant member of the phytoplankton community (Edlund et al. 2000). Those reports that do consider phytoplankton are principally focused on marine-to-marine transfers. There is general agreement that ballast water, or ballast tank

[5] Publishing in the inaugural volume of the journal *Plankton* in 1908, C. H. Ostenfeld reported a mass occurrence of the Asian phytoplankton species *Odontella sinensis* in the North Sea, which he believed originated in either the Red Sea or the Indian Ocean (www.jncc.gov.uk/page-1663).

sediment, could act as a vector for introduction of phytoplankton, and the appearance of novel algal species in the Great Lakes has been documented (see, for example, Mills et al. 1993), but it is unclear whether these taxa arrived via ballast water or on ship hulls. Data on the potential ecological significance of exotic algae for the Great Lakes are lacking, although studies on marine systems suggest that they could pose threats to aquaculture, aquatic food webs, and human health. Thus, while the impacts of high-profile AIS in the Great Lakes are well documented, the impacts of relatively inconspicuous AIS, particularly plants, have not attracted the same degree of attention.

Viruses and Bacteria

A further area that has attracted relatively little attention until recently is invasions by aquatic microorganisms, such as viruses and bacteria. These microorganisms are orders of magnitude more abundant in aquatic systems than macroorganisms such as fish and crustaceans, indicating that large numbers could enter ships' ballast tanks during normal operations (Dobbs and Rogerson 2005). Mean abundances of 8.3×10^8 bacteria per liter and 7.4×10^9 viruslike particles per liter have been reported in the ballast water of vessels entering the Chesapeake Bay from foreign ports (Ruiz et al. 2000).

The invasion biology of aquatic microorganisms is not nearly as well studied as that of vertebrates and macroinvertebrates (Drake et al. 2007), perhaps in part because of the sophisticated microbiological investigation techniques required. Moreover, some researchers have questioned whether free-living microorganisms should be designated as invasive species at all, arguing that these species are found everywhere and that their distribution is not specific to certain geographical areas (Finlay 2002).[6,7] Other researchers

[6] This argument applies only to free-living microorganisms. In the case of a virus attached to a host, for example, if the host has a biogeography (i.e., has a distribution that is specific to certain geographical areas), the virus will have one too.

[7] In discussing bacteria, for example, Fenchel notes that "every habitat will contain a pool of bacterial species that do not thrive locally, but may grow if the environment becomes more favorable" (2003, 925).

dispute the argument that "everything is everywhere" and point to a large body of work supporting the idea that free-living microbial taxa exhibit biogeographic patterns (see, for example, Martiny et al. 2006).[8]

The debate about the invasive nature of microorganisms is directly relevant to efforts aimed at preventing further "introductions" of aquatic microorganisms, such as the virus responsible for the fish disease viral hemorrhagic septicemia (VHS) (see Box 3-1), into the Great Lakes. In light of this ongoing debate and the numerous unknowns and uncertainties with regard to the appearance of VHS in fish populations in the Great Lakes, it remains unclear whether ships' ballast water played any role in the recent VHS outbreak. However, in view of the natural abundance and widespread distribution of aquatic microorganisms, the committee sees merit in the approach taken by the International Maritime Organization, which differentiates microorganisms from other AIS in its proposed ballast water performance standard (IMO 2004). Some of the issues related to this differentiation are discussed in a recent paper by Dobbs and Rogerson (2005).[9]

EXAMINING TRENDS IN INVASION HISTORY

Curves showing the cumulative number of AIS in an ecosystem as a function of time (cumulative invasion curves) are often used to illustrate trends in invasion history and sometimes to assess the

[8] These authors do not consider the question of whether the distribution of viruses is specific to certain geographic areas because "their biology adds further complications and, in most cases, far less is known about their distribution than that of other microorganisms" (p. 103).

[9] The results of an analysis commissioned by the committee suggest that eliminating viruses from ships' ballast water may be a daunting task because of their small size and their possible abundance in ships' ballast tanks (Kelly and Kazumi 2007). These authors note, however, that the VHS virus in a free, non-host-associated form can be inactivated by a variety of means. To control its spread in aquaculture facilities, for example, fish eggs are usually treated with iodophors and hatchery waters with ultraviolet irradiation. If the VHS virus is carried on an infected fish host rather than being in an unassociated form, physical treatment technologies such as screens and media filters could be used to remove both fish and virus from ballast water.

BOX 3-1

Viral Hemorrhagic Septicemia

VHS is a disease that can cause fish to hemorrhage, resulting in rapid mortality. Classified as a reportable disease by the World Organization for Animal Health because of its high mortality and severe economic consequences (U.S. Department of Agriculture 2006), the virus responsible for VHS poses no known health threat to humans.

How long the VHS virus has been present in the Great Lakes ecosystem is unknown. VHS was first observed in the Great Lakes in 2005, when it caused fish die-offs in Lake Ontario and Lake St. Clair, but the virus may have entered the Great Lakes much earlier, perhaps in 2002 or 2003. In 2006 the disease was detected in an increasing number of fish in Lake Erie, and in 2007 it was confirmed in Lake Huron. Although the exact pathway of VHS infection is at present unknown, restrictions have been imposed on the movement of live fish in an effort to prevent (or limit) the spread of the disease. Fish die-offs, together with these restrictions, have had serious implications for the Great Lakes commercial and sport fishing industries.

Several strains of the VHS virus are known to affect freshwater and marine fish around the world. In North America, strains are found in the marine and estuarine waters of the Pacific and Atlantic Oceans. The VHS virus observed on fish in the Great Lakes is a North American strain and is most closely related to that detected in marine fish within waters of the Atlantic and eastern Gulf of St. Lawrence (Fisheries and Oceans Canada n.d.).

As noted in the text, there is an ongoing debate about the "invasive" status of aquatic microorganisms, including viruses. If the VHS virus in the Great Lakes is indeed an AIS, vectors of introduction could include migrating fish (Elsayed et al. 2006), commercial aquaculture operations, and the ballast water of vessels entering the Great Lakes from marine waters in eastern North America[a] (see, for example,

(*continued*)

BOX 3-1 (*continued*)

Whelan 2007). As yet, none of these alternative vectors has been confirmed or excluded from further consideration.

Despite these uncertainties, some organizations have already taken precautionary measures aimed at preventing or slowing the possible spread of the virus by ships' ballast water. In March 2007, the Lake Carriers' Association introduced voluntary ballast water management measures to combat the spread of VHS by U.S.-flagged lakers operating within the Great Lakes, and in September 2007, the U.S. National Park Service closed Lake Superior waters within the boundaries of Isle Royale National Park to the release of untreated ballast water (Lake Carriers' Association 2007; *Lake Superior Magazine* 2007).

[a] In the case of the ballast water vector, the virus could have entered the Great Lakes either suspended in ballast water or on an infected fish transported in ballast water.

effectiveness of measures aimed at preventing invasions. The committee, however, chose not to characterize the progressive invasion of the Great Lakes by AIS by using such a curve because of two inherent sources of uncertainty: (*a*) time lags, which vary by taxa and possibly also by decade of study, and (*b*) the level of investigator interest.

Time Lags

The time scale on typical invasion curves does not reflect the time of entry of an AIS into the Great Lakes. Instead, the date assigned is the reported date of identification of the species. There is an unknown time lag between the date of entry and the date of identification, the duration of which depends on a variety of factors.

A time lag could result from the need to build populations sufficiently large to be detected, assuming adequate sampling. Under this scenario, lags depend on the nature and intrinsic life history of the species. Microbes, for example, are far less likely to be reported than larger organisms unless, like VHS, their impacts are relatively widespread and readily observable. Lags also depend on extrinsic factors, such as initial propagule pressure,[10] extant temperature, or facilitation of new invaders by preoccurring ones (see, for example, Vanderploeg et al. 2002). Alternatively, a small population could persist undetected at a relatively low level for a considerable period of time until the emergence of a superbly adapted local genetic variant results in the establishment of a detectable population.[11]

The nature of the time lag for any particular species influences the pattern of cumulative numbers of invasions over time. Wonham and Carlton (2005) demonstrated that the cumulative number of invasions in the northeast Pacific Ocean increased at linear, quadratic, and exponential rates depending on taxa, invasive pathways, and spatial scales. Consequently, these authors argue against conclusive statements with regard to invasion rate that are based on reported discovery rates.

Investigator Interest

A second important cause of uncertainty in estimating the arrival time of diverse species resides in the number of expert investigators engaged in both searching for and identifying the broad spectrum of potential AIS. The total effort engaged in AIS identification includes lay observers, such as anglers, boaters, and others participating in recreational pursuits, as well as trained professionals. It is the latter, however, who possess the knowledge and experience to distinguish invaders from native species—a challenging task when species may be distinguishable only by subtle differences or,

[10] Propagule pressure, also referred to as "introduction effect," depends on the number of introduction events, the number of propagules introduced per event, and the condition of the propagules upon release.

[11] See, for example, Lee 2002, in which the author identifies a reasonable number of citations supporting the role of genetic attributes in invasion success.

in some cases, only at a genetic level. The number of such professional specialists actively engaged in looking for and identifying invasive species is likely to be variable and limited, with resulting variability in the rate of discovery of new AIS. Global interest in invasive species in general over the past few decades has grown (Ricciardi and MacIsaac 2008), and it is safe to assume a parallel growth in interest in and study of AIS in the Great Lakes region. However, this interest may not be even across taxa, which may explain why many more introduced invertebrate species than microbial species have been described in the Great Lakes.

As noted earlier, the committee recognizes clearly that the number of AIS in the Great Lakes has increased over time and that the number of such species introduced by ships' ballast water is between 55 and 70 percent of AIS introduced since the opening of the seaway. However, it has not attempted to draw on a cumulative invasion curve to interpret the dynamics of the invasive species biology or draw inferences about policy options. The invasion curve is too uncertain a tool to support such conjecture and is not needed to formulate strong policies at this time.

FUTURE AIS INTRODUCTIONS

The vectors and pathways by which AIS enter the Great Lakes are continuously changing. In the case of the shipping vector through the seaway, for example, changing trade patterns and routes may provide opportunities for AIS from new donor areas to enter the Great Lakes or open up alternative pathways for AIS from known donor areas. Thus, Kelly (2007) reports that the 1992 opening of the Main Canal connecting the Danube with the Rhine system provided a new westward colonization pathway for AIS from the Black Sea basin. Changes in the target area (the Great Lakes), such as those associated with climate change, may also result in changes in the pattern of AIS introductions.

The nature of changes that could affect future AIS introductions into the Great Lakes is often difficult to anticipate, which adds to the challenge of eliminating further AIS introductions. However, some progress in identifying the most likely species and sites for further introductions has been made. The following paragraphs provide a brief overview of approaches to identifying "hot species, hot spots, and hot moments" for future AIS introductions and note some possible effects of climate change on AIS introductions into the Great Lakes.

Hot Species, Hot Spots, and Hot Moments

A paper commissioned by the committee in support of its work notes that there have been a number of recent efforts to identify new AIS most likely to establish populations in the Great Lakes ("hot species"), as well as locations that may be particularly susceptible to such AIS introductions ("hot spots") (Vander Zanden 2007 and references therein). The paper also discusses the concept of "hot moments," or windows of opportunity, when introductions are most likely to occur.

Efforts to identify hot species have used risk assessment methods, together with information on invasion corridors,[12] vectors, patterns of invasion, environmental match between donor and recipient regions, and other factors likely to affect the probability of successful introduction. Although such efforts are widely acknowledged to have limitations, they have had at least one notable success. *Hemimysis anomala* was identified as having a high risk of introduction into the Great Lakes several years before its discovery in Lakes Michigan and Ontario in 2006 (Ricciardi and Rasmussen 1998; Grigorovich, Colautti, et al. 2003).

The concept of hot spots appears to have attracted less attention than that of hot species. However, areas with high concentrations of new AIS, as well as invasion "cold spots," have been reported (Grigorovich, Korniushin, et al. 2003), indicating that some locations within the Great Lakes ecosystem are seemingly more susceptible to invasion than others.

[12] An invasion corridor is a physical conduit over or through which a series of species moves en route from a common origin to a common destination.

Possible Effects of Climate Change

Biological responses to climate change are complex and difficult to predict. In addition to changes in the occurrence and distribution of current resident species in the Great Lakes, changes are expected in the survival rates of new AIS. As a result of the higher water temperatures arising from climate change, northward movements of warm water species and the extirpation of cooler water species are anticipated. Warmer water temperatures may also speed rates of growth and development, increasing the possibility that minimum viable populations of AIS will establish before the onset of unfavorable winter conditions (see, for example, Millerd 2007; Great Lakes Water Quality Board 2003; Kling et al. 2003).

CONCLUDING REMARKS

Ships' ballast water has historically been the major vector for AIS introductions into the Great Lakes since the opening of the seaway in 1959, and during the ensuing period of almost 50 years it has accounted for 55 to 70 percent of reported AIS introductions from all sources. Current evidence indicates that the hull fouling vector has played a very minor role in introducing AIS into the freshwater ecosystem of the Great Lakes. Eliminating AIS introductions by vessels transiting the seaway would have an important impact on the AIS problem in the Great Lakes but would not eliminate all further AIS introductions.

A number of high-profile AIS introductions, such as that of the zebra mussel, have had major economic and ecological impacts on the Great Lakes region and have been extensively studied. Other AIS introductions are less readily observable or less widespread and are often less well characterized.

The interpretation of historical trends in AIS introductions is challenging because of the variable time lags between the introduction and reporting of a new AIS and the variable levels of investigator interest, both over time and across taxa. Thus, linking observed trends to measures aimed at preventing further introductions is complicated. In seeking to eliminate further ship-vectored AIS introductions through the seaway, as required by the committee's task, the continuously changing nature of both invasion pathways and the Great Lakes ecosystem must be recognized. Thus, adaptive elimination strategies will likely be needed to respond to the ever-changing threat of AIS introductions.

REFERENCES

Abbreviations

IMO	International Maritime Organization
NRC	National Research Council

Dobbs, F. C., and A. Rogerson. 2005. Ridding Ships' Ballast Water of Microorganisms. *Environmental Science and Technology,* Vol. 39, June 15, pp. 259–264.

Drake, J. M., and D. M. Lodge. 2007. Hull Fouling Is a Risk Factor for Intercontinental Species Exchange in Aquatic Ecosystems. *Aquatic Invasions,* Vol. 2, No. 2, pp. 127–137.

Drake, L. A., M. A. Doblin, and F. C. Dobbs. 2007. Potential Microbial Bioinvasions via Ships' Ballast Water, Sediment and Biofilm. *Marine Pollution Bulletin,* Vol. 55, pp. 333–341.

Edlund, M. B., C. M. Taylor, C. L. Schelske, and E. F. Stoermer. 2000. *Thalassiosira baltica* (Grunow) Ostenfeld (Bacillariophyta), a New Exotic Species in the Great Lakes. *Canadian Journal of Fisheries and Aquatic Sciences,* Vol. 57, pp. 610–615.

Elsayed, E., M. Faisal, M. Thomas, G. Whelan, W. Batts, and J. Winton. 2006. Isolation of Viral Haemorrhagic Septicaemia Virus from Muskellunge, Esox Masquinongy (Mitchell), in Lake St. Clair, USA Reveals a New Sublineage of the North American Genotype. *Journal of Fish Diseases,* Vol. 29, pp. 611–619.

Fenchel, T. 2003. Biogeography for Bacteria. *Science,* Vol. 301, Aug. 15, pp. 925–926.

Finlay, B. J. 2002. Global Dispersal of Free-Living Microbial Eukaryote Species. *Science,* Vol. 296, May 10, pp. 1061–1063.

Fisheries and Oceans Canada. n.d. National Aquatic Animal Health Program—FAQs, Viral Hemorrhagic Septicemia (VHS) in Various Great Lakes Fish Species. www.dfo-mpo.gc.ca/science/aquaculture/aah/VHS_FAQ_e.htm.

Gollasch, S. 2002. The Importance of Ship Hull Fouling as a Vector of Species Introductions into the North Sea. *Biofouling,* Vol. 18, No. 2, pp. 105–121.

Gollasch, S., M. David, M. Voigt, E. Dragsund, C. Hewitt, and Y. Fukuyo. 2007. Critical Review of the IMO International Convention on the Management of Ships' Ballast Water and Sediments. *Harmful Algae,* Vol. 6, pp. 585–600.

Great Lakes Water Quality Board. 2003. *Climate Change and Water Quality in the Great Lakes Basin.* Report to the International Joint Commission, Aug.

Grigorovich, I. A., R. I. Colautti, E. L. Mills, K. Holeck, A. G. Ballert, and H. J. MacIsaac. 2003. Ballast-Mediated Animal Introductions in the Laurentian Great Lakes: Retrospective and Prospective Analyses. *Canadian Journal of Fisheries and Aquatic Sciences,* Vol. 60, pp. 740–756.

Grigorovich, I. A., A. V. Korniushin, D. K. Gray, I. C. Duggan, R. I. Colautti, and H. J. MacIsaac. 2003. Lake Superior: An Invasion Coldspot? *Hydrobiologia,* Vol. 499, pp. 191–210.

Hecky, R. E., R. E. H. Smith, D. R. Barton, S. J. Guildford, W. D. Taylor, M. N. Charlton, and T. Howell. 2004. The Near Shore Phosphorus Shunt: A Consequence of Ecosystem Engineering by Dreissenids in the Laurentian Great Lakes. *Canadian Journal of Fisheries and Aquatic Sciences,* Vol. 61, pp. 1285–1293.

Holeck, K., E. L. Mills, H. J. MacIsaac, M. Dochoda, R. I. Colautti, and A. Ricciardi. 2004. Bridging Troubled Waters: Understanding Links Between Biological Invasions, Transoceanic Shipping, and Other Entry Vectors in the Laurentian Great Lakes. *BioScience,* Vol. 10, pp. 919–929.

Horvath, T. G., R. L. Whitman, and L. L. Last. 2001. Establishment of Two Invasive Crustaceans (Copepoda: Harpacicoida) in the Nearshore Sands of Lake Michigan. *Canadian Journal of Fisheries and Aquatic Sciences,* Vol. 58, pp. 1261–1264.

IMO. 2004. *International Convention for the Control and Management of Ships' Ballast Water and Sediments.* London, United Kingdom.

Kelly, D. W. 2007. *Vectors and Pathways for Nonindigenous Aquatic Species in the Great Lakes.* Landcare Research, Dunedin, New Zealand, June.

Kelly, D. W., and J. Kazumi. 2007. *Retroactive Evaluation of International Maritime Organization Ballast Water Standards.* Landcare Research, Dunedin, New Zealand, and University of Miami, Fla., Sept.

Kling, G. W., K. Hayhoe, L. B. Johnson, J. J. Magnuson, S. Polasky, S. K. Robinson, B. J. Schuter, M. M. Wander, D. J. Wuebbles, D. R. Zak, R. I. Lindroth, S. C. Moser, and M. L. Wilson. 2003. *Confronting Climate Change in the Great Lakes Region: Impacts on Our Communities and Ecosystems.* Union of Concerned Scientists, Cambridge, Mass., and Ecological Society of America, Washington, D.C. www.ucsusa.org/greatlakes.

Lake Carriers' Association. 2007. *Enact Voluntary Measures: U.S.-Flag Lakers to Combat Spread of Fish Virus.* Cleveland, Ohio, March 23.

Lake Superior Magazine. 2007. Isle Royale National Park Prohibits Untreated Ballast Water Release. www.lakesuperior.com/news/070918.html.

Lee, C. E. 2002. Evolutionary Genetics of Invasive Species. *Trends in Ecology and Evolution,* Vol. 17, No. 8, Aug., pp. 386–391.

Lovell, S. J., and S. F. Stone. 2005. *The Economic Impacts of Aquatic Invasive Species: A Review of the Literature.* Working Paper 05-02. U.S. Environmental Protection Agency, National Center for Environmental Economics, Washington, D.C., Jan. yosemite.epa.gov/EE/epa/eed.nsf/ec2c5e0aaed27ec385256b330056025c/0ad7644c390503e385256f8900633987/$FILE/2005-02.pdf.

Martiny, J. B. H., B. J. M. Bohannan, J. H. Brown, R. K. Colwell, J. A. Fuhrman, J. L. Green, M. C. Horner-Devine, M. Kane, J. A. Krumins, C. R. Kuske, P. J. Morin, S. Naeem, L. Ovreas, A.-L. Reysenbach, V. H. Smith, and J. T. Staley. 2006. Microbial Biogeography: Putting Microorganisms on the Map. *Nature Reviews Microbiology,* Vol. 4, No. 2, Feb., pp. 102–112.

Mazak, E. J., H. J. MacIsaac, M. R. Servos, and R. Hesslein. 1997. Influence of Feeding Habits on Organochlorine Contaminant Accumulation in Waterfowl on the Great Lakes. *Ecological Applications,* Vol. 7, pp. 1133–1143.

Millerd, F. 2007. *Global Climate Change and Great Lakes International Shipping.* Wilfrid Laurier University, Waterloo, Ontario, Canada, May.

Mills, E. L., J. H. Leach, J. T. Carlton, and C. L. Secor. 1993. Exotic Species in the Great Lakes: A History of Biotic Crises and Anthropogenic Introductions. *Journal of Great Lakes Research,* Vol. 19, pp. 1–54.

Nicholls, K., and H. J. MacIsaac. 2004. Euryhaline, Sand-Dwelling, Testate Rhizopods in the Great Lakes. *Journal of Great Lakes Research,* Vol. 30, pp. 123–132.

NRC. 1996. *Stemming the Tide: Controlling Introductions of Nonindigenous Species by Ships' Ballast Water.* National Academy Press, Washington, D.C.

Ricciardi, A. 2006. Patterns of Invasion in the Laurentian Great Lakes in Relation to Changes in Vector Activity. *Diversity and Distributions,* Vol. 12, pp. 425–433.

Ricciardi, A., and H. J. MacIsaac. 2008. The Book That Began Invasion Ecology. Charles Elton's 50-Year-Old Text on Invasion Ecology Is Now Cited More Than Ever. *Nature,* Vol. 652, p. 34.

Ricciardi, A., and J. B. Rasmussen. 1998. Predicting the Identity and Impact of Future Biological Invaders: A Priority for Aquatic Resource Management. *Canadian Journal of Fisheries and Aquatic Sciences,* Vol. 55, pp. 1759–1765.

Ruiz, G. M., T. K. Rawlings, F. C. Dobbs, L. A. Drake, T. Mullady, A. Huq, and R. R. Colwell. 2000. Global Spread of Microorganisms by Ships. *Nature,* Vol. 208, Nov., pp. 49–50.

U.S. Department of Agriculture. 2006. *Viral Hemorrhagic Septicemia in the Great Lakes Region.* Animal and Plant Inspection Service, Aug.

U.S. Geological Survey. n.d. Great Lakes Science Center Invasive Species Program. www.glsc.usgs.gov.

Vanderploeg, H. A., T. F. Nalepa, D. J. Jude, E. L. Mills, K. T. Holeck, J. R. Liebig, I. A. Grigorovich, and H. Ojaveer. 2002. Dispersal and Emerging Ecological Impacts of Ponto-Caspian Species in the Laurentian Great Lakes. *Canadian Journal of Fisheries and Aquatic Sciences,* Vol. 59, pp. 1209–1228.

Vander Zanden, M. J. 2007. *Surveillance and Control of Aquatic Invasive Species in the Great Lakes.* University of Wisconsin, Madison, June.

Whelan, G. E. 2007. Viral Hemorrhagic Septicemia (VHS) Briefing Paper. Michigan Department of Natural Resources. www.michigan.gov/documents/dnr/Viral-Hemorrhagic-Septicemia-Fact-Sheet-11-9-2006_178081_7.pdf.

Wonham, M. J., and J. T. Carlton. 2005. Trends in Marine Biological Invasions at Local and Regional Scales: The Northeast Pacific Ocean as a Model System. *Biological Invasions,* Vol. 7, pp. 369–392.

4
The Ballast Water Vector

As discussed in the preceding chapter, ships' ballast water has been identified as the leading vector for recorded introductions of aquatic invasive species (AIS) into the Great Lakes since the opening of the St. Lawrence Seaway in 1959. Thus, the characteristics of the ballast water vector, including the amount of ballast water carried by a vessel, the provenance of that ballast water, and details of the vessel's ballasting operations, are important items to be considered in seeking to eliminate further AIS introductions.

This chapter describes the three categories used by the committee to group the vessels transiting the seaway: transoceanic, coastal, and inland. The characteristics of these three vessel fleets and of typical vessels in each are then described briefly. The section on vessel operations explains the terminology used to describe a vessel's ballast condition and then discusses typical ballasting patterns for each of the vessel categories and current understanding of the associated risks of AIS introduction. The chapter concludes with a description of current measures aimed at preventing further introductions of AIS into the Great Lakes by vessels transiting the seaway.

VESSELS TRANSITING THE SEAWAY

Vessels transiting the St. Lawrence Seaway are frequently assigned to one of two categories: ocean vessels, sometimes referred to as "salties," which are involved in international trade with countries outside of North America; and "lakers," all of which operate within the Great Lakes St. Lawrence Seaway (GLSLS) system (see Figure 2-1) and some of which also operate within Canadian and U.S. coastal waters.[1] For the purposes of this report, however, the committee deemed it more appropriate to group vessels transiting the seaway according to their voyage patterns and associated risk of introducing AIS into the Great Lakes through their ballasting operations. Consequently, it considered three categories of vessel transiting the seaway:

- *Transoceanic vessels* enter the GLSLS system after operating outside of the Canadian and U.S. exclusive economic zones (EEZs). Transoceanic vessels currently operating into the Great Lakes are all foreign-flagged.
- *Coastal vessels* operate within the continental EEZ (i.e., not more than 200 nautical miles from shore) before entering the GLSLS system. Vessels currently operating in coastal trade are predominantly Canadian-flagged and capable of performing transoceanic voyages but restrict their trade to coastal areas for commercial reasons. Foreign-flagged vessels also participate in this coastal trade on an occasional basis.
- *Inland vessels* are Canadian- or U.S.-flagged vessels certified to operate solely within the inland waters of the GLSLS system, which extend as far eastward as Anticosti Island in the Gulf of St. Lawrence.[2]

Thus, transoceanic vessels, as defined here, correspond to the ocean vessel category used in the seaway traffic reports[3] (and elsewhere), while the coastal and inland vessels correspond to the laker category used in the traffic reports. Subdividing the laker category into two groups is important both in examining the risks of AIS introduction posed by different vessels and in considering oppor-

[1] The U.S.-flagged domestic lakes fleet comprises approximately 60 vessels, mostly bulk freighters, the majority of which are too large to transit the Welland Canal. Hence, these vessels trade exclusively on Lakes Erie, Huron, Michigan, and Superior, carrying iron ore and coal for domestic steel production, coal for electric power generation, and limestone for cement manufacturers. The smaller units of this fleet may transit the seaway on an occasional basis.

[2] A few of these vessels are permitted to make occasional summer voyages further into the Gulf of St. Lawrence (i.e., into coastal waters) under strict limitations imposed by the flag administration.

[3] The seaway traffic reports are available on the GLSLS system's website (www.greatlakes-seaway.com).

tunities for and constraints on ballast water management to reduce these risks. However, the coastal and inland components cannot be readily extracted from the reported laker traffic.

The definition of coastal vessels used in this report is a catchall covering all vessels that (*a*) enter the GLSLS system after trading within the continental EEZ and (*b*) do not fall under the definitions of either transoceanic or inland vessels. Hence, this definition may not be related to the definitions used in either Canadian or U.S. regulations.

FLEET AND VESSEL CHARACTERISTICS

Transoceanic Vessels

The fleet of transoceanic vessels currently using the seaway is flagged in more than 30 foreign countries (i.e., excluding Canada and the United States). The majority of these vessels belong to a stable, core group of vessels purpose-built for the trade and operating on regular runs into the Great Lakes every navigation season (liner trades). If cargo demand dictates, these vessels make multiple entries into the Great Lakes through the seaway during a single navigation season. The balance of the transoceanic fleet is made up of tramp vessels, either on single voyages into the Great Lakes or chartered in periodically by the liner operators to satisfy demand.

The size of the transoceanic fleet, and particularly the tramp component, can fluctuate considerably from year to year. The fluctuations reflect not only variations in Great Lakes trade, notably grain exports and steel imports, but also changes in trading opportunities elsewhere in the world and variations in charter rates for ocean vessels. Since the introduction of Lakes-max oceangoing bulk carriers[4] in the early 1980s, the typical fleet size has ranged

[4] The term "Lakes-max" describes a subset of handy-size bulk carriers that have been designed to optimize cargo carriage within the constraints of the seaway's lock dimensions and draft restrictions. Initially designed on a 10:1 length-to-breadth ratio similar to maximum-size inland vessels, the latest vessels are built to a lesser ratio that is more compatible with the stresses imposed on a ship's hull in ocean trade.

from 200 to 300 vessels annually (Colautti et al. 2003). Over the past 5 years (2003–2007), the number of inbound transoceanic vessels entering the seaway each navigation season has averaged 233, with a low of 214 and a high of 260.[5, 6]

The transoceanic fleet using the seaway comprises three distinct groups of vessels. Large dry bulk carriers carrying imports of steel and raw materials and grain exports predominate. Smaller dry bulk and project cargo carriers carry imports of manufactured goods unsuitable for container shipment, such as turbines and ancillary equipment for wind energy farms being developed in New York, Wisconsin, and Ontario, as well as other processed steel products, and exports ranging from fabricated assemblies to bulk grain. Finally, chemical tankers carry imports and exports of bulk liquid chemicals in parcels, rum, liquid fertilizers, animal fats, and vegetable oils.

The cargo-carrying capacities of these ships range from as little as 2,500 deadweight tonnes (DWT) up to 38,300 DWT, with the majority of vessels being bulk carriers in the range of 20,000 to 38,000 DWT. Within the restricted depths of the seaway, the larger ships are limited to less than 30,000 DWT. Their water ballast–carrying capacities range from 1,200 to 24,500 cubic meters.

The transoceanic fleet servicing the Great Lakes is constantly evolving technically to maximize performance given the vagaries of the system. Included in this technical evolution have been changes in design and outfitting of ballast systems to enable more thorough evacuation of ballast tanks. While the oldest vessels, built in the early 1980s, are nearing the end of their useful service life, more than 50 modern ships built specifically for the Great Lakes trade have

[5] Personal communication to Phil Jenkins, committee member, from the St. Lawrence Seaway Management Corporation, January 2008.

[6] It is important to distinguish between the numbers of transoceanic vessels entering the Great Lakes through the seaway each navigation season and the numbers of inbound vessel transits recorded in the seaway traffic reports. Because some vessels make multiple entries during any given navigation season, the number of vessels is less than the number of inbound vessel transits. A transoceanic vessel carries a risk of introducing new invaders each time it enters the Great Lakes, so the number of inbound vessel transits is often used in discussing AIS introductions. However, when the installation of shipboard equipment aimed at preventing such introductions (ballast water treatment or monitoring systems, for example) is considered, the number of vessels is clearly the more relevant figure.

been introduced into service since 2000. Companies dedicated to serving the Great Lakes operate these ships on both owned and chartered bases and enter them into the trade as cargo demands dictate.

Coastal Vessels

The Canadian domestic fleet using the GLSLS system comprises almost 70 vessels. While all these vessels are recorded as lakers in the seaway traffic data, there is a subset of more than 20 vessels that trade beyond the inland waters of the GLSLS system and are more properly described as coastal. These vessels can service the eastern seaboard of the North American continent, from Nunavut in the north to Florida in the south, and in many respects are a microcosm of the entire trade through the seaway. The dry cargo vessels range from Lakes-max self-unloading bulk carriers and gearless bulk carriers to smaller geared bulk carriers and project cargo vessels, with cargo-carrying capacities from 3,000 to 39,000 DWT and ballast capacities from 2,000 to 25,000 cubic meters. Ten oil tankers ranging from 9,500 to 21,000 DWT also operate regularly in coastal trade, and another four or five similar-sized foreign-flagged tankers are chartered into the trade under a flag waiver by the major oil companies during periods of peak demand for fuel and heating oils. In addition, while a number of the Canadian tankers are classed to carry both oil and chemicals, Canada lacks the capacity to train officers for specialized cargo trades and thus to man these ships for chemical carriage. Consequently, domestic movements of bulk liquid chemicals are made through the seaway by foreign-flagged chemical tankers chartered in under the same flag waiver conditions.

The committee's charge addresses specifically AIS introductions by "vessels transiting the St. Lawrence Seaway." However, Canadian dry cargo vessels operating between Montreal (a freshwater port) and Newfoundland and tankers operating between Saint John, New Brunswick, and Montreal could transfer AIS between coastal waters and the freshwater Great Lakes ecosystem, even though they do not enter the Montreal–Lake Ontario (MLO) section of the seaway.

Inland Vessels

The remaining domestic GLSLS fleet, excluding the coastal vessels described above, comprises 43 vessels or tug–barge units that are capable of transiting the seaway locks but are restricted by their design scantling[7] from proceeding beyond the limits of Canadian inland waters (east of Anticosti Island). These vessels are primarily dry bulk carriers, the majority of which are self-unloaders ranging in capacity from 16,000 to 36,000 DWT with ballast capacities of 10,000 to 20,000 cubic meters. The self-unloading vessels, 30 in number, are both operationally and environmentally efficient carriers capable of delivering cargoes to locations with little port infrastructure as noted in Chapter 2, yet having sufficient flexibility to be used in the coal, iron ore, potash, aggregates, salt, and grain trades. Two of the barge units and a further small bulk carrier are specialized carriers of bulk cement with the capability to both load and self-unload the material without any dust release into the local environment. In addition, 16 gearless bulk carriers are used primarily in the export grain transshipment trade. These vessels backhaul iron ore for part of their return passage from the grain transfer elevators on the lower St. Lawrence River to those on the upper lakes.

By ocean-shipping standards, the inland fleet is elderly, with the older vessels built in the 1960s and the last completely new vessel delivered in 1985. It is, however, a fleet best described as a work in progress, since life extension is a specialty of the Great Lakes shipping industry. Such life extension is possible because the vessels operate for the most part in a relatively benign freshwater environment, as opposed to a saltwater ocean environment, and the winter layup of almost 3 months provides an opportunity for extensive steel replacements and major machinery replacements without a forced withdrawal from commercial service. Replacement of the complete forebody (the cargo-carrying section) is not unusual, and at the same time the vessel dimensions can be changed to benefit from draft and beam tolerance changes implemented by the seaway corporations. In the case of self-unloaders, cargo systems

[7] "Scantling" refers to the dimensions of the structural parts of a vessel.

can also be upgraded with the latest technology. Many older vessels in the inland fleet now include only a part of the original vessel.

VESSEL OPERATIONS

Ballast Condition

Vessels carrying little or no cargo carry ballast water to compensate for shear forces on their hulls and to achieve the longitudinal, transverse, and directional stability necessary for safe operation. Whether navigating in confined waters where precise steering is needed or in the open ocean where maintaining steerage in all sea and swell conditions is imperative, adequate submergence of the hull, and particularly the propeller(s) and rudder(s), is of paramount importance. Traditionally, a vessel may be identified as being in one of three ballast conditions.[8] A vessel that is not carrying any cargo and that has water in its ballast tanks is described as being in ballast. A vessel operating with some cargo and some ballast is described as being with ballast. And a vessel fully laden with cargo and with only unpumpable residual water and sediment in its ballast tanks may be described as having no ballast on board and is frequently referred to as a NOBOB.

In the context of efforts to prevent further AIS introductions into the Great Lakes, a distinction has historically been made between vessels in ballast or with ballast that are able, in principle, to exchange the water in their ballast tanks with ocean water during the course of a voyage and NOBOBs that are unable to conduct such ballast water exchange (BWE, see Box 4-1 on pages 78–79) because their ballast tanks contain only unpumpable residual water and sediment (see later).[9] Thus, the term BOB ("ballast on

[8] A more detailed description of ballast water and ships is provided elsewhere (NRC 1996, Chapter 2).

[9] Few ships, particularly in the dry bulk cargo trade that predominates on the Great Lakes, are capable of evacuating their ballast tanks completely during the course of a deballasting/cargo loading cycle (Jenkins 2007). A survey of NOBOB vessels on the Great Lakes indicated that the volume of unpumpable residual water and sediment in their ballast tanks averaged 60 cubic meters per vessel (Bailey et al. 2003).

board") is often used to distinguish vessels in ballast or with ballast from those in NOBOB condition.

As discussed later in this chapter, both ballasted vessels and NOBOBs can introduce AIS into the Great Lakes through their ballasting operations. Whereas AIS introductions by ballasted vessels have been reported in many countries, AIS introductions by NOBOBs are largely confined to the Great Lakes (Jenkins 2007). Thus, some brief comments about the term NOBOB are appropriate in the present context.

Many ships entering the seaway laden with cargo carry small amounts of ballast to attain the necessary trim[10] and to meet the air draft limitations posed by bridges and power lines in various locations throughout the GLSLS system. In addition, a number of project cargo vessels have entered the Great Lakes in recent years carrying large windmill components manufactured in Europe and destined for wind farms in the Great Lakes region and beyond. Carriage of these large and sometimes unwieldy components often requires a vessel to carry a limited amount of ballast water to counterbalance irregular cargo stowage and to achieve the necessary stability. These groups of vessels are not strictly NOBOBs because they carry some ballast, albeit a limited amount. From an AIS perspective, however, they are essentially NOBOB vessels that cannot conduct BWE and have to be treated accordingly for the purposes of ballast water management and inspection (see later).

In seeking to prevent AIS introductions into the Great Lakes, an incoming vessel's NOBOB status needs to be determined at Quebec City, where fresh and tidal waters merge, as opposed to where the vessel enters the MLO section of the seaway. Inbound vessels entering the St. Lambert Lock above Montreal may already have called at one of the freshwater ports on the Saguenay River or on the St. Lawrence River between Quebec City and Montreal to discharge some or all of their cargo. Of particular concern are vessels that enter the GLSLS system fully laden with cargo and discharge all this cargo at one of the freshwater ports, where they take on

[10] A vessel's trim is defined as the difference between its after and forward drafts.

freshwater ballast before transiting the seaway and entering the Great Lakes. Although such vessels are BOBs when they transit the seaway, they have to be inspected and treated as NOBOBs because they entered the freshwater part of the GLSLS system with no ballast on board.

As the above discussion indicates, a simple "BOB" or "NOBOB" designation may be convenient in some cases. However, for the purposes of preventing further AIS introductions into the Great Lakes, it is important to have more detailed information about a vessel's ballast condition and to understand practical constraints on its ballasting capabilities and the associated implications for managing its ballast water. Inspection protocols for vessels entering the GLSLS system take account of these complexities (see later).

Typical Ballasting Patterns and Associated Risks of AIS Introduction

Transoceanic Vessels

Efforts to prevent further ballast-mediated AIS introductions into the Great Lakes focused initially on transoceanic vessels carrying ballast. Ballast water loaded by these vessels in regions outside of the Great Lakes entrains viable freshwater species that are often discharged during cargo loading in Great Lakes ports and may result in AIS introductions. Before the introduction of Canada's Voluntary Ballast Water Exchange Program for ships entering the Great Lakes in 1989 and the subsequent implementation of ballast water management regulations by the U.S. Coast Guard in 1993, transoceanic vessels entered the GLSLS system loaded with fresh, brackish, or marine ballast water probably taken on board at one or more overseas ports of departure. These vessels entered the Great Lakes primarily to collect grain from the export terminals in Toledo, Chicago, Milwaukee, Duluth, or Thunder Bay, where they would discharge their ballast water—and AIS contained therein. It is almost certain that such notorious invaders as zebra mussels (*Dreissena polymorpha*), quagga mussels (*D. rostriformis bugensis*), and round gobies (*Neogobius melanostomus*) were introduced in freshwater ballast of a BOB vessel, since these species are not tolerant of saline water and do not produce viable resting stages, such as cysts, that could tolerate saline conditions.

Because the ballast tanks of NOBOBs contain only unpumpable residual water and sediment, these vessels were not initially identified as a possible vector for AIS introductions. However, the ongoing discovery of new AIS in the Great Lakes after the implementation of the ballast exchange regime (see later) drew attention to the role of NOBOBs in introducing AIS (Aquatic Sciences, Inc., et al. 1996).

Since the early 1980s, the numbers of NOBOB vessels entering the GLSLS system have been increasing steadily. Such vessels currently make up the vast majority of transoceanic vessels entering the system, with only a small percentage of vessels entering in ballast. Colautti et al. (2003) estimated that the number of vessel entries in ballast made up approximately 10 percent of inbound traffic to the Great Lakes during the 1990s. The trend for relatively few transoceanic vessels entering in ballast appears to be continuing, with 54 (10.3 percent) of the 523 inbound vessel transits through the MLO section of the seaway during the 2005 navigation season being in full ballast condition and 64 (9.5 percent) out of 676 inbound transits in ballast in 2006.[11] Today, most transoceanic vessels enter the GLSLS system fully laden with import cargoes and report NOBOB status.

A majority of the NOBOB vessels visit multiple ports while traveling upstream, discharging cargo and loading Great Lakes ballast water to maintain safe operating parameters (see Figure 4-1).[12] This water mixes with the residual water in the ballast tanks, and at a final destination port in the Great Lakes—typically Thunder Bay or Duluth–Superior—the combined solution is discharged when outbound cargo (grain) is loaded. Unless preventive measures

[11] Data from Great Lakes St. Lawrence Seaway Traffic Reports at www.greatlakes-seaway.com.

[12] Figure 4-1 shows a typical transit of a transoceanic NOBOB vessel on the Great Lakes, as reported by Colautti et al. (2003). The vessel illustrated made three stops inbound to off-load cargo before heading to Duluth–Superior to load grain; other vessels may stop only once or twice before heading to Duluth–Superior or Thunder Bay.

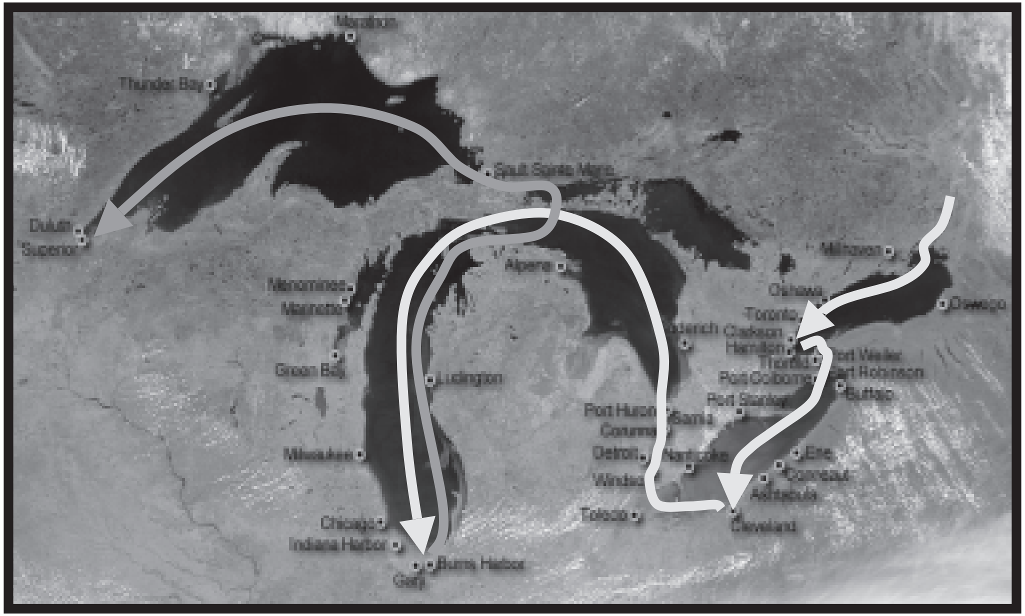

FIGURE 4-1 **Typical transit of a transoceanic NOBOB vessel on the Great Lakes. The inbound leg includes stops in Hamilton, Cleveland, and Burns Harbor, where cargo is discharged and Great Lakes ballast water loaded. This water mixes with residual water of fresh, brackish, or saline origin in the vessel's ballast tanks. The vessel terminates the inbound leg of its voyage with a trip to Lake Superior, where the mixed ballast water is discharged (together with surviving species from the residual ballast) when outbound cargo is loaded in Duluth–Superior.**

are taken, this discharged water may contain AIS that were present in the vessel's ballast tanks when it entered the Great Lakes. In addition, once Great Lakes water is added to ballast tanks, resting stages of AIS contained in ballast sediments may be stimulated to hatch and may eventually be discharged into the lakes with ballast water (Bailey et al. 2005).

Coastal Vessels

Vessels that are engaged in North American coastal trade and that transit the seaway originate primarily from east coast areas of the United States and Canada. These vessels may enter the Great Lakes in either ballasted (BOB) or nonballasted (NOBOB) condition. There does not appear to be any particular or regular pattern to this trade, which is predicated on prevailing market conditions. Cargoes include liquid and dry bulk fertilizer from the southeast United States, gypsum from and feed grain to Nova Scotia, and feedstock and refined petroleum products in either direction. The same tanker fleet services the industry requirements both in the Great Lakes and in the Canadian Maritimes, and trade to the east coast through the seaway system is more a case of providing a cargo to position a ship than a purely commercial venture. Tankers servicing the Great Lakes refineries of Sarnia and Nanticoke in Ontario tend to supply product as far east as Sept Isles, while tankers servicing the refineries in Dartmouth, Nova Scotia, and Saint John, New Brunswick, tend to deliver product as far west as Montreal.

The irregularity of the coastal trade could, however, change dramatically as a result of the current emphasis on short-sea shipping as a means of bypassing congestion on land-based routes and modes and related incentive programs being offered by the seaway corporations. In addition, the development of container feeder trade between the Canadian Maritimes and Lake Ontario could greatly alter the nature of the coastal trade, as noted in Chapter 2.

Until recently, AIS introductions vectored by vessels transiting the seaway were attributed exclusively to transoceanic vessels. However, the amphipod *Gammarus tigrinus,* which is found in coastal marine waters on the east coast of North America, is an AIS in the Great Lakes. This species was likely introduced in ballast water from the Gulf of St. Lawrence, although genetic analysis cannot preclude the Hudson or Elizabeth River estuaries in the United States (Kelly et al. 2006). The viral hemorrhagic septicemia virus is also found in coastal marine waters on the east coast of North America and, while its invasive status in the Great Lakes is debatable, a number of possible vectors of introduction, including ballast water, have been identified (see Chapter 3). At present insufficient information exists to resolve these possibilities.

The ballasting histories of coastal vessels entering the Great Lakes and the numbers of such vessels are only now being explored, so the associated risks of introduction are not well understood. Nonetheless, invasion biologists and other experts have cautioned that the risk of AIS introductions posed by coastal vessels should not be ignored and that appropriate prevention measures should be implemented without further delay (see, for example, Reid et al. 2007).

Inland Vessels

The dry bulk vessels of the inland fleet that transit the MLO section of the seaway downbound generally do so with grain cargoes destined for the transshipment elevators at Montreal, Sorel, Trois Rivieres, Quebec City, Port Cartier, and Baie Comeau. Once that cargo is discharged, these vessels may proceed in ballast to one of the iron ore loading ports on the north shore of the lower St. Lawrence River (Port Cartier or Sept Isles) or to a bulk ore/coal transshipment dock in or above Quebec City to load for their journey back into the lakes. Alternatively, they may proceed in ballast directly back through the seaway to load at another lakes port. Hence, they may return through the seaway into the Great Lakes with fresh, brackish, or saltwater ballast or residuals in their ballast tanks.

These inland vessel operations within the GLSLS system are thought to play a role in distributing AIS already present in the system, although reliable scientific evidence to support this hypothesis is lacking. An ongoing study at the University of Windsor is assembling a database on laker movements, including volumes of cargo (and ballast water) loaded and unloaded at various locations throughout the GLSLS system, to explore and elucidate possible mechanisms by which AIS may be distributed by inland vessels.

CURRENT MEASURES TO PREVENT AIS INTRODUCTIONS INTO THE GREAT LAKES

Current measures aimed at preventing further introductions of AIS into the Great Lakes by vessels transiting the seaway focus on ships' ballast water as the leading invasion vector. The following discussion summarizes these measures and identifies the ballast water management requirements for the three categories of vessel transiting the seaway (transoceanic, coastal, and inland). Inspection and enforcement measures to ensure compliance with the various rules and regulations are then outlined.

Bodies Issuing Rules and Regulations

Rules and regulations specifying ballast water management requirements for vessels entering the GLSLS system are issued by the Canadian and U.S. federal governments and by the joint Seaway Authorities comprising the Canadian St. Lawrence Seaway Management Corporation (SLSMC) and the U.S. St. Lawrence Seaway Development Corporation (SLSDC).

In Canada, the Ballast Water Control and Management Regulations issued pursuant to the Canada Shipping Act of 2006 aim to protect waters under Canadian jurisdiction from nonindigenous aquatic organisms and pathogens that can be harmful to ecosystems.[13] In the United States, the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 directed the U.S. Coast Guard to issue regulations to prevent the introduction and spread of aquatic nuisance species into the Great Lakes through the ballast water of vessels and establish civil and criminal penalties for violating these regulations. Mandatory requirements for ballast water

[13] TP 13617 E, A Guide to Canada's Ballast Water Control and Management Regulations, is available on the Transport Canada website (www.tc.gc.ca).

management for the Great Lakes went into effect in 1993 (33 CFR 151). In addition, Section 30 (2) of the Seaway Practices and Procedures issued jointly by the Seaway Authorities specifies ballast water management practices with which vessels must comply before being granted clearance to transit the seaway.[14]

In contrast to the situation in Canada, where the federal government has sole jurisdiction over all matters dealing with shipping, individual U.S. states may choose to establish their own ballast water legislation to supplement federal regulations. Michigan is currently the only Great Lakes state to have taken such action, although others are considering following suit. Following the passage of state legislation in 2005, vessels coming from outside the GLSLS system and engaging in port operations in Michigan are now required to comply with the state's ballast water control requirements.[15]

Current Ballast Water Management Requirements

The ballast water management techniques (BWE, saltwater flushing, shipboard treatment, and shore-based treatment) specified in the various rules and regulations discussed below are described briefly in Box 4-1.

Canadian regulations require vessels coming from outside the Canadian EEZ (i.e., transoceanic vessels and coastal vessels coming from the U.S. EEZ) to use, either separately or in combination, the following ballast water management measures:

1. Exchange of ballast water or saltwater flushing of ballast tank residuals,
2. Shipboard treatment of ballast water using an accepted technology option,
3. Discharge of ballast water to a shore-based reception facility, or
4. Retention of ballast water on board the ship.[16]

---

[14] The Seaway Practices and Procedures are available on the GLSLS system website (www.greatlakes-seaway.com).

[15] Further information is available on the Michigan Department of Environmental Quality website (www.michigan.gov/deq).

[16] These ballast water management requirements apply to all vessels entering waters under Canadian jurisdiction, with a few exceptions. They are not limited to vessels entering the GLSLS system.

BOX 4-1

Ballast Water Management Techniques

Ballast Water Exchange

BWE involves replacing (exchanging) a vessel's ballast water with ocean water. There are two principal methods of exchange: reballasting and dilution. The reballasting or empty-refill method involves emptying and then refilling a ballast tank, whereas the dilution or flow-through method admits water to the tank at the same time as water is discharged. In either case, BWE has two major effects on biota in ballast tanks. First, because BWE involves replacing 95 to 99 percent of water in the tanks, an equal percentage of organisms is removed by the dilution effect, assuming a homogeneous distribution of flora and fauna. In some cases, populations of some species may be completely purged or rendered low enough that recovery and establishment are not likely once any remaining organisms are released. Second, BWE may involve replacing freshwater ballast with open ocean water (saltwater), resulting in osmotic stress for most freshwater organisms resident in the tank. Consequently, BWE conducted by vessels moving between European freshwater ports and the Great Lakes is expected to reduce both the abundance and diversity of freshwater life dramatically. In situ studies of invertebrates in ships traveling between the Great Lakes and Europe illustrated that BWE sharply reduced both diversity and abundance of freshwater invertebrates in ballast tanks (Gray et al. 2007).

Saltwater Flushing

NOBOB vessels are unable to conduct BWE because their ballast tanks contain only unpumpable residual water and sediments. The alternative to BWE for NOBOBs is saltwater flushing, which is accomplished by allowing a limited amount of saltwater to slosh around in an individual ballast tank as a result of the ship's rolling and pitching motion during passage (Reid et al. 2007). This agitation resuspends trapped sediments and provides a salinity shock to biota, which are then discharged into the open ocean. Thus, saltwater flushing pro-

(*continued*)

vides the dual effects of dilution and salinity shock that are achieved with BWE, but it applies them to empty (NOBOB) tanks. Both BWE and saltwater flushing techniques are currently used by vessels operating into the Great Lakes.

Shipboard Ballast Water Treatment

The use of shipboard systems to kill AIS in ballast water is widely viewed as offering greater operational flexibility than either BWE or saltwater flushing, as well as the potential for greater effectiveness. A variety of proven water treatment technologies are available, but adapting them for shipboard application presents major technical challenges (see, for example, NRC 1996). However, important progress has been made in recent years, largely in response to the International Maritime Organization's proposed ballast water management requirements (IMO 2004), and shipboard ballast water treatment systems are expected to become commercially available by 2009 (*Lloyd's Register* 2007). Some prototype systems have been installed on operational vessels, at least three of which are trading into the GLSLS system, but shipboard ballast water treatment is not currently a proven method of ballast water management in an operational environment.

Shore-Based Ballast Water Treatment

Shore-based ballast water treatment avoids some of the challenges associated with shipboard application of water treatment methods. However, bulk handling of ballast water from a ship to a shore-based facility is complex. In addition, the economics of shore-based ballast water treatment facilities have been identified as problematic by a number of authors (see, for example, NRC 1996). There are currently no shore-based ballast water treatment facilities available to vessels operating on the GLSLS system, although Wisconsin recently announced that the state will spend US$6 million to invest in experimental shore-based ballast water treatment systems for its Great Lakes ports (Egan 2008).

For Option 1, transoceanic vessels are required to conduct mid-ocean BWE during ballast-laden voyages in an area 200 nautical miles from any shore and in water 2,000 meters deep whenever possible, before entering waters under Canadian jurisdiction. Transoceanic NOBOB vessels are required to conduct saltwater flushing in similar areas on their passage to the Great Lakes to eliminate fresh or brackish water residuals in their ballast tanks. Coastal vessels must comply with similar requirements, except that BWE or saltwater flushing is to be conducted in an area at least 50 nautical miles from shore where the water depth is at least 500 meters.[17]

U.S. regulations require that all vessels entering U.S. waters in ballast after operating outside the U.S. EEZ manage their ballast water by undertaking mid-ocean BWE, retaining their ballast water on board, or using an alternative environmentally sound method of ballast water management preapproved by the U.S. Coast Guard. In the case of coastal vessels coming from the Canadian EEZ that elect to manage their ballast water by BWE, this process is to be conducted within designated exchange areas. Since August 2005, NOBOBs entering U.S. waters have been strongly encouraged, but not required, to conduct saltwater flushing before entering the Great Lakes. From the beginning of the 2008 navigation season, however, the seaway regulations require all transoceanic NOBOB vessels to conduct saltwater flushing before entering the Great Lakes, regardless of whether their destination is a U.S. or Canadian port.[18] U.S. regulations also require that every vessel equipped with ballast tanks that operates in U.S. waters and is bound for ports or places in the United States comply with a suite of management practices designed to minimize the quantity of aquatic organisms it may be carrying (33 CFR 151.2035, Subpart D).

[17] Under certain circumstances, vessels may also conduct BWE or saltwater flushing in designated exchange zones within the Canadian EEZ.

[18] A notice of proposed rulemaking issued by the SLSDC (2007) aimed to harmonize U.S. and Canadian requirements for saltwater flushing by transoceanic vessels operating in the binational waters of the GLSLS system. In February 2008, the Seaway Practices and Procedures were updated to include the saltwater flushing requirement for transoceanic NOBOB vessels.

The carriage of vessel-specific ballast water management plans and compliance with mandatory record-keeping and reporting regimes are also required by both Canada and the United States.

In addition, the Seaway Practices and Procedures mandate that every vessel entering the seaway after operating beyond the EEZ (i.e., all transoceanic vessels) must agree to respect the Shipping Federation of Canada's *Code of Best Practices for Ballast Water Management* (2000) while operating anywhere within the Great Lakes and the seaway. Every other vessel entering the seaway (i.e., coastal and inland vessels) 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* (Lake Carriers' Association and Canadian Shipowners Association 2001) while operating anywhere within the Great Lakes and the seaway.

Table 4-1 summarizes current ballast water management requirements for the three categories of vessel transiting the seaway (transoceanic, coastal, and inland). In addition to these requirements, vessels engaging in port operations in Michigan that have operated beyond the mouth of the St. Lawrence River are required to purchase a permit from the Michigan Department of Environmental Quality (MDEQ). This permit applies to vessels that either engage in port operations and do not discharge ballast water or discharge ballast water treated by a method approved by MDEQ.[19]

Inspection and Enforcement Procedures

In January 2006, the agencies that inspect, test, and monitor the ballast water of vessels entering the GLSLS system—Transport

[19] There is a $75 application fee for the certificate of coverage under the general permit and a $150 annual renewal fee. The certificate of coverage under the general permit is effective for 5 years. The approved treatment methods are hypochlorite treatment, chlorine dioxide treatment, ultraviolet radiation treatment preceded by suspended solids removal, and deoxygenation treatment. Vessel owners proposing an alternative treatment method may apply for an individual permit. Penalties for noncompliance with the permit range up to $25,000 per day.

TABLE 4-1 Ballast Water Management Requirements for Vessels Entering the GLSLS System

Vessel Origin	Vessel Destination	Ballast Status	Ballast Water Management Requirements
Transoceanic Vessels			
Outside Canadian and U.S. EEZ	Canadian Great Lakes ports	BOB	BWE, treatment, discharge to reception facility, or retention Code of Best Practices[a]
		NOBOB	Saltwater flushing, treatment, discharge to reception facility, or retention Code of Best Practices[a]
	U.S. Great Lakes ports	BOB	BWE, retention, or alternative preapproved environmentally sound method Code of Best Practices[a] Regulated Management Practices[b]
		NOBOB	Saltwater flushing mandatory from beginning of 2008 seaway navigation season Code of Best Practices[a] Regulated Management Practices[b]
Coastal Vessels			
Within Canadian EEZ	Canadian Great Lakes ports	BOB or NOBOB	Voluntary Management Practices[c]
	U.S. Great Lakes ports	BOB	BWE, retention, or alternative preapproved environmentally sound method Regulated[b] and Voluntary Management Practices[c]
		NOBOB	Regulated[b] and Voluntary Management Practices[c]
Within U.S. EEZ	Canadian Great Lakes ports	BOB	BWE, treatment, discharge to reception facility, or retention Voluntary Management Practices[c]
		NOBOB	Saltwater flushing, treatment, discharge to reception facility, or retention Voluntary Management Practices[c]
	U.S. Great Lakes ports	BOB or NOBOB	Regulated[b] and Voluntary Management Practices[c]

Vessel Origin	Vessel Destination	Ballast Status	Ballast Water Management Requirements
Inland Vessels			
Inland waters of GLSLS system	Canadian ports	BOB and NOBOB	Voluntary Management Practices[c]
	U.S. ports	BOB and NOBOB	Regulated[b] and Voluntary Management Practices[c]

[a] *Code of Best Practices for Ballast Water Management,* Shipping Federation of Canada, Sept. 28, 2000.
[b] 33 CFR 151.2035, Subpart D.
[c] *Voluntary Management Practices to Reduce the Transfer of Aquatic Nuisance Species Within the Great Lakes by U.S. and Canadian Domestic Shipping,* Lake Carriers' Association and Canadian Shipowners Association, Jan. 26, 2001.

Canada Marine Safety, the U.S. Coast Guard, the U.S. SLSDC, and the Canadian SLSMC—formed a U.S.–Canadian Ballast Water Working Group (BWWG). This initiative aimed to standardize commonly needed information, such as ballast water inspections, verifications, testing, sampling, reports, and data collection, and to optimize the use of available resources to ensure maximum coverage (inspection of every vessel) with no duplication of effort. BWWG has developed a standardized ballast water reporting form, developed and coordinated a memorandum of understanding signed by Transport Canada and the U.S. Coast Guard setting out procedures and parameters to conduct joint vessel exams in Montreal, and developed and implemented a standardized GLSLS System Joint Agency Ballast Water Management Inspection Report that captures each agency's inspection needs.

Every vessel entering the GLSLS system from beyond the Canadian EEZ is subject to inspection to ensure that the salinity of the ballast, or ballast residuals, in its tanks is greater than or equal to 30 ppt. Highly trained and experienced inspectors follow a strict inspection protocol, prioritized on the basis of risk, that aims to cover all vessels without causing unnecessary delays to shipping. In the case of such vessels discharging their entire import cargo at a Quebec freshwater port outside the seaway and indicating their intention to enter the GLSLS system, every attempt is made to conduct an inspection before the vessel takes river ballast on board so that the residual salinity can be determined. (As noted earlier, these latter vessels need to be treated as NOBOBs, even though they are carrying ballast when they transit the seaway.)

Ballasted vessels that do not conduct open-ocean BWE before entering the St. Lawrence Seaway may be required either to return to sea to conduct BWE or to retain their ballast water on board for their entire voyage through the Great Lakes. In the latter case, a letter of retention is placed aboard. When the vessel later departs the system, the relevant ballast tank or tanks are inspected to ensure compliance with the retention requirement and the letter of retention is removed. A similar procedure is followed for noncompliant ballast tanks on NOBOBs. In 2006, the U.S. Coast Guard issued seven retention letters for vessels going to U.S. ports, and Transport Canada issued 25 retention letters for vessels going to Canadian ports (U.S. Coast Guard 2007). As noted earlier, vessels carrying project cargoes, such as wind turbines, require ballast to balance their cargo load. For these vessels, retention of ballast water on board is a far safer option than attempting to conduct BWE. A number of the letters of retention issued during the 2006 navigation season are understood to have been issued to such project cargo vessels.

For minor first-time offenses, such as discrepancies in a vessel's ballast water management plan, records, or reports, the U.S. Coast Guard issues a letter of warning. In Canada, letters of correction are used to instruct a ship's operator to correct such discrepancies. Information on letters of warning and correction issued in 2006 has been published by the U.S. Coast Guard (2007). Both Canada and the United States have strict systems of fines as additional penalties for failure to comply with ballast water management regulations.

CONCLUDING REMARKS

Vessels transiting the seaway may be grouped into three categories (transoceanic, coastal, and inland) on the basis of their voyage patterns and associated risks of introducing AIS into the Great Lakes through their ballasting operations. Ballast water has historically been the predominant vector for ship-vectored AIS introductions into the Great Lakes since the opening of the seaway in 1959, and current ballast water management regulations aim to prevent further such introductions.

As of the beginning of the 2008 navigation season, all transoceanic vessels transiting the seaway are required to conduct BWE (ballasted vessels) or saltwater flushing (NOBOBs) in an effort to prevent further ballast-mediated AIS introductions into the Great Lakes. These measures, if rigorously applied, are expected to reduce considerably further AIS introductions by transoceanic vessels. However, coastal vessels also carry a risk of introducing AIS through their ballasting operations, and not all such vessels are currently required to conduct either BWE or saltwater flushing. Ballasted vessels (BOBs) are required to conduct BWE only if they move from one jurisdiction to another (U.S. to Canadian waters, or vice versa), and NOBOBs are required to conduct saltwater flushing only if their voyage takes them from within the U.S. EEZ to a Canadian Great Lakes port.

REFERENCES

Abbreviations

IMO	International Maritime Organization
NRC	National Research Council
SLSDC	St. Lawrence Seaway Development Corporation

Aquatic Sciences, Inc., Philip T. Jenkins and Associates, Ltd., and RNT Consulting. 1996. *Examination of Aquatic Nuisance Species Introductions to the Great Lakes Through Commercial Shipping Ballast Water and Assessment of Control Options Phase I & Phase II.* Canadian Coast Guard.

Bailey, S. A., C. D. A. van Overdijk, P. Jenkins, and H. J. MacIsaac. 2003. Viability of Invertebrate Resting Stages Collected from Residual Ballast Sediment of Transoceanic Vessels. *Limnology and Oceanography,* Vol. 48, pp. 1701–1710.

Bailey, S. A., K. Nandakumar, I. C. Duggan, C. D. A. van Overdijk, T. H. Johengen, D. F. Reid, and H. J. MacIsaac. 2005. *In Situ* Hatching of Invertebrate Diapausing Eggs from Ships' Ballast Sediment. *Diversity and Distributions,* Vol. 11, pp. 453–460.

Colautti, R. I., A. J. Niimi, C. D. A. van Overdijk, E. L. Mills, K. Holeck, and H. J. MacIsaac. 2003. Spatial and Temporal Analysis of Transoceanic Shipping Vectors to the Great Lakes. In *Invasive Species: Vectors and Management Strategies* (G. M. Ruiz and J. T. Carlton, eds.), Island Press, pp. 227–246.

Egan, D. 2008. City's Port to Clean Ballast. *Milwaukee Journal Sentinel,* Jan. 17.

Gray, D. K., T. H. Johengen, D. F. Reid, and H. J. MacIsaac. 2007. Efficacy of Open-Ocean Ballast Water Exchange as a Means of Preventing Invasions Between Freshwater Ports. *Limnology and Oceanography,* Vol. 52, No. 6, pp. 2386–2397.

IMO. 2004. *International Convention for the Control and Management of Ships' Ballast Water and Sediments.* London, United Kingdom.

Jenkins, P. T. 2007. *Brine as a Treatment Solution for the Control of Aquatic Nuisance Species Introductions into the Great Lakes by NOBOB Vessels.* Prepared for Transport Canada Marine Safety by Philip T. Jenkins and Associates, Ltd., Fonthill, Ontario.

Kelly, D. W., J. Muirhead, D. D. Heath, and H. J. MacIsaac. 2006. Contrasting Patterns in Genetic Diversity Following Multiple Invasions of Fresh and Brackish Waters. *Molecular Ecology,* Vol. 15, pp. 3641–3653.

Lake Carriers' Association and Canadian Shipowners Association. 2001. *Voluntary Management Practices to Reduce the Transfer of Aquatic Nuisance Species Within the Great Lakes by U.S. and Canadian Domestic Shipping.* Jan. 26.

Lloyd's Register. 2007. Ballast Water Treatment Technology: Current Status. June.

NRC. 1996. *Stemming the Tide: Controlling Introductions of Nonindigenous Species by Ships' Ballast Water.* National Academy Press, Washington, D.C.

Reid, D. F., T. H. Joehengen, H. MacIsaac, F. Dobbs, M. Doblin, L. Drake, G. Ruiz, and P. Jenkins. 2007. *Identifying, Verifying, and Establishing Options for Best Management Practices for NOBOB Vessels.* Final report to the Great Lakes Protection Fund. www.glerl.noaa.gov/res/Task_rpts/2004/aisreid04-1.html.

Shipping Federation of Canada. 2000. *Code of Best Practices for Ballast Water Management.* Sept. 28.

SLSDC. 2007. Seaway Regulations and Rules: Periodic Update, Various Categories. Notice of Proposed Rulemaking. *Federal Register,* Vol. 72, No. 249, Dec. 31, pp. 74247–74250.

U.S. Coast Guard. 2007. *2006 Summary of Great Lakes Ballast Water Management Exams.* Ninth District.

5

Identifying and Exploring Options for the Great Lakes Region: The Committee's Approach

As noted in Chapter 1, the two project criteria to be met by future options for the Great Lakes region differ in nature and scope. The requirement to enhance the potential for global trade is a broad mandate with no specific directives. In contrast, the requirement to eliminate further introductions of aquatic invasive species (AIS) into the Great Lakes by vessels transiting the St. Lawrence Seaway is absolute and narrow, addressing a specific vector (shipping) and a single route into the Great Lakes (the seaway).

The requirement to eliminate further introductions has two other noteworthy features. First, the term "vessels" without any qualifier required the committee to consider all three categories of vessel transiting the seaway: transoceanic, coastal, and inland (see Chapter 4). Second, vessels can introduce AIS not only through their ballasting operations but also via hull fouling. As discussed in Chapter 3, current evidence suggests that the importance of the ballast water vector far outweighs that of the hull fouling vector for AIS introductions into the freshwater ecosystem of the Great Lakes. Nonetheless, a better understanding of the role of hull fouling is needed to help ensure the elimination of further AIS introductions by shipping through the seaway.

This chapter describes the process used by the committee to identify candidate actions to meet one or the other (or possibly both) of the two project criteria. It then discusses the strengths and weaknesses of the individual candidates. In assessing the strengths and weaknesses, the committee took account of the requirement specified in its task statement that the recommended options for the Great Lakes region be "practical and technically feasible." The chapter ends with the committee's conclusion about the possibility of establishing a suite of actions that would both enhance the potential for trade and eliminate further ship-vectored AIS introductions.

IDENTIFYING CANDIDATE ACTIONS

As a first step in identifying and exploring options for the Great Lakes region, the committee developed preliminary lists of actions that could meet or contribute to meeting one or the other (or possibly both) of the two criteria. The preliminary lists drew on information obtained by the committee during its meetings and field trips (see Appendix A), draft versions of the expert papers commissioned by the committee and discussions with the authors (see Appendix B), examination of the literature, and the expertise of individual committee members. The strengths, weaknesses, unknowns, and uncertainties associated with each candidate action were identified, and the lists of actions were developed further during a "brainstorming" session at the public meeting hosted by the committee in Toronto in May 2007 (see Appendix C). The resulting candidate actions to enhance the potential for global trade and to eliminate further AIS introductions are listed in Boxes 5-1 and 5-2, respectively.

The inclusion of a candidate action in Box 5-1 or 5-2 does not necessarily indicate that the committee viewed it as promising or endorsed the proposed approach. The intent at this initial stage was to capture a wide range of ideas and not to limit the investigation of candidate actions to those already being pursued. By engaging the authors of the commissioned papers, stakeholders, and the public in the process of identifying candidate actions, the committee sought to expand the list of possibilities beyond the status quo—while recognizing that some background knowledge of the issues is a

BOX 5-1

Candidate Actions to Enhance the Potential for Global Trade

Invest in Transportation Infrastructure

- Develop binational strategy to finance seaway capital maintenance and renovation
- Establish new saltwater ports to handle transshipment throughout the Great Lakes region

Develop an Array of Transportation Options

- Facilitate short-sea shipping
- Expand use of ships into the Great Lakes heartland
- Encourage more holistic treatment across all modes of transport
- Enhance intermodal service for bulk commodities
- Enhance intermodal service for containers

Foster an Environment Conducive to Economic Development and Trade

- Develop a binational guarantee that the seaway will remain open
- Encourage greater collaboration among ports within the Great Lakes St. Lawrence Seaway (GLSLS) system
- Build on bonding authority of ports
- Market freshwater assets of Great Lakes region in economic development strategies

Account for the External Costs of Transportation

- Provide transition assistance to shippers
- Charge for externalities

prerequisite to suggesting actions that are practical and technically feasible.

The candidate actions listed in Boxes 5-1 and 5-2 are broad in scope and variable in their level of detail. Some of the underlying concepts have already been applied in different contexts (e.g., posting of bond and testing for compliance), whereas others are relatively unknown, at least in practice (e.g., charging for externalities). The committee gave due consideration to all the candidates listed,

BOX 5-2

Candidate Actions to Eliminate Further Introductions

Exploit Ballast Water Management Technologies

- Require mandatory ballast water exchange or flushing with automated reporting
- Install shipboard ballast water treatment systems
- Implement design changes for new ships to enhance ballast water management
- Develop portable modular ballast water treatment system
- Provide shore-based ballast water treatment options
- Treat ballast water as it is handled (loaded or discharged)

Adopt Ballast Water Management Regulations, Including Standards

- Adopt International Maritime Organization (IMO) ballast water standards for vessels entering the Great Lakes in advance of ratification of IMO convention
- Adopt ballast water standards more stringent than those of IMO
- Adopt ballast water standards more stringent than those of IMO, with voluntary phase-in period
- Implement tiered system of ballast water permits
- Regulate ballast water discharges in a manner consistent with the U.S. Clean Water Act

Enforce Regulations and Standards

- Require posting of bond and testing for compliance
- Engage major shippers in requiring compliance with prevention measures

Monitor Progress and Plan Ahead

- Implement surveillance, control, and rapid response capabilities
- Accelerate research and development on role of hull fouling as a vector for introductions

Coordinate Prevention Efforts

- Coordinate state and provincial actions to prevent introductions
- Adopt unified binational approach to IMO convention: Canada has indicated its intention to ratify, and the United States should follow suit

- Harmonize U.S. and Canadian regulations such that both nations require saltwater flushing by ships with no ballast on board
- Be cognizant of different political mechanisms for implementing policies

Involve Stakeholders
- Encourage environmental initiatives by the shipping industry
- Involve all Great Lakes users and beneficiaries in seeking solutions
- Encourage self-regulation by carriers and shippers

Assign Liability
- Encourage litigation under tort law
- Require carriers, shippers, and receivers to have "invasive species insurance"

Close the Seaway
- Introduce a moratorium on ocean vessels entering the Great Lakes until protective standards are in place
- Close the seaway to transoceanic shipping
- Close the seaway to all inbound vessel traffic

drawing wherever possible on reports about candidate actions that are already being investigated or implemented. The two following sections summarize the candidate actions to enhance the potential for trade and eliminate further ship-vectored AIS introductions and discuss their potential strengths and weaknesses. Areas of uncertainty and unknowns are noted, and any potential roadblocks are highlighted.

CANDIDATE ACTIONS TO ENHANCE THE POTENTIAL FOR GLOBAL TRADE

Economic development and ensuing trade are influenced by myriad forces. Some of these forces arise from government policies with regard to fiscal, monetary, and trade issues that affect expectations among entrepreneurs who risk capital to profit from trade. Policies related to tariffs and quotas have particular relevance to trade, as do the policies and practices of the public and private institutions needed to execute trade-related functions, such as customs agencies and customs brokers. Efficient transportation infrastructure and services are also important to economic development and trade.

The discussion by Cangelosi and Mays (2006) of key drivers and influences for transoceanic waterborne trade activity in the GLSLS system illustrates how actions related to the global economy and financial system can influence trade in the Great Lakes region. Examples include the introduction or removal of U.S. steel tariffs, stipulations by the European Union concerning genetically modified crops, increases in oil prices, rapid growth in development activities in China, and mergers of companies to form larger and more powerful global organizations.

Given the focus of the current project—namely, the seaway as a transportation route into the Great Lakes for both trade and AIS—the committee did not consider examination of the full range of actions potentially capable of enhancing the Great Lakes region's trade to be within the scope of its charge. Instead, as dictated by the overall study context and objective, it focused primarily on transportation-related actions for meeting the requirement to enhance the potential for global trade.

This section summarizes candidate actions that may meet or contribute to meeting the first project criterion, namely, enhance the potential for global trade in the Great Lakes region (Box 5-1). To facilitate the discussion, the candidates have been grouped into four categories:

- Invest in transportation infrastructure.
- Develop an array of transportation options.
- Foster an environment conducive to economic development and trade.
- Account for the external costs of transportation.

Invest in Transportation Infrastructure

Investments in transportation infrastructure can enhance trade by reducing transportation costs. Thus, investing in the seaway infrastructure and in Atlantic ports could be a means of enhancing the Great Lakes region's potential for global trade.

The seaway infrastructure has reached or exceeded its design life, and major renovations will be needed in coming years if service reliability is to be maintained. Absent such renovations, the decline in reliability could well lead to an associated decline in trade through the seaway. Developing a binational strategy to finance the seaway's capital maintenance and renovation could, therefore, contribute to enhancing the Great Lakes region's potential for global trade by removing an anticipated impediment to such trade. As discussed in Chapter 2, ongoing maintenance and long-term capital expenditures needed through 2050 to ensure the continuing reliability of the GLSLS system have been estimated at more than $2 billion (Transport Canada et al. 2007). However, given the difficulties experienced in the past in forecasting seaway traffic (see Chapter 2), the impact of a major renovation project on seaway trade is difficult to quantify with any confidence.

The expected growth in trade (notably container trade) from South Asia to North America through the Suez Canal and across the Atlantic Ocean has led to examination of opportunities to expand port capacity along the northern range of Atlantic ports. The development of a new saltwater port in Sydney, Nova Scotia, is one option under consideration. Such port expansion and development could well increase the potential for global trade in the Great Lakes region and enhance opportunities to develop feeder services (see later).

These candidate actions involving investment in transportation infrastructure are major and expensive projects that would take many years to complete. While renovation of the seaway infrastructure and development of a new saltwater port in Sydney, Nova Scotia, are both under consideration, it remains to be seen whether these projects will be judged to have economic merit and whether the necessary funding will be available.

Develop an Array of Transportation Options

Facilitate Short-Sea Shipping and Expand Use of Ships into Great Lakes Heartland

There is already considerable domestic short-sea shipping of both liquid and dry bulk cargoes within the GLSLS system. Because the seaway serves the industrial and agricultural heartland of North America, it could be used as a route for transshipping goods from saltwater ports on the east coast of North America to inland ports. Such transshipment would expand the use of ships into the Great Lakes heartland and might include container feeder services between deepwater transoceanic ports on the eastern seaboard and Great Lakes ports, such as Hamilton, Ontario.

Realizing new short-sea shipping services is seriously handicapped by a number of Canadian and U.S. government policies, including the U.S. Harbor Maintenance Tax, customs regulations, a 25 percent Canadian import duty on vessels for domestic use built outside of Canada, and pilotage and cabotage rules. However, the governments of both Canada and the United States are exploring issues related to short-sea shipping, which is viewed by many as offering a safe and sustainable alternative to increasingly congested land-based modes, notably highways.[1]

While some containerized cargoes have been shipped on the seaway, containers currently account for less than 0.01 percent of total annual cargo tonnage through the Montreal–Lake Ontario (MLO) section. The degree to which containerized traffic will grow in the future is unclear. On the one hand, the GLSLS system is operating at only about 50 percent of capacity and could provide an alterna-

[1] In 2003, Canada and the United States signed a Memorandum of Cooperation on Sharing Short-Sea Shipping Information and Experience, and in 2006, the U.S. Maritime Administration and Transport Canada jointly sponsored the North American Short-Sea Shipping Conference in Vancouver, Canada. At this meeting, Canada, the United States, and Mexico signed a trilateral declaration committing the three nations to expand marine highway operations in North America by establishing a steering committee focused on the creation of a trilateral strategy.

tive to some increasingly congested land-based corridors (Transport Canada et al. 2007). On the other hand, water-based modes are, in general, a slower means of transporting goods than land-based modes, and seaway-based container feeder services could have difficulty overcoming this time penalty. The seasonal nature of the seaway navigation system could also be a major disadvantage, since shippers and receivers would need to stockpile inventories of relatively high-value containerized cargoes or find alternative means of moving goods during the seaway's winter closure.

Enhance Intermodal Services and Encourage More Holistic Treatment Across All Modes

Enhancing intermodal services for goods moving on the seaway could add to the Great Lakes region's potential for global trade by offsetting the adverse impacts of policies aimed at preventing further ship-vectored AIS introductions. Such services would require improved integration of different transportation modes, as discussed in a recent report on the future of the GLSLS system (Transport Canada et al. 2007).

Intermodal transportation service for bulk commodities of the types that often move on the seaway could be enhanced on certain rail routes with spare capacity. Government-guaranteed loans, subsidized interest rates, or outright capital grants for intermodal facilities could be provided to improve rail access for shippers now dependent on the seaway. Loans or tax credits might be provided to railroads or shippers to purchase additional hopper cars to move bulk commodities by rail. Investments in more efficient transshipment facilities to move bulk commodities between modes could be part of the overall effort. The initiative would be designed to meet the "but for" test; that is, but for the government assistance a market demand would not be met. Loan guarantees and interest rate subsidies would be preferred since they would require risk sharing by carriers, who would not act in the absence of expected demand.

Intermodal transportation services for containers could be enhanced through use of the same financial mechanisms and through promotion of intermodal service from the east coast of North America to the Great Lakes region by either water or rail.

The committee was unable to obtain a clear picture of the extent to which there is unused rail capacity in the region of the GLSLS system. Some experts suggest that the rail network in northeastern North America is not facing any capacity constraints, at least for nonpriority freight. Others confirm this view but note that logistical issues, such as a lack of spare rolling stock, could limit opportunities to shift cargoes from water to rail. Yet others indicate that there are capacity constraints and bottlenecks in certain areas, such as around Chicago. Thus, there may well be opportunities for some shifting of cargoes from water to rail as part of a strategy to enhance intermodal transportation services, but the extent to which such shifts are feasible is unclear.

The financial assistance mechanisms proposed are familiar to governments but may not be attractive. In Canada, government assistance mechanisms have been strenuously avoided in the transportation sector, where subsidies that distort modal selection are generally viewed as undesirable. Applying such strategies in one region of Canada (the Great Lakes) and not others would also be problematic. Nonetheless, the seaway is already subsidized by the Canadian and U.S. governments, which provide funds for capital improvement projects and maintenance (see Chapter 2). In the case of intermodal services, however, the market may well stimulate development without the need for government assistance, particularly in the case of container movements, which are expected to grow considerably.

Foster an Environment Conducive to Economic Development and Trade

Role of Ports

Encouraging greater collaboration among ports within the GLSLS system is a possible approach to enhancing the Great Lakes region's potential for global trade. While some ports may compete for cargoes, different ports serve different hinterlands to a large extent.

Hence, collaborative efforts to encourage use of the GLSLS system could benefit the region's trade without compromising the competitive position of an individual port. Many Great Lakes ports are already participating in an initiative that unifies the GLSLS system of rivers, lakes, canals, locks, and ports under a single marketing brand, namely, Highway/Autoroute H2O (www.hwyh2o.com/). Through this effort, ports collaborate in encouraging use of the "marine highway" and seek to optimize its use as part of the supply chain. The extent to which these efforts will affect longer-term trends in seaway traffic is unclear, but some short-term benefits have been reported, with market developments centered on the Highway/Autoroute H2O campaign bringing in more than 500,000 tonnes of new cargo movements during the course of 2006 (GLSLS 2007).

There may also be opportunities for U.S. ports to build on their bonding authority for competitive advantage—for example, by facilitating nonmaritime development to take advantage of waterfront assets or by investing in shore-based ballast water treatment or other industrial facilities.[2] This candidate action would build on existing abilities and trends, such as the development of waterfront housing, retail outlets, and office buildings.[3] While such development can bring economic benefits, it could also result in more constituencies opposed to port operations and a resulting loss of trade. In addition, the economic feasibility of shore-based ballast water treatment facilities has been widely questioned (see later discussion), indicating that such facilities could constitute a risky investment.

Develop Binational Guarantee That Seaway Will Remain Open

Developing a binational (Canadian and U.S.) guarantee that the seaway will remain open to vessels complying with ballast water management regulations could help stimulate several seaway-dependent, economy-enhancing initiatives within the Great Lakes

---

[2] Because Canadian ports do not have bonding authority, the option of using this authority for competitive advantage is available only to U.S. ports.

[3] Specific examples of development projects already funded by ports in the Great Lakes region (Cleveland and Toledo) are cited by Cangelosi and Mays (2006).

region, such as developing new feeder services to deepwater container ports, enhancing trade in bulk commodities and specialized cargoes, and encouraging cruise ship operations associated with ecotourism. While it is not clear which, if any, of these ventures will prosper, all depend on unhindered shipping via the seaway. The current uncertainties about what regulations will be promulgated, by whom, and when, and even about whether the seaway may be closed to some categories of vessels, make it difficult for shipping companies to generate the investment capital needed to expand their capabilities and thereby catalyze economic development within the Great Lakes region.

The proposed guarantee could be particularly important in encouraging shipping companies that operate regular services into the Great Lakes to invest in new vessels designed to optimize shipboard management of ballast water and sediments. Thus, it could be a valuable component of a suite of actions to prevent further ship-vectored AIS introductions and enhance the potential for global trade.

Market Freshwater Assets in Economic Development Strategies

Given that drinking water is an increasingly precious commodity, it has been suggested that the Great Lakes region could market its freshwater assets in various economic development strategies.[4] For example, a report from the Brookings Institution observes that the Great Lakes and its waterways offer "a tremendous opportunity for reinvigorating the economy of the region," while other regions face long-term sustainability challenges arising from lack of water, among other factors (Austin et al. 2007, 10). The report envisages new technologies and industries built around an environmentally improved Great Lakes region. In the absence of specifics about such economic development strategies, the committee was unable to reach any conclusions about the strengths and weaknesses of this candidate action or its likely impacts on the Great Lakes region's potential for global trade.

[4] This candidate action would not involve exporting freshwater to other regions.

Account for the External Costs of Transportation

Transportation services, such as shipping lines, railroads, and motor carriers, impose external costs on society as a result of their environmental impacts, including emissions, habitat degradation, introductions of invasive species, congestion, risk of accidents, and noise. While some organizations are choosing to change their actions in response to these detrimental effects on the environment, special measures are needed to address the issue of externalities in a consistent, rational, and comprehensive fashion. For example, laws or regulations may require particular actions or impose costs on polluters consistent with the costs they impose on society. Quantifying environmental effects as a basis for such laws or regulations remains problematic, however (see TRB 1996).

Provide Transition Assistance to Shippers

Shipping companies are likely to incur additional costs in ensuring that their vessels take measures to prevent further AIS introductions into the Great Lakes. These costs may take various forms, such as capital and operating costs associated with shipboard ballast water treatment systems,[5] added time per voyage if additional port procedures are necessary, and opportunity costs if less cargo can be loaded. It is difficult to generalize about the effects of such costs on voyage profitability. In some instances, shipping companies may be able to pass the additional costs on to customers in the form of higher freight rates. In other instances, competition from other modes of transportation may preclude this option, and the additional costs may have to be absorbed by the shipping company. Under the latter scenario, some shipping companies might decide to cease operations into the Great Lakes altogether to avoid the costs of complying with requirements to treat ballast water on board ship. The resulting loss of competition could lead to increased freight rates for cargo carried on vessels transiting the

---

[5] A recent report from *Lloyd's Register* (2007) tentatively estimates the cost of a 200-m^3/h plant at \$135,000 to \$165,000, with operating costs ranging from \$0.01 to \$0.35 per cubic meter of treated water.

seaway, as well as reduced service to certain ports. An increase in the cost of shipping goods via the seaway would put steel companies, grain exporters, and other shippers at a competitive disadvantage, as would service reductions. This competitive disadvantage could result in some companies moving their facilities (and associated jobs) to locations outside of the Great Lakes region. To avoid such losses, financial assistance could be provided to shippers during a transitional period to help them adjust to the higher transportation costs. If water service were reduced to certain shippers, for example, assistance could take the form of subsidizing rail rates to facilitate the shift from ship to rail.

The proposed transition assistance strategy could help mitigate the possible loss of manufacturing and other facilities, and associated jobs, from the Great Lakes region. However, such subsidies could run afoul of the World Trade Organization, would be difficult and potentially costly to administer, and could be difficult to terminate once established. Also, fair compensation could be difficult to establish, since the differential between water and rail rates is commercially sensitive information and not widely available. Moreover, a transportation subsidy that distorts modal selection would be unlikely to find favor in Canada.

Charge for Externalities

The case of shipowners incurring additional costs to ensure that their vessels do not introduce AIS into the Great Lakes is an example of the far broader issue of the external costs associated with transportation services. To encourage trade with the least environmental impact, society could charge for such externalities by requiring carriers to internalize their external costs. This strategy, which could include the elimination of subsidies where they exist, would result in fairer competition among the different modes and in commerce that reflects true environmental costs. However, it would increase the costs of transportation, and as a result it would not enhance the potential for global trade.

In the committee's judgment, the above strategies for taking account of the external costs of transportation are unlikely to enhance the Great Lakes region's potential for global trade. However, if a global user-pay system were to be established, the Great Lakes region might benefit because the availability of water transportation could result in a lower overall incidence of environmental costs. Thus, the region could enjoy a relative trade advantage over some other regions.

Concluding Remarks

Various aspects of Great Lakes regional economic development, including opportunities to enhance global trade, are already being explored by many highly qualified individuals and organizations in government, the private sector, and academia. For example, Canada's National Policy Framework for Strategic Gateways and Corridors aims to enhance the competitiveness of the Canadian economy in the rapidly changing field of global commerce.[6] The two seaway corporations and Great Lakes ports undertake trade development functions aimed at enhancing use of the GLSLS system (Highway/Autoroute H2O), and entrepreneurs in the private sector are exploring new opportunities to develop transportation services linked to the seaway. And the aforementioned report from the Brookings Institution explores the broader regional economic benefits of restoring the Great Lakes ecosystem (Austin et al. 2007). Thus, it is not surprising that most of the candidate actions listed in Box 5-1 are already under investigation.

In a number of instances, the future outcomes of the candidate actions are uncertain and are difficult to forecast with any confidence—for example, the growth of container shipping on the GLSLS system. Nonetheless, if commercial opportunities arise, the market may well respond without the need for government action, as in the example of developing improved intermodal transportation services.

The efficiency of transportation infrastructure, including that of the seaway and of the GLSLS system's ports and harbors, is

[6] Development of the Ontario–Quebec Continental Gateway and Trade Corridor will not only examine global markets and trade opportunities for Canada but also address issues linked to transportation, including protection of the environment (Transport Canada 2007).

important for trade. Thus, candidate actions involving infrastructure renewal and development may well enhance the potential for global trade, particularly in the longer term. The two cases examined—developing a binational strategy to finance seaway capital maintenance and renovation and establishing a new saltwater port to handle transshipment throughout the Great Lakes region—would both require major financial investments and many years to bring to fruition.

Expanding the use of ships into the Great Lakes heartland through the facilitation of short-sea shipping appears to be a promising candidate, although detailed recommendations about the implementation of this strategy would require further investigation of policy issues that are beyond the scope of the committee's work. For example, analysis of any of the policy impediments to short-sea shipping—customs duties, import duties on vessels, the U.S. Harbor Maintenance Tax, pilotage and cabotage rules—would be a substantial undertaking requiring specialized knowledge and expertise.

The committee concluded that there are few new and promising transportation-related opportunities to enhance the Great Lakes region's potential for global trade over and above the candidate actions already under consideration. It did, however, identify one promising new approach to reducing impediments to global trade—developing a binational guarantee that the seaway will remain open to shipping. Whether such action would be compatible with actions to prevent further ship-vectored AIS introductions into the Great Lakes is discussed later.

CANDIDATE ACTIONS TO ELIMINATE FURTHER AIS INTRODUCTIONS

There are two fundamentally different approaches to eliminating further ship-vectored AIS introductions into the Great Lakes. The shipping vector can be eliminated either by removing or killing potentially invasive organisms carried by vessels or by keeping vessels that may be carrying such organisms out of the Great Lakes. The candidate actions listed in Box 5-2 build on these approaches. For example, encouraging self-regulation by carriers and shippers and requiring posting of bond and testing for compliance are both actions that could help ensure the effective implementation of technologies that kill or remove AIS in ships' ballast water. Alternatively, the threat of litigation under tort law could deter vessels from trading into the Great Lakes, thereby reducing the likelihood of further ship-vectored AIS introductions.

This section describes candidate actions listed in Box 5-2 that may meet or contribute to meeting the second project criterion: eliminate further introductions of nonindigenous aquatic species into the Great Lakes by vessels transiting the St. Lawrence Seaway. To facilitate the discussion, the candidates have been grouped into the following categories:

- Exploit ballast water management technologies;
- Adopt ballast water management regulations, including standards;
- Enforce regulations and standards;
- Monitor progress and plan ahead;
- Coordinate prevention efforts;
- Involve stakeholders;
- Assign liability; and
- Close the seaway.

Exploit Ballast Water Management Technologies

Ballast Water Exchange, Saltwater Flushing, and Shipboard Treatment Systems

Ship-based ballast water management technologies—notably ballast water exchange (BWE), saltwater flushing, and treatment (see Box 4-1)—are widely viewed as the most feasible technological approaches for preventing further introductions of AIS by ships entering the Great Lakes. The advantages and limitations of these technologies, including opportunities to enhance their effectiveness in new vessels, are discussed more fully in Chapter 6. Candidate actions using these technologies are summarized briefly here.

The proposed requirement for mandatory BWE or flushing with automated reporting would require all vessels that risk introducing AIS through their ballasting operations to conduct open-ocean BWE [in the case of ballasted vessels (BOBs)] or flush their empty ballast tanks with ocean water [in the case of vessels with no ballast on board (NOBOBs)] before entering the seaway. The salinity of water in the tanks of BOB and NOBOB vessels following BWE or flushing should be at least 30 ppt. As discussed in Chapter 4, the effects of BWE or flushing are twofold. Many freshwater organisms potentially able to flourish in the Great Lakes are killed by exposure to saltwater, and the concentrations of such organisms are greatly reduced by the dilution effects of the exchange or flushing process.

Compliance with the proposed requirement would be monitored by automated shipboard systems, with information on the vessel's Global Positioning System location, the salinity of water in its ballast tanks, and information about its ballasting operations being transmitted to the relevant authorities in advance of the vessel's entry into the GLSLS system. Noncompliant vessels would be required to take additional ballast water management measures before being granted permission to enter the seaway.

The shipping industry currently uses automated shipboard reporting systems for maintenance and insurance purposes, and the International Convention for the Safety of Life at Sea requires certain vessels to carry voyage data recorders similar to the "black boxes" carried on aircraft. Discussions with experts in marine informatics and with vendors of black box monitoring systems for ships suggest that available technologies could be readily adapted to monitor the salinity of water in ballast tanks, although current systems are not being used for this purpose. Work would be needed to optimize automated shipboard reporting systems for monitoring BWE or flushing, but such systems could be fully implemented on both existing and new vessels within the next few years without the need to develop costly new technologies. Whether the associated expenditures could be justified would depend to a large extent on the time line for the implementation of alternatives to BWE and flushing. If shipboard ballast water treatment systems and associated ballast water discharge standards render BWE or flushing redundant within a year or so, automated reporting systems of the type described would probably not be a worthwhile investment. On the other hand, if BWE or flushing is more than a short-term stopgap measure for ballast water management, automated reporting could be an attractive option.

The main weakness of the candidate action just described (mandatory BWE or flushing with automated reporting) is that the designs of current vessels limit the effectiveness of BWE and flushing in removing or killing freshwater organisms in ballast tanks. While methodologically rigorous studies have shown BWE to be highly effective in reducing the diversity and abundance of freshwater invertebrates in ballast tanks (see, for example, Gray et al. 2007), most ships were not designed to optimize exchange or flushing efficiency from a biological standpoint. Ongoing research using experimental and computational fluid dynamics methods to examine the flow behavior inside ballast tanks during flow-through BWE has highlighted potential "dead spots" where very low local flow velocities may prove problematic (Wilson et al. 2006). Changes in vessel design and modular construction methods could enhance the effectiveness of BWE and flushing and could be incorporated cost-effectively in new-builds, but such changes represent a long-term solution, given the typical 25-year lifetimes of transoceanic vessels operating into the Great Lakes. As noted in Chapter 4, the oldest vessels in the current transoceanic fleet are nearing the end of their useful service life, but more than 50 modern vessels have been introduced into service since 2000.

Ballast water treatment systems installed on board individual ships to kill a wide range of organisms in ballast water are being developed and evaluated, with commercially available systems meeting IMO specifications expected within the next year or so (see Chapter 4). Such shipboard systems would allow a vessel to treat its ballast water in transit or during normal ballasting operations. The main challenge in developing these treatment systems is to adapt proven water treatment technologies for shipboard operation. For new-builds, cost-effective incorporation of ballast water treatment systems is not expected to be a problem, but retrofitting such systems on existing vessels is likely to be technically challenging and costly in many cases (Kazumi 2007).

Portable Modular and Shore-Based Ballast Water Treatment Systems
An additional technology-based ballast water management option would be to use a modular treatment system operating on the ship's power independently of any ship function. The system would be placed on board a ship at a convenient location before it entered the seaway and removed when it was no longer needed. This option would have several advantages. Ships transiting the seaway would require only limited modifications to shipboard systems and would not have to conduct ballast water management before entering the seaway. In addition, there would be only a negligible delay in vessel transit times along the seaway. However, development of efficient and effective ballast water treatment systems that could be modularized and that could operate unsupervised would be a major technical challenge, particularly if treatment of NOBOBs as well as ballasted vessels were required.

The geography of the GLSLS system with its pinch point at the entrance to the seaway also appears to lend itself to the establishment of shore-based ballast water treatment facilities. The estimated total volume of ballast water from ships entering the seaway is relatively small, so such facilities would not need to be extensive. However, bulk handling of ballast water from a ship to a shore-based facility is complex. With few exceptions, the types of ship using the seaway lack the capability to transfer ballast ashore and would require extensive modification with commensurate expense. While this option is possible, it would not be considered attractive by the shipping industry, particularly in view of the unavoidable delays while the original ballast is removed, residuals are treated, and ballast is replaced so that the voyage can be safely resumed. In addition, the economics of shore-based ballast water treatment facilities have been identified as problematic by a number of authors (see, for example, NRC 1996). More recently, a study for Transport Canada explored the possibility of converting an existing shore-side wastewater facility at the Port of Belledune, New Brunswick, to a shore-based ballast water treatment facility to supplement shipboard ballast water management practices (PPD Technologies 2006). The authors concluded that two major problems would need to be overcome: how to load and off-load ballast water and how to finance the ongoing operation of a treatment plant on perpetual standby awaiting the few vessels that are not in compliance with current ballast water management regulations. Another recent assessment was more optimistic in its conclusions, but in this case, shore-based treatment was considered as the primary ballast water management method for transoceanic BOBs rather than as a supplement to shipboard ballast water management for noncompliant vessels (Wisconsin Department of Natural Resources 2007).

Adopt Ballast Water Management Regulations, Including Standards

The adoption of revised ballast water management regulations for vessels entering the Great Lakes has received widespread attention as a key component of efforts to prevent further ballast-mediated AIS introductions. Much of the discussion has concerned IMO's *International Convention for the Control and Management of Ships' Ballast Water and Sediments,* and in particular the proposed ballast water performance standard (IMO 2004). Whether this proposed standard is sufficiently stringent to protect the freshwater ecosystem of the Great Lakes has been the subject of much debate, and conclusive scientific evidence indicating the degree of stringency needed to protect the Great Lakes is lacking. The potential biological effectiveness and the technical feasibility of a standard more stringent than that proposed by IMO are topics for further research. Moreover, slow progress toward ratification of the convention has led to suggestions that Canada and the United States adopt ballast water standards identical to those proposed by IMO in advance of the convention's entry into force.[7] Canada has already taken this step, but the United States has not.

[7] The convention will enter into force 1 year after it has been ratified by at least 30 nations representing at least 35 percent of the world's oceangoing commercial tonnage. As of May 31, 2008, only 14 nations representing less than 4 percent of the world's tonnage had ratified the convention.

As indicated in Box 5-2, several approaches to regulating ballast water management by vessels entering the Great Lakes can be envisaged with the IMO convention as a baseline. As already noted, one option would be to restrict, before the convention enters into force, passage through the seaway to vessels equipped with treatment technologies capable of meeting the proposed IMO ballast water performance standard. Alternatively, Canada and the United States could set and implement a ballast water performance standard more stringent than that proposed by IMO. Such a standard would reflect the unique freshwater character of the Great Lakes ecosystem, and all vessels entering the Great Lakes would be required to meet the more stringent standard. A variation on this approach would involve establishing a more stringent ballast water performance standard than that proposed by IMO but with a voluntary phase-in period. In this proposal, Canada and the United States would move as rapidly as possible to ratify the IMO convention and apply its ballast water standards, but as soon as possible thereafter they would identify more stringent standards for the Great Lakes. Compliance with the more stringent standards would be voluntary, but vessels meeting them would be rewarded with significant incentives, such as reduced tolls or port charges. At some time in the future, the more stringent standards would likely become mandatory.[8]

Ballast water management regulations for the Great Lakes that are not directly related to the IMO convention have also been proposed. For example, individual states and provinces could require vessels to purchase a permit and prove that they either will not discharge ballast water in state or provincial ports or that they are equipped to treat the water to prevent the release of AIS. Michigan has already implemented such a ballast water permit requirement for transoceanic vessels calling at its ports, and other Great Lakes states are considering following suit. A variation of this approach could involve a tiered system of ballast water permits, with the du-

[8] Further discussion of the candidate actions outlined in this paragraph is provided in a paper commissioned by the committee (Hodgson 2007).

ration of the permit linked to the level of ballast water treatment the vessel could achieve. Vessels able to comply with the proposed IMO ballast water performance standard would be eligible for a 10-year permit, for example, whereas vessels able to comply with a more stringent performance standard would be granted a permit for the lifetime of the vessel.

Yet another approach—regulation of ballast water discharges under the U.S. Clean Water Act (CWA)—is currently being assessed by the U.S. Environmental Protection Agency (EPA). Ballast water discharges have been excluded from the CWA's permitting requirements since 1973, but in 1999 environmental groups petitioned EPA to repeal the ballast water exemption, claiming that the CWA prohibits discharge of pollutants, including biological materials, into U.S. waters without a permit. As a result of this and related lawsuits, EPA may be required to regulate ballast water discharges under the CWA after September 30, 2008, pending the outcome of an appeal. However, such regulation would not apply to discharges into Canadian waters and is of questionable value in protecting the binational waters of the Great Lakes. In particular, it would not prevent species discharged in Canadian waters from spreading into U.S. waters.

All the proposed approaches for adopting revised ballast water management regulations, including standards, aim to allow "environmentally responsible" vessels to continue operating on the Great Lakes while turning away vessels that are unwilling or unable to make the necessary technology investments and operational changes. One of the major challenges is to achieve this objective within the Great Lakes region's complex multijurisdictional system. While some argue that harmonization with international requirements is desirable, others argue that IMO's proposed ballast water performance standard is inadequate to protect the Great Lakes' unique freshwater ecosystem. International standards aside, it is far from clear that the diverse organizations with authority to establish ballast water management regulations affecting vessels using the Great Lakes could agree among themselves on how best to achieve the desired protection. A complex patchwork of federal, state and provincial, and local ballast water management regulations could well result, leading to reduced levels of compliance and increases in associated costs.

New ballast water regulations and standards are also important in stimulating technology development, as evidenced by the increased effort to develop shipboard treatment systems following the establishment of the proposed IMO standards in 2004. In this context, it may well be in the interests of Canada and the United States to move as quickly as possible in setting ballast water standards for the Great Lakes. In the absence of standards and the reduction of technical and market risks that they provide, the usual incentives for stimulating technology development are stymied. In particular, developers of ballast water treatment technologies are handicapped in attracting investment capital to investigate and develop new treatment systems in the absence of clearly defined requirements. This issue has been recognized by the U.S. Department of Commerce, which funds the National Oceanic and Atmospheric Administration's Ballast Water Management Demonstration Program. The purpose of this program is to create test platforms for use by technology vendors in developing new ballast water treatment systems.

Practical considerations about achievable levels of ballast water treatment and associated verification capabilities are also important in establishing ballast water standards. At present, the only available performance data for shipboard ballast water treatment systems are from trials of prototypes. Experts anticipate that data from shipboard treatment systems on vessels engaged in commercial operations will prove valuable in assessing and improving system performance. Thus, there is considerable merit in setting ballast water performance standards at technically feasible levels that will encourage operational deployment of shipboard treatment systems, thereby providing an opportunity to learn from practical experience. In addition, compliance with the standard must be verifiable with available techniques.[9] If compliance could

[9] Gollasch et al. (2007) discuss some of the issues associated with ballast water sampling to demonstrate compliance (or noncompliance) with the IMO ballast water performance standard.

not be reliably demonstrated, the usefulness of the standard would be questionable.

Enforce Regulations and Standards

Without adequate enforcement, ballast water management regulations and accompanying standards would be of limited effectiveness in preventing further ballast-mediated AIS introductions into the Great Lakes. One approach to strengthening current enforcement practices would be to require a vessel entering the seaway to post bond. Samples would also be taken from the vessel's ballast tanks and stored in a suitable repository for testing later. The sampling protocol could be based on the vessel's risk of introducing AIS, as determined by factors such as its port of origin, its ballasting history, and the "track record" of its operator. Historical data for individual vessels could also be used in the case of vessels that transit the seaway on a regular basis. Random spot checks of ballast tanks could also be conducted as part of the enforcement program. A vessel that failed the test because its ballast water did not comply with requirements would forfeit its bond.

Such a scheme would have the advantage that samples could be taken while a vessel was in a lock or awaiting lockage, so the economic impact on operations would be minimal. Even if not all vessels were tested, the possibility of forfeiture could have a strong deterrent effect if the cost of the bond were sufficiently high. A major weakness, however, would be the delay between taking ballast water samples and testing them. This delay could result in the entry of a vessel carrying high-risk ballast water into the Great Lakes before remedial action had been taken. Although the vessel would forfeit its bond, the Great Lakes ecosystem would not be protected from the risk of new AIS introductions. In addition, distinguishing viable from dead organisms is not always an easy task, and development of specific assays would be needed for successful implementation of the proposed spot checking approach.

Monitor Progress and Plan Ahead

Measures to prevent further AIS introductions into the Great Lakes could be supplemented by a surveillance program, which would focus on early detection of new invaders through targeted monitoring. Guided by assessments of environmental susceptibility and species risk, such monitoring would target specific high-risk locations and likely invaders. On detection of a new invasive species, an eradication assessment would inform decision making and guide the response to managing the invasion (eradicate or control). A surveillance program would also allow ongoing assessment of measures aimed at preventing further introductions and could inform the development of improved prevention measures.[10]

Efforts to gain a better understanding of AIS introductions into the Great Lakes—for example, the importance of the hull fouling vector (see Chapter 3) and the risks of introduction associated with vessels in coastal trade (see Chapter 4)—could also help in developing a more robust set of prevention measures.

In the committee's judgment, efforts to monitor progress in preventing further AIS introductions and investigate possible deficiencies in current prevention strategies are key components of any technology-based approach to eliminating further AIS introductions by vessels transiting the seaway.

Coordinate Prevention Efforts

As discussed in Chapter 4, rules and regulations specifying ballast water management requirements for vessels entering the GLSLS system are issued by the Canadian and U.S. federal governments and by the joint seaway authorities comprising the Canadian St. Lawrence Seaway Management Corporation and the U.S. St. Lawrence Seaway Development Corporation. Within the context of these rules and regulations, vessels may be required to comply with guidelines and codes of practice issued by industry groups, notably the Shipping Federation of Canada, the Lake Carriers' Association, and the

[10] Surveillance strategies and their benefits are discussed more fully in Chapter 6.

Canadian Shipowners Association. Thus, as Table 4-1 illustrates, the ballast water management requirements for vessels transiting the seaway are complicated and depend on a vessel's ballast status (BOB or NOBOB) and its ports of origin and destination. In addition, the state of Michigan has introduced its own ballast water management regulations, and local Great Lakes ballast water management regulations were introduced in September 2007, when the U.S. National Park Service closed Lake Superior waters within the boundaries of Isle Royale National Park to release of untreated ballast water (*Lake Superior Magazine* 2007).

Many in the shipping industry have noted that a complicated patchwork of differing federal, state and provincial, and local ballast water management regulations could well reduce levels of compliance while increasing associated costs. They have emphasized the importance of coordinating efforts to prevent further ballast-mediated AIS introductions. As noted earlier, the number of jurisdictions with authority to issue ballast water management regulations affecting vessels operating on the Great Lakes makes it difficult to establish a harmonized system of regulations, particularly in the absence of robust scientific evidence about the levels of ballast water "cleanliness" required to prevent further ship-vectored AIS introductions. The arguments in favor of a holistic approach are well known. New invaders are oblivious to national, state and provincial, and local boundaries, and they will establish new populations wherever favorable conditions occur. Because the Great Lakes are open water, species discharged in Canadian waters will spread to U.S. waters, and vice versa. Similarly, species discharged in the waters of one Great Lakes state or province will spread to the waters of other Great Lakes states and provinces without regard for any state or provincial ballast water management regulations.

Involve Stakeholders

Engaging stakeholders in efforts to prevent further AIS introductions into the Great Lakes is widely viewed as a key component of any prevention program, regardless of the vector of introduction.

For example, the “Stop Aquatic Hitchhikers” campaign has been effective in encouraging boaters and anglers to take action at water access points to prevent the spread of AIS, and the “Habitattitude” campaign has encouraged home aquarium and water garden owners to prevent the release of fish and aquatic plants into the environment.[11] The Green Marine initiative, an environmental program of the St. Lawrence and Great Lakes maritime industry, is seeking to strengthen environmental performance through a process of continuous improvement, with the establishment of performance standards and codes of conduct, as well as implementation of guidance to members and verification of adherence to agreed policies. Green Marine has identified AIS as one of its priority issues and developed a series of collective actions aimed at reducing the risk of introducing and propagating aquatic organisms and harmful pathogens by means of ships’ ballast water.[12]

Assign Liability

Because transoceanic vessels entering the Great Lakes have been a major source of biological pollution in the form of AIS, some have argued that shipowners and operators should be held accountable for damages resulting from past releases. Proponents of this strategy would encourage litigation under tort law based on the principle of “the polluter pays.” As many have noted, however, establishing clear, unequivocal evidence that links a release of ballast water containing AIS by a particular vessel (a culpable defendant) to an invasion of a given species is problematic, not least because of the time lag between the release and the discovery and reporting of a new AIS in the Great Lakes (see Chapter 3). A recent study for the Great Lakes Protection Fund suggests that the law of nuisance may provide grounds on which to hold carriers (shipping companies)

---

[11] As reported by Doug Jensen, University of Minnesota Sea Grant Program, during a presentation to the committee entitled “It’s Not Just About Ballast Water: Opportunities and Successes,” Washington, D.C., July 31, 2007.

[12] See Green Marine’s website, www.green-marine.org/index.php?lang=en.

accountable for unauthorized releases of invasive species (GLPF 2006), but this approach has not been tested in court.

The committee is not qualified to explore the likely legal implications and ramifications of an approach to preventing further ship-vectored AIS introductions based on litigation under tort law. However, recent lawsuits relating to the regulation of ballast water under the CWA have been protracted, and the final outcomes remain far from certain.[13] Thus, it appears unlikely that the litigation route would result in timely action to address the problem of AIS introductions by vessels transiting the seaway.

Requiring carriers (ships carrying goods), shippers (those sending goods), and receivers (those receiving goods) to have "invasive species insurance" to cover the damages associated with introductions of AIS would take account of the "chain of responsibility" associated with the supply chain. Rather than imposing the burden solely on shipping companies (carriers), it would ensure the involvement of those who ship and receive goods in promoting environmentally responsible freight transportation.[14] The results of the aforementioned study, however, raise questions about whether any insurer would be willing to offer AIS coverage (GLPF 2006). In general, the usual antipollution tools, such as bonding, insurance, assignment of liability, and litigation, may have limited applicability in preventing AIS introductions because of the absence of robust evidence identifying a culpable defendant.[15]

---

[13] As noted earlier, the litigation was initiated in 1999 when environmental groups petitioned EPA to repeal the long-standing exemption of ballast water discharges from the CWA's permitting requirements. As of December 2007 (almost 9 years after the initial action), the issue remains unresolved.

[14] Business for Social Responsibility's Clean Cargo Working Group is already seeking to involve both carriers and shippers in promoting environmentally and socially responsible transportation (www.bsr.org/membership/working-groups.cfm).

[15] A statutory liability scheme modeled after the Comprehensive Environmental Response, Compensation, and Liability Act may be an option, although the committee is not qualified to assess such an approach. Such a scheme would impose strict (that is, without regard to fault) joint and several liability on vessels that discharge ballast for the cost of remediation plus damages to natural resources. Thus, the difficulty of identifying a culpable defendant could be circumvented.

Close the Seaway

Closing the seaway to transoceanic shipping, either permanently or temporarily, has been proposed as a means of eliminating further AIS introductions into the Great Lakes.[16] This candidate action is seen by many people as the most obvious and the most direct way of eliminating further AIS introductions vectored by transoceanic shipping. In the case of temporary closure (a moratorium), transoceanic vessels would not be allowed to enter the Great Lakes until the Canadian and U.S. governments enforce ballast water regulations that protect the lakes from further AIS introductions. Cargo would be off-loaded from transoceanic vessels before entering the lakes and would be transshipped by laker,[17] barge, rail, or truck to its destination within the Great Lakes region. A preliminary estimate indicates that the transportation cost increases resulting from a cessation of transoceanic shipping in the Great Lakes would be approximately $55 million per year (Taylor and Roach 2005). This analysis has shortcomings, as discussed in Appendix D, and does not, in the committee's judgment, constitute a robust basis for informing a major transportation policy decision—that is, whether to close the seaway to transoceanic shipping. Nonetheless, it is the only published estimate of transportation cost savings associated with transoceanic vessels using the seaway, and at the time of writing, no alternative (improved) estimate has been proposed.

Closing the seaway to transoceanic shipping would eliminate the leading vector for AIS introductions into the Great Lakes, namely, the ballast water of transoceanic vessels. This action would not, however, eliminate further AIS introductions by vessels transiting the seaway. Two categories of vessel—coastal and inland—would continue to operate through the seaway, and both could transport new AIS into the Great Lakes, as discussed in Chapter 4.

---

[16] See, for example, Great Lakes United's Salt Free Lakes campaign (www.glu.org/english/invasive_species/saltfreelakes/index.htm).

[17] As noted in Chapter 4, the term "laker" is often used to describe vessels that operate within the GLSLS system. Some of these vessels also operate within Canadian and U.S. coastal waters.

Thus, closing the seaway to transoceanic vessels would significantly reduce—but not eliminate—the risk of further AIS introductions into the Great Lakes by vessels transiting the seaway.[18] Complete closure to all vessel traffic would, however, guarantee the elimination of all further AIS introductions by vessels transiting the seaway, as required by the second project criterion.

Concluding Remarks

While Box 5-2 lists a number of promising candidate actions to eliminate, or help eliminate, further ship-vectored AIS introductions into the Great Lakes, the committee's review indicates that most are not stand-alone options. They would need to be part of a suite of actions aimed at meeting the second project criterion. For example, ballast water management technologies would need to be combined with appropriate regulations, enforcement, and monitoring to ensure that the technologies were being implemented correctly and were proving effective in preventing further AIS introductions.

In contrast, closing the seaway to all vessel traffic appears, at least at first sight, to be a more straightforward and effective approach. It is the only candidate action listed in Box 5-2 that could guarantee to eliminate all further ship-vectored AIS introductions into the Great Lakes. This action would eliminate not only the ballast water vector associated with transoceanic, coastal, and inland vessels, but also the hull fouling vector. This latter vector is far less well studied and understood than the ballast water vector in the context of AIS introductions into the Great Lakes and is thought to pose far less risk (see Chapter 3). Nonetheless, the absolute requirement to eliminate further ship-vectored introductions dictates that even relatively minor invasion risks not be ignored.

However robust technology-based measures are and however much they improve over time, they cannot guarantee to eliminate every viable propagule from a vessel's ballast system and thus to

[18] Other strengths and weaknesses of closing the seaway to transoceanic vessels are examined in detail in the next chapter.

eliminate ballast-mediated AIS introductions. In some cases, a single propagule could, in principle, give rise to a new population. Closing the seaway to all vessels would obviate the need for such ballast water management technologies, as well as regulations and enforcement.

Thus, complete closure of the seaway to vessel traffic appears to be the most promising candidate action to eliminate further ship-vectored AIS introductions into the Great Lakes—and is the only candidate identified by the committee that could guarantee to meet the absolute requirement to eliminate further introductions by vessels. The effects of this candidate action on the other project criterion—enhancing the Great Lakes region's potential for global trade—are discussed in the following section.

OPTIONS THAT MEET BOTH CRITERIA?

Closing the seaway to all vessel traffic would not, of course, prevent all further AIS introductions into the Great Lakes. Historically, 30 to 45 percent of AIS introductions have been attributed to nonshipping vectors (see Chapter 3), and these vectors would not be eliminated by closing the seaway. Nonetheless, closing the seaway to all vessels would eliminate further ship-vectored AIS introductions into the Great Lakes via the seaway. This action would also eliminate a trade route into and out of the Great Lakes.

If the seaway were closed to all vessel traffic, some cargoes could move by alternative modes and routes. Evaluating transportation system capacity is difficult, but it is doubtful that these alternatives currently have sufficient spare capacity to handle the more than 30 million tonnes of cargo moving through the MLO section of the seaway each year.[19, 20] Alternative transportation options for sea-

[19] For the purposes of the present discussion, the MLO section of the seaway was assumed to be the point of entry into the Great Lakes.

[20] For the 10 years from 1997 through 2006, the volume of cargo moving on the MLO section of the seaway each year has ranged from a low of 28.9 million tonnes in 2003 to a high of 39.2 million tonnes in 1998, with an average annual volume of 33.5 million tonnes (seaway traffic reports at www.greatlakes-seaway.com).

way cargoes would likely emerge over time in response to market demand, but the costs of moving cargoes would increase because of the elimination of competition from the seaway. Such transportation cost increases would not enhance trade, and some industries and sectors could be particularly hard-hit. For example, about 40 percent of the iron ore extracted from the mines of the Labrador Trough in Quebec moves upstream through the MLO section of the seaway to steel mills in the United States and Canada (Transport Canada et al. 2007). The committee concluded, therefore, that complete closure of the seaway to all vessel traffic would not enhance the Great Lakes region's potential for global trade.

Because there is no alternative to complete seaway closure for eliminating further ship-vectored AIS introductions, and because such closure would be incompatible with the requirement to enhance the potential for global trade, the committee concluded that there is no option that could meet both project criteria simultaneously. It is not possible to combine actions meeting the two criteria individually in such a way that the potential for global trade is enhanced and further AIS introductions by vessels transiting the seaway are eliminated.

The committee focused, therefore, on identifying compromise options that would both enhance the Great Lakes region's potential for global trade and greatly reduce the risk of further ship-vectored AIS introductions via the seaway. The following chapter presents the committee's conclusions about possible compromise options, with particular reference to the two different approaches to preventing further ship-vectored AIS introductions—removing or killing organisms carried by vessels or keeping these vessels out of the Great Lakes altogether. It then enumerates the actions necessary to implement the committee's recommended approach for greatly reducing the risk of further AIS introductions by vessels transiting the seaway and enhancing the Great Lakes region's potential for global trade.

REFERENCES

Abbreviations

GLPF	Great Lakes Protection Fund
GLSLS	Great Lakes St. Lawrence Seaway
IMO	International Maritime Organization
NRC	National Research Council
TRB	Transportation Research Board

Austin, J. C., S. Anderson, P. N. Courant, and R. E. Litan. 2007. *Healthy Waters, Strong Economy: The Benefits of Restoring the Great Lakes Ecosystem.* Brookings Institution, Washington, D.C. www.healthylakes.org/site_upload/upload/GrtLakesCostBenefit.pdf.

Cangelosi, A., and N. Mays. 2006. *Great Ships for the Great Lakes? A Scoping Report for the Great Ships Initiative.* Northeast Midwest Institute, Washington, D.C.

GLPF. 2006. *Final Report on Grant 706, Investigation of Potential of Risk Management as a Stimulus to Action for Reducing or Eliminating Unauthorized Introduction of Invasive Species into Great Lakes Waters.* Evanston, Ill.

GLSLS. 2007. Seaway's 48th Navigation Season Established New Record. Cornwall, Ontario, Canada, Jan. 2. www.greatlakes-seaway.com/en/news/pr20070102.html.

Gollasch, S., M. David, M. Voigt, E. Dragsund, C. Hewitt, and Y. Fukuyo. 2007. Critical Review of the IMO International Convention on the Management of Ships' Ballast Water and Sediments. *Harmful Algae,* Vol. 6, pp. 585–600.

Gray, D. K., T. H. Johengen, D. F. Reid, and H. J. MacIsaac. 2007. Efficacy of Open-Ocean Ballast Water Exchange as a Means of Preventing Invasions Between Freshwater Ports. *Limnology and Oceanography,* Vol. 52, No. 6, pp. 2386–2397.

Hodgson, J. R. 2007. *Carrots and Sticks: Opportunities to Accelerate the Development and Adoption of Ballast Water Treatment Technologies for Vessels Operating into the Great Lakes.* Hodgson and Associates, Halifax, Nova Scotia, April.

IMO. 2004. *International Convention for the Control and Management of Ships' Ballast Water and Sediments.* London, United Kingdom.

Kazumi, J. 2007. *Ballast Water Treatment Technologies and Their Application for Vessels Entering the Great Lakes via the St. Lawrence Seaway.* University of Miami, Fla., May.

Lake Superior Magazine. 2007. Isle Royale National Park Prohibits Untreated Ballast Water Release. www.lakesuperior.com/news/070918.html.

Lloyd's Register. 2007. Ballast Water Treatment Technology: Current Status. June.

NRC. 1996. *Stemming the Tide: Controlling Introductions of Nonindigenous Species by Ships' Ballast Water.* National Academy Press, Washington, D.C.

PPD Technologies, Inc. 2006. *Ballast Water Study.* Transport Canada.

Taylor, J. C., and J. L. Roach. 2005. *Ocean Shipping in the Great Lakes: Transportation Cost Increases That Would Result from a Cessation of Ocean Vessel Shipping.* Grand Valley State University, Grand Rapids, Mich., Aug. www.gvsu.edu/cms3/assets/C6D78A67-0AEF-0264-A38619EC6FB0793A/OceanShippingReport091105.pdf.

Transport Canada. 2007. Governments of Canada, Ontario and Quebec to Develop the Ontario–Quebec Continental Gateway and Trade Corridor. News release, July 30. www.tc.gc.ca/mediaroom/releases/nat/2007/07-h141e.htm.

Transport Canada, U.S. Army Corps of Engineers, U.S. Department of Transportation, St. Lawrence Seaway Management Corporation, Saint Lawrence Seaway Development Corporation, Environment Canada, and U.S. Fish and Wildlife Service. 2007. *Great Lakes St. Lawrence Seaway Study.* Final Report. www.glsls-study.com/Supporting%20documents/GLSLS%20finalreport%20Fall%202007.pdf.

TRB. 1996. *Special Report 246: Paying Our Way: Estimating Marginal Social Costs of Freight Transportation.* National Research Council, Washington, D.C.

Wilson, W., P. Chang, S. Verosto, P. Atsavapranee, D. F. Reid, and P. T. Jenkins. 2006. Computational and Experimental Analysis of Ballast Water Exchange. Presented at American Society of Naval Engineers Marine Environmental Engineering Technical Symposium, Arlington, Va., Jan. 23–24. www.ensight.com/images/stories/pdf/MEETS_2006_Wilson_etal_final.pdf.

Wisconsin Department of Natural Resources. 2007. Onshore Treatment of Ship Ballast Water Feasible, Study Concludes. *DNR News,* Dec. 4. www.dnr.state.wi.us/org/caer/ce/news/DNRNews_Lookup.asp?id=96#art6.

6

Committee's Conclusions and Recommended Option for the Great Lakes Region

The committee was asked to develop a range of practical and technically feasible options that would meet the following two criteria: (*a*) enhance the potential for global trade in the Great Lakes region and (*b*) eliminate further introductions of nonindigenous aquatic species by vessels transiting the St. Lawrence Seaway.

After examining a wide range of candidate actions aimed at meeting these criteria, the committee concluded that the only way to satisfy the absolute requirement to eliminate further ship-vectored introductions of aquatic invasive species (AIS) would be to close the seaway to *all* vessel traffic. Such action would eliminate a trade route into and out of the Great Lakes and would not, therefore, enhance the Great Lakes region's potential for global trade. In the committee's judgment, moreover, such closure is not a realistic solution to the AIS problem since it is far from clear that both the Canadian Parliament and the U.S. Congress would pass the legislation that would be needed to close the binational waterway to traffic. Hence, closure of the seaway to all vessels would not address the AIS issue in a timely manner. As noted in Chapter 5, such closure would also not prevent all further AIS introductions into the Great Lakes, given that 30 to 45 percent of such introductions have historically been attributed to nonshipping vectors.

In the absence of an ideal suite of actions that enables both project criteria to be met simultaneously, the committee's task became one of selecting the most promising alternatives from among possible compromise options. After some brief comments about distinguishing features of these compromise options, this chapter discusses the committee's rationale for identifying practical and technically feasible options for the Great Lakes region. Two alternatives—closure of the seaway to transoceanic shipping and the technology-based approach recommended by the committee—are then examined. The various components of the recommended approach are then discussed and the actions necessary to implement this approach are enumerated. After an examination of the strengths and weaknesses of the recommended approach, the chapter concludes with brief remarks about future management of the waters of the Great Lakes.

COMPROMISE OPTIONS

The most important difference among the alternative compromise options lies in how to meet the requirement to eliminate further ship-vectored AIS introductions. As noted in Chapter 5, examination of the candidate actions listed in Box 5-2 led the committee to conclude that there are two distinct approaches to eliminating further AIS introductions by vessels transiting the seaway:

1. Eliminate the shipping vector by removing or killing AIS carried by vessels.
2. Keep vessels that may be carrying AIS out of the Great Lakes.

The first approach would rely on a combination of technologies, regulation, enforcement, and monitoring. Prevention strategies would address all vessels transiting the seaway that pose a risk of introducing AIS into the Great Lakes. The most serious limitation of this approach is that current technologies cannot guarantee to kill or remove all potential invaders, although they offer the potential to reduce markedly the risk of further AIS introductions if they are rigorously implemented. Furthermore, improvements in the effectiveness of technologies are anticipated, particularly for new vessels.

As already discussed, the second approach—closing the seaway to all vessel traffic—is not a realistic solution. The question remains whether closing the seaway to transoceanic vessels, which have historically been the main source of AIS introductions into the Great Lakes since the waterway opened, would be an effective and implementable compromise. Such closure would not eliminate further ship-vectored AIS introductions by vessels transiting the seaway but would reduce substantially the risk of such introductions.

The committee's conclusions with regard to both the above compromise options are discussed later.

COMMITTEE'S RATIONALE

In its efforts to identify practical and technically feasible options for meeting the two project criteria, the committee sought an approach that is the most robust among various alternatives because it

- Offers the potential to make progress toward the ultimate goals in a timely manner,
- Minimizes undesirable consequences, and
- Keeps options open for an uncertain future.

Timeliness

Timeliness was identified as a critical consideration following the public meeting in Toronto in May 2007. One of the major messages that the committee took away from the meeting was the urgency of taking action to prevent further introductions of AIS into the Great Lakes. A wide range of stakeholders expressed the view that actions rather than words are needed, and they are needed now. This view derives not only from the observed impacts of AIS on the Great Lakes ecosystem and the costs incurred by public and private organizations in managing a number of high-profile invaders, such as the zebra mussel, but also from the continuing reports of new AIS discoveries in the Great Lakes. Chapter 3 indicated that a considerable time may elapse between the introduction of a new AIS and reports of its discovery. Nonetheless, the fact that new AIS continue to be reported argues strongly against any complacency in prevention efforts.

Avoid Undesirable Consequences

An acceptable solution to the problem of AIS introductions into the Great Lakes cannot be developed without consideration of its broad environmental and other consequences. Thus, a "solution" that shifts the AIS problem to a different geographic location, such as marine ports on the east coast of North America, would be unacceptable. An approach that substitutes one environmental problem for another would also be unsatisfactory. For example, attempts to solve the AIS problem in the Great Lakes by shifting marine cargoes to alternative modes of transportation would need to take account not only of introductions of invasive species but also of other environmental impacts of transportation, including greenhouse gas emissions, criteria air contaminant emissions, accidents, and noise. Moreover, the possibility of shifting seaway cargoes to alternative land-based modes may raise questions about capacity and logistical constraints and the effects of trying to move even more freight on an already overburdened system. Thus, while shifting seaway cargoes to alternative routes or modes of transportation may be viable, the various trade-offs would need to be evaluated carefully before advocating such an approach to solving the AIS problem in the Great Lakes.

Keep Options Open for an Uncertain Future

The need to keep options open and retain flexibility reflects the uncertainties underlying the selection and implementation of actions aimed at meeting the two project criteria. For example, experts are not yet in a position to make quantitative estimates of how effective ballast water management technologies will be when they are applied rigorously to all vessels posing a risk of AIS introductions. Similarly, reliable forecasts of the direction, composition, and magnitude of global trade affecting the Great Lakes region are not possible. In addition, the extent to which the Great Lakes ecosystem should be modeled as biologically fragile (easily subject to perturbation) or resilient is unclear, and there is no widely accepted ethical calculus for weighing the interests of the different uses and users of the Great Lakes.

One approach to decision making under such conditions of deep uncertainty is to develop sophisticated models with enhanced predictive capabilities. In this case, the committee did not consider such an approach to be productive. Even experts are unable to create simulations of a complex and adaptive system (the Great Lakes economy), placed within a larger environment of other world economies, that will yield reliable predictive outputs. Large and well-refined macromodels are not entirely satisfactory in predicting even 1 year into the future, to say nothing of a decade or more.

In this case, the objective is not to forecast the future but rather to understand (*a*) how changes in the future might affect the choice among alternative actions taken today and (*b*) how these actions, if taken, would affect the chances of meeting specified goals in the future. If today's actions are to be chosen wisely in light of long-term objectives, the key question is not, What will happen? Rather, because the future cannot be forecast accurately, we want to ascertain which actions taken today will both further our goals and preserve options that may be desirable later in light of improved understanding. The committee sought to take account of such considerations in assessing candidate options for the Great Lakes region.

The remainder of this chapter addresses two compromise options for meeting the project criteria. It gives the committee's assessment of whether the proposed approaches are timely, free of undesirable consequences, and flexible in light of future uncertainties.

CLOSURE OF THE SEAWAY TO TRANSOCEANIC SHIPPING

As the following discussion illustrates, the committee's assessment of the effects of closing the seaway to transoceanic shipping was beset with uncertainties. The various economic, environmental, political, and legal unknowns indicated to the committee that any decision to close the seaway to transoceanic vessels would be a high-risk strategy—even in view of the uncertainty with regard to the future role of the seaway within the larger Great Lakes transportation system (see Chapter 2). The current limited understanding of the consequences of closing the seaway to transoceanic vessels is insufficient to support a robust public policy decision about such closure.

The committee's remarks about the economic impacts of closing the seaway to transoceanic shipping focus on their general direction and nature. The remarks are founded on economic principles and thus are compelling. However, no attempt was made to quantify the effects, and any attempt to do so would be subject to wide uncertainties. For example, individuals and organizations are adaptive in their responses to change, so the full nature of their responses is uncertain, as is the estimation of transportation costs for alternative routes and modes (Taylor and Roach 2005). As discussed at some length in Appendix D, estimating the economic benefits of transoceanic shipping through the seaway is a challenging task. The committee's review of the literature suggests that partial answers are available to some of the relevant questions, but the comprehensive analysis needed to quantify with confidence the economic impacts of closing the seaway to transoceanic vessels is lacking.

Permanent or Temporary Closure

A few preliminary remarks about the two variants listed in Box 5-2—permanent and temporary closure of the seaway to transoceanic vessels—are appropriate in the present context. Advocates of temporary closure (a moratorium) are careful to note that they are not calling for permanent closure. However, a prolonged moratorium could have serious financial consequences for the seaway's future because of the loss of Canadian toll revenues. These revenues are needed to support day-to-day operations of the seaway, as well as ongoing maintenance, which cannot be deferred without jeopardizing safety. Tolls, which made up more than 90 percent of the St. Lawrence Seaway Management Corporation's (SLSMC's) total revenue for 2006, are generally higher for the higher-value commodities often carried by transoceanic vessels (see Chapter 2). A recent study examined the revenue impacts of a cessation of transoceanic shipping through the seaway on the seaway corporations and concluded that, for the period 2002–2006, SLSMC would have incurred a loss in toll revenues of about $18 million annually (Taylor and Roach 2007).[1]

It has been suggested that the economic shortfall resulting from a loss of transoceanic traffic through the seaway could be remedied either by increasing the tolls on domestic vessels or by increasing government subsidies (Taylor and Roach 2005). The committee did not explore either of these possibilities in detail. It noted, however, that even small increases in freight rates for low-value bulk commodities of the type carried by many domestic laker vessels can make the difference between a carrier being profitable or unprofitable. In light of the aforementioned uncertainties about responses to change, the effects of increased tolls on domestic vessels are unclear. Whether the Canadian government would increase its current subsidy to SLSMC to keep the seaway operating in the absence of transoceanic traffic is unknown. However, if revenues were insufficient to ensure continuing maintenance of the waterway's infrastructure—a plausible consequence of a permanent or prolonged temporary closure to transoceanic shipping—the seaway could cease to be a viable transportation option and could end up closing to all vessel traffic, not just to transoceanic vessels.

Potential for Global Trade

The Great Lakes region's trade with the rest of the world consists of far more than the movement of cargoes through the seaway. Much of this trade is carried to and from the region via other routes and by other modes of transportation. The actual value of

[1] As noted in Chapter 2, tolls on the U.S. portion of the seaway were eliminated in 1986. The U.S. St. Lawrence Seaway Development Corporation (SLSDC) relies almost exclusively on federal appropriations for its revenues and thus would not be directly affected by a loss of toll revenues from transoceanic vessels (Taylor and Roach 2007).

transoceanic shipping through the seaway has proved difficult to specify, as discussed in Appendix D, but closing the seaway to transoceanic shipping could hardly serve to enhance the potential for global trade. Economic principles indicate that, in the absence of the seaway option, the costs of moving cargoes by alternative modes and routes would almost certainly increase. As noted earlier, the responses of individuals and organizations to such changes are subject to wide uncertainties. Some bulk commodities currently relying on the seaway might shift to rail, albeit at a higher cost, but in other cases the higher cost of movements could result in a curtailment of the enterprises generating the cargoes. Shipping companies (i.e., carriers) that have invested in specialized vessels for Great Lakes international trade would lose a key market if the seaway were closed to transoceanic shipping. While there may be opportunities to use such vessels elsewhere, companies that these carriers service may not be able to relocate and could go out of business.

The committee endeavored to obtain estimates of the value of international seaway trade as a percentage of the Great Lakes region's trade in its entirety, by all modes and all routes. However, a literature search did not reveal any such estimates, perhaps because compiling the necessary data represents a major challenge. Taylor and Roach (2005) note that, in 2002, Great Lakes transoceanic shipping accounted for 10.9 percent of all Canadian grain exports and 21.4 percent of all Canadian steel imports in terms of tonnage. The corresponding data for the United States are 1.9 percent of all grain exports and 6.3 percent of all iron and steel imports.

Available data suggest that it would be hard to posit the continued use of the seaway as vital to the economic health of North America. However, the seaway may be critical for the continued operation of certain industries in the Great Lakes region, particularly in a time of heightened international competitiveness. For specific communities, sectors, and port operators, closure of the seaway to transoceanic shipping would have serious and disruptive effects. For example, shippers would incur not only higher freight rates but also the expense of changes in their logistics infrastructure and practices. Although the full nature of responses to such changes is unclear, some shippers and their supporting logistics providers might go out of business. Thus, the region's trade could be adversely affected, at least in the short term pending the development of alternative transportation options. Whether competitive transportation alternatives to transoceanic shipping through the seaway could be provided has not been demonstrated convincingly, although the absence of such evidence should not lead one to conclude that such alternatives do not exist or would not emerge in response to demand.

The political and legal uncertainties surrounding any decision to close the seaway to transoceanic vessels (see below) would also hamper efforts to catalyze economic development in the Great Lakes region through investment in transportation options that are water based or multimodal with a water-based component.

Timeliness

Closing the seaway to transoceanic shipping would require legislative action by the Canadian Parliament and the U.S. Congress. Furthermore, recent litigation relating to the regulation of ballast water under the U.S. Clean Water Act and to Michigan's ballast water permit requirement suggests that any action to initiate closure of the seaway would bring the issue before the courts. Working through the political and legal issues, particularly in a binational context, could be a protracted process, and the eventual outcome is not clear. Unforeseen circumstances, coalitions of political forces with asymmetric strength and influence, and unpredictable outcomes could result in no closure—or no resolution of the issue.

In the committee's judgment, closure of the seaway to transoceanic shipping would require many years, if it could be carried out at all. Years could be lost awaiting uncertain legal and political outcomes, during which time AIS introductions would continue. The prolonged period of uncertainty could also adversely affect efforts to develop technological solutions to eliminate AIS from ballast water. Few factors have a more deleterious effect on investment, innovation, and the ability of market mechanisms to alter behavior than a climate of uncertainty. While international efforts to develop ballast water treatment systems are expected to continue regardless of the status of shipping on the seaway, uncertainties about the future market could stymie the development of treatment systems optimized for the Great Lakes' freshwater environment. Thus, valuable time that could have been spent pursuing technical solutions to the AIS problem would have been lost. In this respect, a decision to pursue closure of the seaway to transoceanic vessels could impede quick and comprehensive action with the potential to achieve the same end, namely, a significant reduction in further ship-vectored AIS introductions into the Great Lakes.

Environmental Consequences

Closing the seaway to transoceanic vessels would be expected to eliminate further AIS introductions by such vessels and would address both the ballast water and hull fouling vectors. (As discussed in Chapter 3, the hull fouling vector is thought to play a minor role compared with the ballast water vector in introducing AIS into the freshwater ecosystem of the Great Lakes.) A variety of environmental consequences would accompany the likely increase in transshipment of cargoes by rail (and possibly by truck[2]) resulting from closure of the seaway to transoceanic shipping. To estimate the environmental impact of such modal shifts, the committee commissioned an expert paper on the environmental footprints of ship, rail, and truck modes of freight transportation (Lawson 2007). The paper led the committee to conclude that precise estimates and rigorous quantitative comparisons of the environmental effects of freight transportation by ship and overland modes in hypothetical scenarios resulting from seaway closure are not currently possible because of data limitations. However, the paper provided general indications with regard to the effects of ship, rail, and truck modes on 13 environmental factors. The ship mode was found to have the

[2] For relatively low-value bulk commodities moving on the seaway, many of which can be stockpiled if necessary, rail would be the most likely alternative mode. Truck is generally a more attractive option for medium- or high-value semifinished or finished products for which inventories are low and short transit times are critical (see Table 2-1).

smallest and least undesirable footprint in 11 of the 13 environmental categories, and rail is preferable to truck in virtually every category. The two areas where the ship mode ranks unfavorably are AIS introduction and particulate matter emission.[3] The committee concluded, therefore, that shifts of cargoes to land-based modes (notably rail) that would result from closing the seaway to transoceanic shipping could result in increased environmental impacts in terms of fuel use, greenhouse gas emissions, accidents, noise, congestion, and several other factors.[4]

Closure of the seaway to transoceanic vessels could also result in an increased number of such vessels discharging and loading cargoes at marine (i.e., saltwater) ports in Canada or the United States for transshipment by water- or land-based modes to and from locations within the Great Lakes region. These marine ports could become more vulnerable to AIS introductions vectored by hull fouling. Thus, while closing the seaway to transoceanic vessels would reduce the risk of ship-vectored AIS introductions into the Great Lakes, it could increase the risk of such introductions elsewhere by diverting vessel traffic to alternative destinations.

Future Options

A decision should not be made on the basis of sunk costs—costs that have already been incurred. In the case of an infrastructure asset, such as the seaway, any decision about its future should not be prejudiced by considerations of the money that went into its creation and cannot now be unspent. The key question, from a purely economic perspective, is whether the asset has a future value (option value) that more than offsets the direct and indirect costs associated with maintaining it.

[3] Lawson (2007) notes that anticipated reductions in the sulfur content of fuels are expected to reduce emission rates of sulfur oxides and particulate matter for all modes.

[4] A recent study examines the likely air quality impacts of shifting seaway cargoes from transoceanic vessels to alternative modes, notably rail (Taylor and Roach 2007). In common with Lawson (2007), these authors comment on the difficulties of obtaining relevant emissions data. Their analysis, which is based on the single comprehensive data source they were able to find, indicates that "the cessation of ocean shipping into the Great Lakes would have no significant impact on air quality" (p. 44).

The committee heard testimony that the continued existence of the seaway is of value and may prove to be of greater value as the years pass—although forecasting domestic and international trade patterns is problematic because of its complexity and numerous uncertainties (see Chapter 2). Climate change, for example, is likely to be a mixed blessing for global trade and shipping on the Great Lakes St. Lawrence Seaway (GLSLS) system (see Chapter 2 and Millerd 2007).

On the basis of the evidence available to the committee, the net effect of factors such as global warming and the changing balance in stores of freshwater on the Great Lakes region's economy and global trade remains unclear. In addition, the energy savings inherent in waterborne transport could prove to be of great importance in the future. For example, Corbett and Winebrake (2007) note that environmental performance is motivating new models for selecting intermodal freight routes. Environmental parameters, such as carbon dioxide emissions and energy consumption, are more likely to be considered in decision making, together with competing logistics constraints, such as time of delivery, cost, and distance. In addition, national emergencies on either side of the border may cause the seaway to assume greater importance than it has in the recent past.[5] The committee concluded, therefore, that while the option value of maintaining the seaway cannot currently be calculated with certainty, it is almost certainly nonzero. Whether this option value outweighs the costs of operating and maintaining the seaway is a question for the future.

The possibility of closing the seaway to international shipping also raises concern about reactions by trading partners, among others. Such closure could lead to similar decisions around the globe, thereby preventing international shipping from operating into certain ports. As a result of such restrictions, both the Great Lakes region's and the world's trade would be adversely affected.

---

[5] An early seaway concept envisaged the waterway as having strategic value for the United States by allowing the transport of vital commodities to and from the nation's heartland.

Conclusion

The committee's evaluation of the effects of closing the seaway to transoceanic shipping led it to conclude that this action would be not only high risk but also an impractical and unsatisfactory compromise in terms of the two project criteria. Its main strength—a substantial reduction in the risk of further AIS introductions into the Great Lakes by vessels transiting the seaway—would be outweighed by a number of serious disadvantages, as follows:

- Closure of the seaway to transoceanic traffic in a timely fashion appears extremely unlikely, if it could be achieved at all.
- Shifting seaway cargoes to alternative modes of transportation could well have adverse environmental impacts in terms of increased fuel use, greenhouse gas emissions, accidents, and noise.
- The diversion of international vessel traffic could render Canadian and U.S. saltwater ports more vulnerable to ship-vectored AIS introductions.
- The increased cost of moving goods would not be trade enhancing, although the committee was unable to quantify the likely impact on the region's global trade.
- Closure of the seaway to international shipping could lead to copycat actions or other reprisals by trading partners of the United States and Canada, with resulting adverse impacts on all trade, not just that of the Great Lakes region.
- Closing the seaway to transoceanic vessels for any prolonged period could raise concerns about the financial viability (and continued operation) of a transportation asset that is likely to have value in the future, even though that value cannot currently be quantified with any degree of certainty.

COMMITTEE'S RECOMMENDED OPTION

The committee concluded that using technological approaches to remove or kill organisms in ships' ballast water is the preferred strategy for reducing the risk of further ship-vectored AIS introductions into the Great Lakes. Keeping transoceanic vessels out of the Great Lakes is not a practical approach and could delay the development of effective ballast water treatment systems for the Great Lakes.

A combination of technological solutions, enforcement, and monitoring offers the potential to reduce markedly the risk of AIS introductions by shipping. At the same time it retains the seaway as a transportation option for a future in which the impacts of global warming, the changing balance of stores of freshwater, and sectoral and regional changes affecting both global trade and the Great Lakes region's economy are all uncertain. As noted in Chapter 3, 55 to 70 percent of recorded AIS introductions into the Great Lakes since the opening of the seaway have been attributed to ships' ballast water. Other vectors collectively account for the remaining introductions. Thus, an important reduction in the risk of ballast-mediated introductions would be expected to result in major reductions in both the total number of introductions and the proportion of these introductions attributable to the ballast water vector.

In parallel with the actions needed to implement the recommended technology-based approach, the committee sees great value in a change in perspective, with access to the Great Lakes through the seaway viewed as a privilege rather than a right. This privilege would be restricted to vessels meeting criteria designed to eliminate further introductions of AIS. The geographic pinch point at the entrance to the seaway provides an important opportunity to protect what lies within, and those responsible for the seaway's management and operation would be viewed as the guardians of the resource represented by the Great Lakes. The seaway would welcome vessels conforming to the criteria necessary to prevent further AIS introductions. It would be incumbent on those seeking passage to provide assurances that they have taken the measures necessary to merit this welcome.

The option recommended by the committee and summarized in Box 6-1 does not guarantee enhancement of the potential for global trade or elimination of further ship-mediated AIS introductions into the Great Lakes. It does constitute a practical and technically

BOX 6-1

Committee's Recommended Option

Access to the Great Lakes through the St. Lawrence Seaway should be restricted to vessels taking protective measures aimed at ensuring that they do not harbor living aquatic organisms. Such measures, which should be approved immediately by both Canadian and U.S. authorities, should form part of a comprehensive technology-based AIS control program targeting all vessels transiting the seaway. Although transoceanic vessels have been the primary focus of efforts to date to prevent further ballast-mediated introductions of AIS into the Great Lakes, vessels entering the Great Lakes from coastal areas of eastern North America may have played a role in some introductions. Thus, the latter vessels should be required to take the same protective measures as transoceanic vessels.

The AIS control program should incorporate the following features:

- A uniform set of effective and enforceable standards that form a basis for preventing the release of AIS into the Great Lakes basin;
- Monitoring for compliance with the standards, strict enforcement mechanisms, and remediation options for arriving vessels that do not immediately meet standards for entry;
- Surveillance of the Great Lakes ecosystem for early detection of new AIS from any source;
- Capabilities for containment, control, and possible subsequent eradication after the discovery of any new AIS; and
- Feedback mechanisms to ensure that lessons learned from practical experience with prevention measures, including any failures of protective mechanisms, and knowledge gained through research are used to update and improve the control program over time. In this way, the control program would adapt to both new knowledge and experience with AIS introductions.

The control program should emphasize the urgent need for action in preventing further introductions of AIS. It should also have a sound basis in science and incorporate the best available technologies.

To avoid unacceptable delays, the recommended actions making up the control program should be undertaken by existing organizations, in some cases with expanded mandates.

feasible approach that goes a long way toward meeting the two project criteria. Furthermore, many of the actions recommended in the following sections of this chapter could be implemented within the next 2 to 3 years if Canada and the United States have the necessary political will. Thus, the proposed approach is responsive to the calls for action by the many groups and individuals concerned about continuing reports of new AIS introductions into the Great Lakes.

The committee recognizes that some may view its recommended control and eradication program and adaptive process as being beyond the scope of its charge, since they require actions to be taken after AIS have entered the Great Lakes. However, in light of the unknowns and uncertainties discussed in earlier chapters, the committee deemed it necessary to recommend an approach that aims not only to eliminate further ship-mediated AIS introductions but also to remedy possible deficiencies in elimination strategies.

The recommended approach focuses on vessels with a demonstrated risk of AIS introduction—transoceanic and coastal vessels—and on the dominant vector for ship-mediated introductions into the Great Lakes (i.e., ballast water). If research were later to show that hull fouling is an important mechanism for AIS introductions into the Great Lakes, additional prevention measures would be needed. Similarly, if vessels operating exclusively within the inland waters of the GLSLS system were shown to be playing a role in introducing AIS, further preventive action would be required. The adaptive AIS management processes recommended by the committee address such possibilities by providing for updates and improvements that reflect practical experience and knowledge gained through research.

The following sections address ballast water management technologies, a surveillance and control program for the Great Lakes ecosystem, and an adaptive process for strengthening prevention measures over time. After an assessment of the strengths and weaknesses of the committee's recommended approach, the chapter concludes by considering briefly a future approach to managing the waters of the Great Lakes.

BALLAST WATER MANAGEMENT TECHNOLOGIES

Ballast water management (BWM) technologies—notably ballast water exchange (BWE), saltwater flushing, and shipboard ballast water treatment—can kill or remove AIS in ships' ballast water. If they are rigorously applied and strictly monitored, these technologies could reduce markedly the risk of further introductions of AIS into the Great Lakes by vessels transiting the St. Lawrence Seaway. Furthermore, the efficacy of BWM technologies is likely to increase over time as understanding of their advantages and limitations gained through practical experience leads to technological improvements.

Much current BWM technology development is focused on shipboard treatment systems that aim to reduce the numbers of viable organisms in ballast water to the levels specified in the International Maritime Organization's (IMO's) proposed ballast water performance standard (IMO 2004). While this development is certainly important for vessels transiting the seaway, as discussed later, the freshwater nature of the Great Lakes means that BWE for ballasted vessels (BOBs) and saltwater flushing for vessels declaring no ballast on board (NOBOBs) can be effective techniques for killing or removing potential invaders when conducted properly.

BWE and Saltwater Flushing

The ballast tanks of both BOB and NOBOB vessels may harbor potentially invasive freshwater organisms taken on board during ballasting operations in freshwater areas outside of the Great Lakes ecosystem. If a vessel conducts open-ocean BWE or saltwater flushing, these freshwater organisms are subjected to a physiological shock due to the salinity change and a dilution effect due to tank purging. Recent research has demonstrated the practical effectiveness of BWE and saltwater flushing in reducing the numbers of viable freshwater organisms in the ballast tanks of vessels. Gray et al. (2007) assessed the efficacy of BWE on six operational transoceanic vessels traveling across the North Atlantic and found the process to be highly effective in reducing the diversity and abundance of freshwater invertebrates in ballast tanks. Concentrations of freshwater zooplankton were reduced by more than 99 percent, the recruitment of zooplankton from dipausing eggs present in ballast sediments was reduced dramatically, and benthic invertebrates showed nearly universal mortality. Reid et al. (2007) investigated BWM practices for NOBOBs and reported that the routine use of saltwater flushing for NOBOB tanks would greatly improve the level of protection for the Great Lakes against further AIS introductions. In addition, an analysis commissioned by the committee indicated that a number of invasions of the Great Lakes, including those of the zebra mussel and the Eurasian ruffe, would have been prevented by BWE conducted in accordance with the proposed IMO BWE standard (Kelly and Kazumi 2007).

For saltwater-tolerant species that survive the physiological saline shock associated with BWE, it is unclear whether the reduced density of organisms in a vessel's ballast tanks following 95 percent volumetric exchange as specified by the proposed IMO standard would, when discharged into the Great Lakes, be sufficient to result in the establishment of a new population (Kelly and Kazumi 2007). However, the research cited above demonstrates that both BWE and saltwater flushing reduce the likelihood of introductions of AIS by reducing propagule pressure—a measure that depends on the number of introduction events, the number of propagules introduced per event, and the condition of the propagules on release. The committee is not aware of any studies that assess the condition of organisms after BWE or flushing. It notes, however, that stirring of sediments associated with these processes would adversely affect many zooplankton, since these species typically perform poorly in water with high levels of suspended sediment (Hart 1988; Kirk 1991).

Given the potential effectiveness of BWE and flushing in preventing further introductions of AIS into the Great Lakes by vessels transiting the seaway, the committee concluded that (*a*) these methods should be used by all categories of vessel known to present a risk of AIS introduction and (*b*) future technological enhancements of these methods merit investigation.

Use of BWE and Flushing by Vessels Transiting the Seaway

As indicated in Table 4-1, all transoceanic BOB vessels transiting the seaway and destined for Great Lakes ports are required to conduct BWE or take alternative BWM measures. In addition, as of the beginning of the 2008 navigation season, all transoceanic NOBOB vessels transiting the seaway are required to conduct saltwater flushing. Such action by transoceanic NOBOB vessels destined for U.S. Great Lakes ports has been strongly encouraged by the U.S. Coast Guard since 2005 and required for vessels destined for Canadian Great Lakes ports since 2006.[6] Because all transoceanic NOBOB vessels carry a risk of introducing AIS (see Chapter 4), the committee considers it essential that all such vessels be subject to the same mandatory saltwater flushing requirement, regardless of their destination within the Great Lakes.

As Table 4-1 shows, there is no consistent requirement for coastal vessels transiting the seaway after operating within the Canadian and U.S. exclusive economic zones (EEZs) to conduct BWE or flushing (or other BWM practices), even though such vessels are known to present a risk of introducing AIS (see Chapter 4). BOBs are required to conduct BWE only if they move from one jurisdiction to another (U.S. to Canadian waters or vice versa), and NOBOBs are required to conduct saltwater flushing only if their voyage takes them from within the U.S. EEZ to a Canadian Great Lakes port.

The great majority of coastal vessels transiting the seaway are Canadian, coming from within the Canadian EEZ and destined for Canadian Great Lakes ports. At present, such vessels are subject to the voluntary BWM practices issued by the Lake Carriers' Association and the Canadian Shipowners Association (2001) but are not required to conduct either BWE (BOBs) or saltwater flushing (NOBOBs). To reduce the risk of AIS introduction associated with coastal vessels, the committee recommends that BWE and flushing requirements similar to those for transoceanic vessels be instituted

[6] A notice of proposed rulemaking issued by SLSDC (2007) aimed to harmonize U.S. and Canadian requirements for saltwater flushing by transoceanic vessels operating in the binational waters of the GLSLS system. In February 2008, the Seaway Practices and Procedures were updated to include the saltwater flushing requirement for transoceanic NOBOB vessels.

for all vessels entering the Great Lakes from coastal areas of eastern North America.

> *Recommendation:* **Transport Canada and the U.S. Coast Guard should ensure that all vessels entering the Great Lakes after operating in coastal areas of eastern North America take protective measures similar to those required for transoceanic vessels, notably BWE for BOBs and saltwater flushing for NOBOBs.**

The committee recognizes that some vessels may face operational constraints (dangerous sea states, carriage of specialized project cargoes) that prevent them from safely conducting open-ocean BWE or saltwater flushing before transiting the seaway. In such cases, alternative BWM processes are needed to ensure that every vessel transiting the seaway after operating outside of the inland waters of the GLSLS system uses proven BWM methods to reduce the risk of introducing AIS through its ballasting operations. One possibility for some vessels is to conduct BWE or flushing in the alternate exchange zone in the Laurentian Channel. However, use of this zone is now restricted to the beginning and end of the seaway navigation season because of concerns about the effects of ballast water discharges on the ecosystem in the Gulf of St. Lawrence. Thus, the use of approved methods for treating the ballast tanks of arriving vessels appears to be a preferred and more widely applicable approach. For example, a recent report explores the possibility of using sodium chloride brine to treat low-salinity tanks of vessels entering the GLSLS system (Jenkins 2007).[7]

> *Recommendation:* **Transport Canada and the U.S. Coast Guard should not allow vessels unable to conduct open-ocean BWE or flushing for safety or other reasons to enter the Great Lakes until they have undertaken to perform alternative BWM measures. Such measures may include BWE or flushing in approved alternative discharge sites or**

[7] The salinity of water in the ballast tanks of a vessel that has conducted BWE or flushing is required to be at least 30 parts per thousand for the vessel to receive permission to enter the Great Lakes.

an approved type of shore-based treatment applied to each noncompliant tank before any contents of such tanks can be discharged into the waters of the Great Lakes.

Future Enhancements

Implementation of the above recommendations would result in a requirement for all vessels known to present a risk of introducing AIS to conduct BWE or flushing or to take alternative BWM measures before permission to enter the Great Lakes is granted. If accompanied by effective enforcement, this requirement would be an important step in ensuring that policies aimed at preventing further AIS introductions reflect the best current understanding of aquatic invasion biology and proven BWM practices. In the future, opportunities to increase the effectiveness of BWE or flushing through improved monitoring systems and new vessel designs could lead to enhanced protection of the Great Lakes against further introductions of AIS.

Monitoring for Compliance Evidence indicates that the procedures implemented by the agencies that inspect, test, and monitor the ballast water of vessels entering the GLSLS system—Transport Canada Marine Safety, the U.S. Coast Guard, and the seaway corporations—are effective in ensuring that all vessels required to conduct BWE or flushing before transiting the seaway have in fact done so (see Chapter 4 and U.S. Coast Guard 2007). However, the committee identified future opportunities to use technology to enhance the inspection process and reduce the associated manpower needs for the inspection authorities.

Knowing whether BWE or saltwater flushing has been performed and has been effective in raising the salinity of the water in the vessel's ballast tanks before a vessel enters the GLSLS system would be helpful in targeting additional prevention measures to high-risk vessels. The committee learned that automated shipboard monitoring systems capable of recording water flows into and out of individual ballast tanks (i.e., ballasting operations) could become commercially available within the next few years, particularly if demand for such systems were identified. Such systems could also be used to measure the salinity of the water in individual tanks, although research would be needed to identify appropriate locations for the sensors. Transmission of information on ballasting operations and tank salinities, together with Global Positioning System coordinates, to Transport Canada and the U.S. Coast Guard would permit remote monitoring of a vessel's compliance with BWE and flushing requirements. High-risk vessels could thus be identified before their entry into the GLSLS system, thereby providing timely opportunities for remedial action.

Further information is needed on retrofitting existing vessels to accommodate such monitoring systems and on manpower requirements to operate and maintain them. The burden of installing, operating, and maintaining such shipboard ballast water monitoring systems on the shipping industry would need to be commensurate with the benefits in terms of more cost-effective inspection by enforcement agencies and more effective protection against AIS introductions. As discussed in Chapter 5, the rate at which BWE or flushing is superseded by shipboard ballast water treatment systems and associated ballast water discharge standards will be important in determining the overall cost-effectiveness of the automated reporting option.

> ***Recommendation:*** **Transport Canada and the U.S. Coast Guard should explore the possibility of using a secure system of in-tank salinity monitors, location verification, and telemetry to allow remote monitoring of a vessel's compliance with BWE and flushing requirements prior to entry into the GLSLS system.**

Improved Vessel Designs The capacity, location, and flexibility of use of ballast tanks are key features of ship design. Consideration of required drafts and trim, hull loading limitations, and required vertical center of gravity establishes the necessary ballast volume and location (NRC 1996). The designs of most current vessels are not optimized for BWM practices aimed at eliminating AIS. While there have been improvements in the outfitting of the new generation of bulk carriers servicing the Great Lakes, there is still room for substantial improvements in ship design and construction, with an emphasis on facilitating more effective and efficient BWE and flushing and reducing the buildup of residuals in ballast tanks.

Depending on a ship's design and outfitting and the method of exchange selected, the system components or tank structure may preclude effective mixing within the tank during the exchange process or allow significant volumes of unmixed residuals to remain throughout the ship. Many of the constraints associated with tank shape and plumbing could be eliminated by changes in design and modular construction methods for new-builds. Specifically, with respect to flow-through exchange, hydraulic structures within a ballast tank could be designed so that complete mixing occurs in the tank during the exchange process. This would ensure that the anticipated dilution actually takes place within ballast tanks during an exchange event. In addition, tank design could be modified to minimize untreated residuals, and virtually all material in the ballast tank would be removed during a pump-out process.

> *Recommendation:* **Transport Canada and the U.S. Coast Guard should require that all new vessels operating into the Great Lakes take full advantage of opportunities offered by revised designs and modular construction methods to facilitate effective and efficient management of ballast water and residuals.**

Shipboard Ballast Water Treatment

BWE for ballasted vessels and saltwater flushing for NOBOBs are inexpensive and effective means of killing most of the freshwater organisms in ballast tanks. They do not, however, guarantee elimination of all potential invaders for several reasons.

First, as noted in the preceding discussion, ship designs may result in incomplete mixing within ballast tanks during the exchange or flushing process. Second, if there is significant sediment accumulation, the efficacy of BWE or flushing may well be reduced. A recent study of best management practices for NOBOBs (Reid et al.

2007) found that saline water introduced into ballast tanks during the exchange process may not penetrate residual sediments. Thus, while BWE is highly effective in killing benthic invertebrates, individual organisms may survive below the sediment–water interface and could present an invasion risk if sediments were disturbed during subsequent ballasting operations (Gray et al. 2007). Third, species that are salinity tolerant or have salinity-tolerant life stages may survive the physiological saline shock associated with BWE or flushing. Finally, while prolonged exposure to ocean water is likely to reduce organisms' survival rates and enhance the effectiveness of BWE and flushing, such exposure may not be practical. For example, a transoceanic vessel would ideally conduct BWE or flushing as early as possible during its voyage for maximum effectiveness, but weather conditions in the North Atlantic, particularly during the winter, may preclude this option. In addition, the shorter voyages (typically 2 to 3 days) undertaken by coastal vessels provide less opportunity for prolonged exposure to saltwater.

Because of these limitations, shipboard ballast water treatment systems are widely regarded as potentially more desirable than BWE or flushing for eliminating aquatic organisms from ballast water. In addition to giving vessels greater flexibility in managing their ballast water under a variety of operational conditions, such systems offer the promise of effective elimination of invasive organisms.

An investigation of the peer-reviewed literature on ballast water treatment technologies commissioned by the committee (Kazumi 2007) indicates that filtration/physical removal systems, biocides, and a combination of technologies (notably filtration followed by the use of biocides or ultraviolet radiation to kill remaining organisms) show promise for shipboard application. However, the freshwater environment of the Great Lakes poses unique challenges for shipboard ballast water treatment. Because the basin supplies drinking water for more than 30 million people, public health issues relating to the discharge of treated ballast water require special attention. The proposed use of biocides, in particular, will require careful evaluation of the fate and toxicity of any residuals.

The engineering challenges involved in redesigning and modifying land-based water treatment systems for shipboard use constitute a major challenge for the development and implementation of shipboard ballast water treatment systems. In some respects, these challenges are less demanding for seaway-size vessels than for the larger vessels in the world fleet. Large tankers may carry in excess of 200,000 m^3 of ballast (NRC 1996), whereas the ballast capacities of vessels transiting the seaway do not exceed 25,000 m^3 (see Chapter 4). However, retrofitting existing vessels to accommodate treatment systems is demanding and involves issues such as the availability of space on the vessel, power use, controls, and piping. In contrast, new vessels offer opportunities to incorporate innovative ballast water treatment systems more cost-effectively.

Several large companies have become involved in the development of ballast water treatment technologies over the past 5 years.[8] Assessment of commercially available systems is difficult because available data may have been generated under different operating conditions and other data remain proprietary (Kazumi 2007). However, the establishment of the proposed IMO standards for BWM in 2004 (see below) and the resulting creation of a worldwide market have stimulated development activities. A recent report from *Lloyd's Register* (2007) indicates that shipboard ballast water treatment systems should be commercially available by 2009, with testing to IMO requirements conducted in 2007 and 2008, although the authors note that these estimates may be optimistic. At the time of writing, a number of treatment systems are going through the lengthy IMO approval process. This process aims to ensure that a system meets the proposed IMO ballast water performance standard, is sufficiently robust for shipboard use, has minimal environmental impact, and is suitable for use in the specific shipboard environment where it is to be installed.

The *Lloyd's Register* report notes that capital cost information for shipboard treatment systems is not widely available and that

[8] As reported during a presentation to the committee from Richard Everett, U.S. Coast Guard, Toronto, Ontario, August 30, 2006.

any prices quoted should be regarded as tentative, given the developmental nature of the products (2007). Data provided indicate that the capital cost of a 200-m^3/h plant ranges from \$135,000 to \$165,000. Estimated operating costs range from \$0.01 to \$0.35 per cubic meter of treated water.

Role of Standards

In February 2004, after more than 10 years of preparatory work, IMO adopted the *International Convention for the Control and Management of Ships' Ballast Water and Sediments* (IMO 2004). An annex to the convention includes proposed technical standards for BWM, namely, a BWE standard and a ballast water performance standard (see Box 6-2).

The convention will enter into force 1 year after it has been ratified by at least 30 nations representing at least 35 percent of the world's oceangoing commercial tonnage. As of May 31, 2008, only 14 nations representing less than 4 percent of the world's tonnage had ratified the convention. Hence, it will be at least 2016 before all vessels are required to comply with the proposed D-2 ballast water performance standard, and some years will elapse before sufficient data are available to assess the effectiveness of this standard in preventing AIS introductions.[9] In addition, as noted in Chapter 3, this assessment will be further complicated by the time lag between the date of AIS introduction and the date of detection or reporting.

An outstanding question is whether the proposed IMO standards, and in particular the D-2 standard, are sufficiently stringent to protect the Great Lakes against further AIS introductions by vessels transiting the St. Lawrence Seaway. Some argue that more stringent standards are needed, although scientific evidence to support this argument is lacking. The committee's arguments in favor of initially adopting a ballast water treatment standard (or discharge standard) equivalent to the proposed IMO D-2 standard—

[9] Although the convention notes that BWE could be used to meet the performance standard, it is widely acknowledged that ballast water treatment will likely be needed to meet the proposed D-2 standard.

BOX 6-2

Proposed IMO Standards for Ballast Water Management[a]

D-1 *Ballast Water Exchange Standard*

Ships performing ballast water exchange shall do so with an efficiency of 95 percent volumetric exchange of ballast water. For ships exchanging ballast water by the pumping-through method, pumping through three times the volume of each ballast water tank shall be considered to meet the standard described.

D-2 *Ballast Water Performance Standard*

Ships conducting ballast water management shall discharge less than 10 viable organisms per cubic meter greater than or equal to 50 micrometers (microns) 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; and discharge of the indicator microbes shall not exceed the specified concentrations.

The indicator microbes, as a human health standard, include but are not to be limited to

a. Toxicogenic Vibrio cholerae (O1 and O139) with less than 1 colony forming unit (cfu) per 100 milliliters or less than 1 cfu per 1 gram (wet weight) zooplankton samples;
b. Escherichia coli less than 250 cfu per 100 milliliters;
c. Intestinal Enterococci less than 100 cfu per 100 milliliters.

SOURCE: IMO 2004.
[a]Although IMO has adopted BWM standards, these standards will not be in force until the entry into force of the convention itself. Thus, the IMO standards are described as "proposed" in the present discussion.

as opposed to a more stringent standard—are discussed in the following paragraphs.

First, while the efficacy of the proposed D-2 standard has not yet been demonstrated in practice, it combines scientific input and the results of engineering analyses (see, for example, Raaymakers 2001) with practical considerations about technological options for ballast water treatment. In common with most international standards, it also represents a compromise reached through negotiation among the nations participating in its development. The IMO convention recognizes that additional standards may be needed for specific situations, including different geographical regions. In addition, experts in BWM and treatment agree that flexibility must be retained to allow the standards "to be revised and updated over time as technology develops, knowledge increases and improved ballast water treatment biological effectiveness becomes possible" (Raaymakers 2001, 3). In the committee's judgment, however, revising and updating the proposed standards at this time for vessels operating into the Great Lakes would be premature, given that IMO-approved ballast water treatment systems have not yet entered service in the world fleet.

Second, evidence available to the committee makes it clear that routine, accurate, and cost-effective monitoring systems to verify compliance with any ballast water treatment standard do not exist. For example, the proposed IMO D-2 standard requires reliable monitoring of numbers and viability of the entire ambient microfauna before and after treatment, which is a daunting challenge. If even more stringent standards were adopted—for example, 1/100 as many viable organisms remaining as specified in the proposed D-2 standard—enormous volumes of water and sediment would need to be analyzed, making monitoring for compliance even more difficult.[10] Thus, even if a standard more stringent than the

[10] Gollasch et al. (2007) discuss some of the issues associated with ballast water sampling to demonstrate compliance or noncompliance with the proposed IMO D-2 standard. One issue concerns demonstration of noncompliance with the proposed D-2 standard as part of port state control measures. At present, the discharge limits defined in the proposed standard can be interpreted as applying either to concentrations of organisms averaged over the entire volume of ballast water discharged by a vessel or to concentrations of organisms measured for some smaller volume of the total discharge. This issue will need to be resolved before the proposed D-2 standard can be enforced by the relevant regulatory bodies. The committee notes that routine monitoring of treatment efficiency may be facilitated by monitoring the performance of treatment equipment or the generation of a biocide residual. This approach has been used for many years in monitoring water and wastewater treatment systems, where it has proved to be an effective and safe procedure for assuring the desired water quality.

proposed IMO D-2 standard were established, it would at present be extremely difficult to determine whether vessels were in compliance. Under such a scenario, gathering the data necessary to assess the efficacy of the standard would not be possible, and the opportunity to develop robust knowledge about the levels of ballast water "cleanliness" needed to protect the Great Lakes ecosystem would be lost.

Finally, the committee notes that different Canadian and U.S. ballast water standards for the GLSLS system would add to the already complex array of BWM requirements (see Table 4-1), thereby further complicating compliance and adding to the costs of verifying compliance. While the Canada Shipping Act of 2006 mirrors the standards for BWM defined in the IMO convention, the United States is considering a ballast water performance standard that is 100 times more stringent than the proposed IMO D-2 standard. The implementation of more stringent standards by either nation would reduce the overall risk of AIS introduction into the Great Lakes by reducing the propagule supply, although the degree of protection would be less than if both nations were to adopt the more stringent standard. However, disparities between Canadian and U.S. standards would raise the possibility of a diversion of maritime trade away from the nation with more stringent standards, with vessels choosing to use ports with less demanding constraints on ballast water discharge.

In the committee's view, common ballast water standards are needed for all vessels entering the Great Lakes. The proposed IMO standards, which represent a broad international consensus based on scientific input, expert judgment, and practical and political considerations, form a robust and pragmatic starting point. In the case of BWE, as noted earlier, a retroactive evaluation indicated that a number of invasions of the Great Lakes would have been prevented by the proposed IMO D-1 standard (Kelly and Kazumi 2007). In addition, adoption by the United States of a BWE standard for the Great Lakes equivalent to D-1 would harmonize U.S. and Canadian BWE standards and facilitate compliance.[11]

A ballast water discharge standard for the Great Lakes equivalent to the proposed IMO D-2 standard would form a basis for organizing data-gathering efforts to determine whether the specified treatment levels are attainable in practice, thereby providing data to inform future policy decisions. In addition, establishing such a standard would remove current market and technical uncertainties and could, therefore, encourage investment by equipment manufacturers and shipowners in the development and demonstration of ballast water treatment systems for vessels entering the Great Lakes (Hodgson 2007). In contrast, delays and uncertainties in the regulatory process could well delay the innovation process. The establishment of a standard as proposed would also provide a focal point for regulatory bodies to develop monitoring procedures and inspection protocols for demonstrating compliance (or noncompliance). The committee envisages that a risk-based approach to monitoring and inspection could be useful in optimizing enforcement of the standard.

Recommendation:* The United States should follow Canada's lead and take immediate action to adopt and implement BWE and performance standards for the Great Lakes that are identical to those specified in IMO's *International Convention for the Control and Management of Ships' Ballast Water and Sediments.

***Recommendation:* Transport Canada and the U.S. Coast Guard should develop certification processes for shipboard treatment systems and for monitoring systems to verify compliance with ballast water quality standards identical to those proposed by IMO.**

[11] The committee did not consider the advantages and disadvantages for Canada and the United States of ratifying the IMO convention and has not taken a position on this issue. To avoid any unintended implications about ratification, the discussion refers to ballast water standards identical to those proposed by IMO rather than to the proposed IMO standards per se.

SURVEILLANCE AND CONTROL PROGRAM

Even well-designed prevention programs and the rigorous enforcement of appropriate BWM procedures cannot guarantee that no further AIS will enter the Great Lakes via ships' ballast water. Thus, the committee concluded that a surveillance program to detect and identify new invaders should be a component of a comprehensive package of actions aimed at preventing further introductions of AIS by all vectors, routes, and pathways, including vessels transiting the St. Lawrence Seaway. Such a surveillance program would provide information both to assess the effectiveness of prevention policies and to enhance understanding of the full suite of invasion vectors, routes, and pathways. In addition, early detection of new AIS could form the basis for efforts to control, or possibly even eradicate, new invaders.

The committee strongly endorses the view that preventing further AIS introductions—as opposed to controlling or eradicating populations of new AIS following their establishment—is the preferred approach to managing AIS. Prevention should be the cornerstone of efforts to eliminate further introductions of AIS into the Great Lakes, and control or eradication should be backup measures to be used only when prevention proves less than 100 percent effective. Furthermore, as discussed later, any deficiencies in prevention measures should be examined carefully with a view to taking corrective action. Thus, control or eradication strategies are supplements, rather than alternatives, to prevention.

Surveillance

A surveillance program designed to detect new AIS in the Great Lakes would inform efforts to prevent further introductions by any vector, route, or pathway, and not only by ships transiting the seaway. If a new AIS were found, expert analysis would be needed to determine the likely introduction vector. Once such a determination had been made, a prompt review of prevention strategies could then be undertaken to identify weaknesses and opportunities for improvement. Pending this determination, efforts to control or eradicate the new invader could be initiated. To increase the effectiveness of control and eradication efforts, early detection of new AIS would be critical, and the proposed surveillance program reflects this requirement.

Looking for new AIS in an ecosystem the size of the Great Lakes basin, with almost 300,000 square miles (more than three-quarters of a million square kilometers) of watershed and 10,000 miles (17,000 km) of shoreline, requires surveillance strategies that make the most effective use of all available resources through a targeted approach. Attempting to apply the same level of scrutiny throughout the entire ecosystem risks diluting the effort to such an extent that its overall effectiveness would be greatly reduced. Vander Zanden (2007) suggests targeting surveillance efforts on "hot species," "hot moments," and "hot spots" to increase the likelihood of early detection of new AIS. Such a strategy would use the results of risk assessments that identify potential invaders on the basis of information about donor regions and invasion corridors. It would also make use of information about seasonal variations in the likelihood of invasion by different species and about locations most likely to be invaded. For example, researchers have found that 5 percent of the Great Lakes' surface area supports more than half of recent AIS introductions and that invasion hot spots are approximately 20 times more highly invaded than other areas (Grigorovich et al. 2003).

The committee proposes an AIS surveillance program that focuses on physical sampling of selected habitats (including coastal wetlands) around the Great Lakes to monitor for the presence of new invaders. Dedicated lake teams would play the central role in surveillance efforts, conducting a variety of field surveys. The lake teams would coordinate their efforts with those of academic researchers, resource managers, and local citizens groups (Vander Zanden 2007). Leveraging ongoing monitoring activities, including the Sea Grant extension and outreach programs on invasive species, could help in establishing a scientifically robust and cost-effective AIS surveillance program for the Great Lakes. The proposed program would be a continuing science-based effort, separate from any enforcement activities associated with measures to prevent further AIS introductions. It would emphasize traditional sample collection methods but could draw on newer techniques, such as remote sensing, rapid genetic detection, and the use of molecular markers, to address specific AIS questions.

The committee explored the possibility of assigning responsibility for the binational AIS surveillance program to an existing organization (or organizations), possibly through expansion of current mandates. The results of the committee's investigations are not conclusive, but they provide a basis for further examination of the options. The Great Lakes Fishery Commission (GLFC) was identified as one candidate, in light of its binational status and its experience with field monitoring as part of the sea lamprey control program. Alternatively, two organizations, one in Canada and one in the United States, could jointly assume responsibility for the surveillance program. The Department of Fisheries and Oceans was identified as the most appropriate organization in Canada. In the United States, there are several candidates, including the National Oceanic and Atmospheric Administration's Great Lakes Research Laboratory, the U.S. Fish and Wildlife Service, and the U.S. Environmental Protection Agency.

> ***Recommendation:*** **A binational science-based surveillance program should be established to monitor for the presence of new AIS in the Great Lakes. The program should involve dedicated lake teams, as well as academic researchers, resource managers, and local citizens groups, and should leverage existing monitoring activities wherever possible.**

Control and Eradication

An extensive literature addresses the control and eradication of invasive species in terrestrial environments, and some reported efforts achieved their targets (Vander Zanden 2007). In contrast, efforts to control or eradicate invasive species in aquatic habitats have been more limited and generally directed toward small isolated water bodies, with varying effectiveness. The most notable exception is GLFC's program to control the sea lamprey in the Great Lakes. Overall, this binational program has resulted in a 90 percent reduction of sea lamprey populations in most areas of the Great Lakes. GLFC acknowledges, however, that eradicating the sea lamprey from the Great Lakes is impossible. Continuing control efforts are expected to keep populations at levels that lessen the impact on the Great Lakes fishery, which is estimated to be worth up to $4 billion annually to Canada and the United States. The control program itself has cost more than $318 million since 1958, with average annual costs of $17 million over the past 3 years.[12]

Conditions favoring AIS eradication can be either biological or institutional (Vander Zanden 2007). From a biological perspective, a new AIS introduction is most likely to be susceptible to eradication if the species is detectable at low densities before a large population has formed and is detected early in the invasion sequence, if factors such as habitat type and life history make it possible to remove individuals faster than they reproduce, and if there is a low likelihood of reinvasion. Thus, highly mobile organisms occupying open habitats and exhibiting high population growth rates and dormant resting stages would not be good candidates for eradication. In contrast, stationary organisms occupying isolated habitats, such as coastal wetlands, and exhibiting low population growth rates and no dormant resting stages could be susceptible to eradication. Institutional requirements favoring eradication include sufficient resources to carry the effort to its conclusion, clearly defined lines of authority with the lead organization able to take immediate action if necessary, broad support and public participation, and the knowledge base necessary to inform decisions.

An eradication program would need to be closely linked to the recommended surveillance program. As soon as a new AIS was reported, the potential for its eradication would have to be evaluated from the biological and institutional perspectives. The costs of taking action or of inaction would also have to be estimated. A

[12] As reported to the committee by John Dettmers, GLFC, during a presentation in Washington, D.C., on May 23, 2006.

formal process could help in reviewing and integrating the available information, identifying and evaluating alternative options, and deciding whether to attempt eradication and, if so, how. Advanced readiness preparations could also be made—for example, available control methods for each type of AIS could be compiled in a technical handbook; collateral impacts, such as damage to nontarget species, could be listed; and the organizations and individuals who would have to be mobilized to implement the eradication plan could be identified. Targeting such preparations to species already identified as likely invaders could help focus limited resources on areas of greatest risk.

Given the limited experience on which to draw, an AIS eradication program for the Great Lakes would have to be at the forefront of developing and evaluating eradication methods. Because of uncertainties about its effectiveness, the program would likely be a secondary component of a broader program to minimize AIS impacts by controlling populations, as in the case of the sea lamprey. Responsibility for such a control and eradication program would be most effectively assigned to the organizations responsible for the recommended science-based surveillance program, given the knowledge and expertise needed and the strong links between the two activities.

> ***Recommendation:*** **Efforts to limit the impacts of AIS in the Great Lakes should include a program aimed at developing capabilities for containment, control, and possible subsequent eradication following the discovery of any new AIS. The program should be established as an adjunct to the recommended binational surveillance program.**

AN ADAPTIVE PROCESS

Progress in invasion biology has led to a greater understanding of which species are likely to invade and the risk factors for invasions. However, ongoing changes in donor regions, in vectors and pathways of introduction, and in the Great Lakes ecosystem itself mean that combating further AIS introductions will require strategies that can adapt to such changes. For example, the vast majority of AIS introduced into the Great Lakes since 1959 via the ballast water of transoceanic vessels originated in Eurasia, with most coming from Europe and the Ponto-Caspian basin (Kelly 2007). The pathways of introduction for these species are generally complex, may involve secondary invasions, and may change as a result of changes in the colonization pathway, as illustrated by the 1992 opening of the Main Canal connecting the Danube and Rhine River systems, which provided a new westward colonization pathway from the Black Sea basin. In the future, higher water temperatures resulting from global warming could increase the likelihood of invasions by increasing the probability of new AIS achieving minimum viable population sizes before growth and reproductive cycles are curtailed by the seasonal onset of cooler temperatures (see Chapter 3).

Experience in attempting to prevent ship-vectored introductions of AIS into the Great Lakes has also indicated the importance of updating prevention strategies in a timely fashion to take account of practical experience and knowledge gained through research. The recent change in the Seaway Practices and Procedures to reflect improved understanding of the role of transoceanic NOBOB vessels in introducing AIS is a case in point. Since 1993, when BWE became mandatory for all transoceanic vessels entering the Great Lakes in ballast, a total of 19 new AIS have been reported in the Great Lakes, including the freshwater shrimp *Echinogammarus ischnus* in 1995, the waterflea *Cercopagis pengoi* in 1998, and the mysid shrimp *Hemimysis anomala* in 2006. Notwithstanding the possibility that time lags between the dates of introduction and reporting may hinder determination of the efficacy of BWE (Costello et al. 2007), the ongoing discovery of new AIS in the Great Lakes has drawn attention to the role of transoceanic NOBOB vessels as vectors for AIS introductions. Such vessels entering the Great Lakes were, until recently, exempt from BWM requirements because they carry no pumpable ballast water and were not, therefore, thought to present a risk of introducing AIS. However, research in recent years has shown that transoceanic NOBOB vessels do indeed pose an invasion risk, as discussed in Chapter 4.

In light of the ever-changing nature of the AIS problem and the lessons learned about transoceanic NOBOB vessels, the committee considers it essential that an adaptive process be established to ensure that prevention strategies are as effective as possible and remain so.[13] This process would examine both individual AIS introductions and the overall problem of AIS in the Great Lakes.

Periodic review of field surveillance data and vessel compliance data from Transport Canada and the U.S. Coast Guard would be undertaken to assess the effectiveness of measures to prevent further introductions of AIS into the Great Lakes by vessels transiting the seaway. The discovery of a new AIS would trigger an expert review to determine possible and likely vectors of introduction and the possible date of entry. If the species was in all likelihood a recent introduction via ballast water, safeguards would have to be reviewed and possibly revised.

Any changes in the relative importance of different AIS vectors and pathways over time would also be subject to periodic review. Such a review would form the basis for recommendations to the governments of Canada and the United States about changes needed in AIS prevention policies across the Great Lakes basin. For example, if the committee's recommendations are fully implemented, the relative importance of the ballast water vector for vessels transiting the seaway would be expected to decline significantly over time. Greater effort could then be directed to other vectors and pathways, which would make up a greater proportion of the much smaller total number of introductions.

In addition, the periodic expert review would be an occasion to assess lessons learned from recent research and to recommend new prevention measures, if needed. For example, if new research were to show that hull fouling is a more important mechanism for AIS

[13] Ruiz and Carlton (2003) envisage a feedback loop similar to the adaptive process recommended by the committee to determine whether prevention strategies are working as designed.

introductions into the Great Lakes than indicated by current evidence, measures to eliminate or control this vector could be identified by the review panel. Similarly, if new information on the role of the ballasting operations of inland vessels in spreading AIS within the Great Lakes indicated a need for greater protection, the review panel could identify revised BWM practices for such vessels.

The committee envisages that a single organization would be responsible for the adaptive process, including conduct of the expert reviews to examine and advise on prevention policies relating to individual AIS introductions and the overall issue of AIS in the Great Lakes. This organization would require a formal binational mandate, together with the appropriate resources, and should be widely perceived as independent and free from conflicts of interest. It should be in a position to draw on the advice of scientific and policy experts in Canada, the United States, and elsewhere in conducting its reviews and developing its recommendations.

Two existing organizations—the International Joint Commission (IJC) and GLFC—appear to be candidates. Both already have binational mandates from Canada and the United States and are widely viewed as independent agencies. However, their mandates would have to be revised to include the proposed adaptive process, and the necessary resources would have to be made available. From a scientific perspective, the adaptive process could be deemed an extension of the current work of GLFC in invasive species control. Although IJC does not possess such hands-on experience, it has extensive experience in convening groups of experts from Canada and the United States to serve on its study boards, which are analogous to the expert review panels envisaged by the committee. Furthermore, the committee notes that a 2003 report from the Standing Committee on Fisheries and Oceans of the Canadian House of Commons recommended that Canada seek a permanent reference (i.e., a formal mandate) to IJC "to coordinate and harmonize binational efforts for action to counter the threat of AIS in the Great Lakes basin" (Standing Committee on Fisheries and Oceans 2003, 27). The proposed adaptive process appears to fall within the scope of such a reference.

> ***Recommendation:* An adaptive process should be established to ensure that policy measures designed to prevent further AIS introductions into the Great Lakes are updated in a timely and periodic fashion to reflect practical experience and knowledge gained through research. The organization responsible for this process should have a binational mandate; adequate resources to conduct its work; and the ability to draw on the advice of scientific and policy experts in Canada, the United States, and elsewhere as needed. It should also be widely perceived as independent and free from conflicts of interest.**

STRENGTHS AND WEAKNESSES

This section discusses the strengths and weaknesses of the committee's recommended suite of actions. While the proposed option is not a silver bullet, as noted earlier, it offers the potential to bring about progress toward the ultimate goals in a timely manner, to minimize undesirable consequences, and to keep options open for an uncertain future. Sources of funding for some of the actions will require further investigation if the committee's recommended approach is to be fully implemented.

Eliminating Further AIS Introductions

Given the number, diversity, and distribution of vectors and pathways for AIS introductions into the Great Lakes, the committee views elimination of all further invasions as unlikely. This view is reinforced by the observation that a number of potential invaders have robust survival strategies that make them particularly difficult to eliminate, such as the ability to reproduce asexually from a single individual (parthenogenesis) or to produce large numbers of highly resistant cysts (resting stages) that can survive hostile environments for long periods until conditions are right for development and possible establishment of a new population.

Despite the challenges of preventing further AIS introductions, the invasion vector and route that are the focus of this study—vessels transiting the St. Lawrence Seaway—are, in the committee's view, easier to control than some other vectors, routes, and pathways. For example, angling and bait fishing, home aquaria, and water gardens are widely distributed geographically, involve large numbers of individual citizens, and are not highly regulated. In addition, controlling these vectors and pathways requires changing human behavior, which many would argue is more difficult to achieve than implementing technological solutions. In contrast, the geographic chokepoint at the entrance to the seaway provides an opportunity for Canada and the United States to enforce measures aimed at preventing vessels from transporting AIS into the Great Lakes. Furthermore, the number of vessels using the seaway annually (approximately 300[14]) is small in absolute terms, and the shipping industry is already highly regulated.

If vessels transiting the seaway were the only vector and route for introducing AIS into the Great Lakes, the committee could well have recommended a different suite of actions from among the possibilities identified in Chapter 5. However, its examination of the shipping vector through the seaway in the broad context of all AIS introductions into the Great Lakes led it to conclude that a combination of technology, enforcement, and monitoring for compliance constitutes the most robust, practical, technically feasible, and effective approach, and the one that offers the most rapid response to the issue. The committee is optimistic that its recommended suite of actions, if fully implemented, would result in substantial progress toward elimination of further introductions of AIS by vessels transiting the seaway and would reduce this vector/route to a minor contributor to the overall problem of AIS introductions into the Great Lakes.

[14] As noted in Chapter 4, the number of transoceanic vessels using the seaway each year is approximately 230, and the Canadian domestic fleet of coastal and inland vessels using the seaway comprises about 70 ships.

Enhancing the Potential for Global Trade

A recent report from the Brookings Institution observes that the Great Lakes and its waterways "offer a tremendous opportunity for reinvigorating the economy of the region" (Austin et al. 2007, 10). Consistent with this observation, the committee's recommended suite of actions, and in particular the harmonization of Canadian and U.S. BWM standards for vessels entering the Great Lakes, could help create an environment conducive to enhancing the region's global trade by removing current regulatory uncertainties about the availability of waterborne freight transportation. In addition, opposition to Great Lakes shipping from those concerned about the negative impacts of ship-vectored AIS introductions could be greatly reduced in the event of substantial progress toward eliminating such introductions. As a result, states and provinces would feel less constrained in promoting economy-enhancing initiatives dependent on waterborne transportation. Possible seaway-dependent, economy-enhancing initiatives include container feeder services between Great Lakes ports and container ports in Nova Scotia, increased short-sea shipping to avoid the growing congestion on certain land-based transportation corridors, and cruise ship operations associated with ecotourism. While it is not clear which, if any, of these ventures will succeed, all have a common thread: the need for unhindered shipping via the St. Lawrence Seaway.

In the current climate of uncertainty about future BWM regulations, shipping companies and their business partners have difficulty in developing sound business plans for future initiatives and in generating the investment capital needed to modernize and expand their capabilities. Specifically, shipowners are reluctant to invest in ballast water treatment systems for existing or new vessels when the goals of the treatment are unclear.

Widespread frustration at the delays in updating the U.S. National Invasive Species Act of 1996 appears to have led some groups to take action themselves to address the AIS problem. For example, the state of Michigan has established its own ballast water legislation, and other Great Lakes states are considering following suit. In addition, environmental groups are taking action through the courts to have ballast water discharges regulated under the U.S. Clean Water Act.

The adoption by the United States of BWM standards equivalent to those of IMO, as recommended by the committee, would not necessarily halt other legislative initiatives, including those by individual states. However, it would remove much of the current uncertainty and result in greater consistency in BWM requirements for vessels using the binational GLSLS system. Many observers have noted that a complex patchwork of BWM requirements would complicate compliance, and the committee concurs with this view.

The committee envisages that the shipping industry would bear the costs of installing and operating ballast water treatment and remote monitoring systems on its vessels. It recognizes that these additional costs could result in some transoceanic vessels ceasing operations into the Great Lakes—probably "tramp" vessels that visit the lakes infrequently. However, its discussions with representatives of the St. Lawrence and Great Lakes maritime industry, the creation of marine industry environmental initiatives such as the binational Green Marine program,[15] and efforts by individual shipping companies to investigate and implement ballast water treatment systems led the committee to conclude that transoceanic shipping through the seaway would not cease as a result of the additional costs associated with the proposed AIS control program.

Forecasting future seaway traffic and associated trade is fraught with difficulties, as discussed in Chapter 2. Moreover, as discussed in Chapter 5, economic development and ensuing trade are influenced by myriad forces, of which policies aimed at preventing further AIS introductions are only one. Thus, the impact of the committee's proposed suite of measures on seaway traffic and on the Great Lakes region's global trade in general is impossible to anticipate with certainty. By keeping the seaway open to vessels that

[15] Information on the marine industry environmental partnership, Green Marine, is available at www.cmc-ccm.com/cmc/english/greenmarine.asp.

take appropriate measures to protect against further AIS introductions, the proposed approach provides opportunities to develop a variety of seaway-dependent, economy-enhancing initiatives. Furthermore, it helps ensure the availability of a variety of transportation options (routes and modes) within the region, thereby resulting in competitive pricing, which may in turn facilitate trade.

Robust Approach

The committee's recommended approach has the advantage that many of the proposed actions, notably the changes in BWM regulations, could be implemented within the next 2 to 3 years. The committee anticipates that the surveillance program, the control and eradication program, and the adaptive process could also be established in at least a preliminary form in a similar time frame, with enhancements being implemented in later years.

The recommended approach has the further advantage of helping to solve the AIS problem in the Great Lakes without transferring it to other locations, such as marine ports on the east coast of Canada and the United States. It also avoids the replacement of one environmental problem with another. While eliminating further introductions of AIS is desirable, it is questionable whether achievement of this goal should be at the expense of increases in other adverse environmental impacts associated with transportation, including greenhouse gas emissions, criteria air contaminant emissions, accidents, and noise. Although data limitations preclude detailed quantitative comparisons of the environmental impacts of different modes of freight transportation, the marine mode is in many respects more environmentally friendly than the rail alternative that could be used to move the relatively low-value bulk commodities shipped on the seaway (Lawson 2007).

The committee's recommended approach does not preclude future options that may further enhance opportunities for global trade in the Great Lakes region, as discussed earlier. In particular, it recognizes that the seaway has a future value as a component of the region's transportation network, even though that value cannot currently be quantified. In addition, it does not preclude the possibility of strengthening measures to protect against further AIS introductions, if experience and improved knowledge indicate that such action is necessary. The recommended adaptive process aims to facilitate such revisions by establishing a formal mechanism whereby necessary changes to prevention policies would be identified and brought to the attention of the governments of Canada and the United States.

Resource Requirements

Experience has shown that solving environmental problems requires resources, and the present case is no exception. The committee anticipates that full implementation of its suite of recommended actions will require resources over and above those already devoted to the prevention of further AIS introductions into the Great Lakes. In particular, the recommended surveillance, control and eradication, and adaptive management initiatives will require new dedicated and continuing funding to ensure that their objectives are met. Although limited opportunities exist to leverage ongoing monitoring efforts as part of the surveillance program, these efforts alone are insufficient to ensure that the overall scope of the proposed program is sufficiently comprehensive to detect new AIS in a timely fashion.

The committee anticipates that the recommended actions to be taken by Transport Canada and the U.S. Coast Guard would be supported by federal funding, given that they are closely related to the two agencies' current regulatory activities. The question remains, however, as to what extent federal funding (i.e., taxpayer revenues) could (or should) cover some of the other recommended actions, notably the surveillance, control, and adaptive management initiatives.

Application of the "user pays" principle is one approach to generating funds for AIS prevention measures. As noted earlier, the committee envisages that the shipping industry will bear the costs of installing and operating shipboard systems on its vessels. A further option could be to levy user fees on vessels transiting the seaway to help cover the costs of the recommended surveillance, control, and adaptive management efforts. However, because these proposed efforts address the whole gamut of vectors and pathways by which AIS enter the Great Lakes, and not just shipping through the seaway, additional sources of funding would be needed. Furthermore, the imposition of such user fees would raise a number of potentially divisive issues, including the effects of assessing environmental fees against one mode of transportation (shipping) and not others (rail, truck), and against marine carriers in the Great Lakes region but not in other geographic regions. As noted in Chapter 5, the debate about the extent to which users of transportation services should pay for externalities, such as the environmental costs of transportation, is complicated (see, for example, TRB 1996) and well beyond the scope of this report.

In view of these complexities and those inherent in other funding approaches (see, for example, Stewart 2007), the committee notes that further investigation of funding sources will be needed to ensure full implementation of its recommended AIS control program.

MANAGING THE WATERS OF THE GREAT LAKES—A VISION FOR THE FUTURE

In the committee's view, changes driven by nature and by human activities on the Great Lakes themselves and on the immense drainage basin call for collective management. The present system of Great Lakes' governance is fragmented among agencies and offices of two federal governments; eight states; two provinces; and myriad municipalities, local governments, and aboriginal peoples. All manner of treaties, agreements, institutions, and organizations have been created to address activities relating to the quantity and quality of waters from the lakes, such as commerce, planning, and pollution control. While many of these endeavors are cooperative efforts between Canada and the United States, there is no comprehensive, coordinated, and coherent binational governance or management structure that can identify shared societal goals and ensure that the Great Lakes are managed in such a way that desired values and uses are nurtured and sustained.

During its work, the committee observed that discrepancies between Canadian and U.S. approaches can complicate efforts to prevent further AIS introductions into the Great Lakes. For example, inconsistencies between Canadian and U.S. BWM regulations complicate compliance for vessels but do not provide a greater degree of protection against AIS introductions for the nation with more stringent requirements. In contrast, efforts by the two nations to work together in preventing further AIS introductions can optimize the use of available resources to ensure maximum effectiveness, as illustrated by the example of the binational Ballast Water Working Group, which was formed in 2006 to address inspection and enforcement procedures for vessels entering the GLSLS system (see Chapter 4).

To avoid unacceptable delays, the committee proposes that its recommended actions be undertaken by existing organizations with the appropriate expertise. In the case of the surveillance, control, and adaptive management initiatives, this approach will likely require an expansion of the existing mandates of relevant organizations. The committee recognizes that the issues of Great Lakes governance and environmental protection are far broader in scope than the subject of the present report. Nonetheless, it envisions that, in the longer term, the recommended AIS control program might be implemented most effectively within the context of a revised governance structure, such as a new binational institution charged with managing the waters of the Great Lakes. The new institution's mission would be to ensure that the Great Lakes support the values and uses important to society in a sustainable manner, consistent with a vision proposed by Conservation Ontario (2006, 1):

> The Great Lakes Basin is a global treasure and the Great Lakes and St. Lawrence region is one where people, the environment, and the economy are healthy and thrive for generations to come.

KEY POINTS

- The only way to eliminate further AIS introductions into the Great Lakes by vessels transiting the seaway would be to close the waterway to all vessel traffic. Such action, which appears unlikely from a political perspective, would eliminate a trade route into and out of the Great Lakes and would not, therefore, enhance the region's potential for global trade.
- Closing the seaway to transoceanic shipping would reduce substantially the risk of AIS introductions by vessels using the waterway. However, this action would not address the AIS problem in the Great Lakes in a timely fashion and would increase the cost of moving goods. It could also result in adverse environmental impacts associated with alternative transportation modes and routes, copycat actions or other reprisals by trading partners of the United States and Canada, and the elimination of future transportation options for the Great Lakes region.
- A comprehensive technology-based AIS program targeting all vessels transiting the seaway would constitute a practical and technically feasible approach that would go a long way toward eliminating further ship-vectored introductions into the Great Lakes and could help enhance the region's potential for global trade.
- A requirement for all transoceanic and coastal vessels transiting the seaway to conduct BWE or saltwater flushing, if combined with effective enforcement, would be an important step in ensuring that policies aimed at preventing further AIS introductions into the Great Lakes reflect the best current understanding of aquatic invasion biology and proven BWM practices.
- The adoption of a single set of ballast water standards for the Great Lakes equivalent to the proposed IMO BWM standards would provide a robust basis for evaluating the effectiveness of shipboard ballast water treatment systems and for informing future decisions about AIS prevention policies. This approach could also encourage investment by equipment manufacturers and shipowners in the development and demonstration of ballast water treatment systems for vessels entering the Great Lakes.

- A binational science-based surveillance program to monitor for the presence of new AIS in the Great Lakes would provide information that could be used to (*a*) investigate possible deficiencies in prevention strategies and (*b*) develop capabilities for containment, control, and possible subsequent eradication following the discovery of any new AIS.
- An adaptive process that takes account of new knowledge and lessons learned in preventing AIS introductions would ensure that the proposed technology-based AIS control program responds to the ever-changing challenges posed by AIS in the Great Lakes.

REFERENCES

Abbreviations

IMO	International Maritime Organization
NRC	National Research Council
SLSDC	St. Lawrence Seaway Development Corporation
TRB	Transportation Research Board

Austin, J. C., S. Anderson, P. N. Courant, and R. E. Litan. 2007. *Healthy Waters, Strong Economy: The Benefits of Restoring the Great Lakes Ecosystem*. Brookings Institution, Washington, D.C. www.healthylakes.org/site_upload/upload/GrtLakesCostBenefit.pdf.

Conservation Ontario. 2006. Position on Great Lakes Sustainability. Dec. conservation-ontario.on.ca/policy-issues/CO_GL_position.pdf.

Corbett, J. J., and J. J. Winebrake. 2007. Sustainable Goods Movement: Environmental Implications of Trucks, Trains, Ships, and Planes. *Environmental Management,* Nov., pp. 8–12. coast.cms.udel.edu/Papers/EMCorbettWinebrake2007.pdf.

Costello, C., J. M. Drake, and D. M. Lodge. 2007. Evaluating an Invasive Species Policy: Ballast Water Exchange in the Great Lakes. *Ecological Applications,* Vol. 17, pp. 655–662.

Gollasch, G., M. David, M. Voigt, E. Dragsund, C. Hewitt, and Y. Fukuyo. 2007. Critical Review of the IMO International Convention on the Management of Ships' Ballast Water and Sediments. *Harmful Algae,* Vol. 6, pp. 585–600.

Gray, D. K., T. H. Johengen, D. F. Reid, and H. J. MacIsaac. 2007. Efficacy of Open-Ocean Ballast Water Exchange as a Means of Preventing Invertebrate Invasions Between Freshwater Ports. *Limnology and Oceanography,* Vol. 52, pp. 2386–2397.

Grigorovich, I. A., A. V. Korniushin, D. K. Gray, I. C. Duggan, R. I. Colautti, and H. J. MacIsaac. 2003. Lake Superior: An Invasion Coldspot? *Hydrobiologia,* Vol. 499, pp. 191–210.

Hart, R. C. 1988. Zooplankton Feeding Rates in Relation to Suspended Sediment Content: Potential Influences on Community Structure in a Turbid Reservoir. *Freshwater Biology,* Vol. 19, pp. 123–139.

Hodgson, J. R. 2007. *Carrots and Sticks: Opportunities to Accelerate the Development and Adoption of Ballast Water Treatment Technologies for Vessels Operating into the Great Lakes.* Hodgson and Associates, Halifax, Nova Scotia, April.

IMO. 2004. *International Convention for the Control and Management of Ships' Ballast Water and Sediments.* London, United Kingdom.

Jenkins, P. T. 2007. *Brine as a Treatment Solution for the Control of Aquatic Nuisance Species Introductions into the Great Lakes by NOBOB Vessels.* Prepared for Transport Canada Marine Safety by Philip T. Jenkins and Associates, Ltd., Fonthill, Ontario.

Kazumi, J. 2007. *Ballast Water Treatment Technologies and Their Application for Vessels Entering the Great Lakes via the St. Lawrence Seaway.* University of Miami, Fla., May.

Kelly, D. W. 2007. *Vectors and Pathways for Nonindigenous Aquatic Species in the Great Lakes.* Landcare Research, Dunedin, New Zealand, June.

Kelly, D. W., and J. Kazumi. 2007. *Retroactive Evaluation of International Maritime Organization Ballast Water Standards.* Landcare Research, Dunedin, New Zealand, and University of Miami, Fla., Sept.

Kirk, K. L. 1991. Inorganic Particles Alter Competition in Grazing Plankton: The Role of Selective Feeding. *Ecology,* Vol. 72, pp. 915–923.

Lake Carriers' Association and Canadian Shipowners Association. 2001. *Voluntary Management Practices to Reduce the Transfer of Aquatic Nuisance Species Within the Great Lakes by U.S. and Canadian Domestic Shipping.* Jan. 26.

Lawson, J. 2007. *The Environmental Footprint of Surface Freight Transportation.* Lawson Economics Research, Inc., Ottawa, Ontario, Canada, June.

Lloyd's Register. 2007. Ballast Water Treatment Technology: Current Status. June.

Millerd, F. 2007. *Global Climate Change and Great Lakes International Shipping.* Wilfrid Laurier University, Waterloo, Ontario, Canada, May.

NRC. 1996. *Stemming the Tide: Controlling Introductions of Nonindigenous Species by Ships' Ballast Water.* National Academy Press, Washington, D.C.

Raaymakers, S. 2001. *1st International Ballast Water Treatment Standards Workshop.* Globallast Monograph Series No. 4, Workshop Report, IMO, London, March 28–30. globallast.imo.org/monograph%204%20standards%20workshop.pdf.

Reid, D. F., T. H. Joehengen, H. MacIsaac, F. Dobbs, M. Doblin, L. Drake, G. Ruiz, and P. Jenkins. 2007. *Identifying, Verifying, and Establishing Options for Best Management*

Practices for NOBOB Vessels. Final report to the Great Lakes Protection Fund. www.glerl.noaa.gov/res/Task_rpts/2004/aisreid04-1.html.

Ruiz, G. M., and J. T. Carlton. 2003. Invasion Vectors: A Conceptual Framework for Management. In *Invasive Species: Vectors and Management Strategies* (G. M. Ruiz and J. T. Carlton, eds.), Island Press, pp. 459–504.

SLSDC. 2007. Seaway Regulations and Rules: Periodic Update, Various Categories. Notice of Proposed Rulemaking. *Federal Register,* Vol. 72, No. 249, Dec. 31, pp. 74247–74250.

Standing Committee on Fisheries and Oceans. 2003. *Aquatic Invasive Species: Uninvited Guests.* House of Commons, Canada, May.

Stewart, R. D. 2007. *Do Institutional Mechanisms Exist to Set and Enforce Standards for the Great Lakes That Exceed the Ballast Water Performance and Exchange Standards Established by the International Maritime Organization?* University of Wisconsin, Superior, June 11.

Taylor, J. C., and J. L. Roach. 2005. *Ocean Shipping in the Great Lakes: Transportation Cost Increases That Would Result from a Cessation of Ocean Vessel Shipping.* Grand Valley State University, Grand Rapids, Mich., Aug. www.gvsu.edu/cms3/assets/C6D78A67-0AEF-0264-A38619EC6FB0793A/OceanShippingReport091105.pdf.

Taylor, J. C., and J. L. Roach. 2007. *Ocean Shipping in the Great Lakes: An Analysis of Issues, Phase 2.* Grand Valley State University, Grand Rapids, Mich., Oct. www.gvsu.edu/business/index.cfm?id=11971F16-DBAF-2179-96B0680A95CC6F83.

TRB. 1996. *Special Report 246: Paying Our Way: Estimating Marginal Social Costs of Freight Transportation.* National Research Council, Washington, D.C.

U.S. Coast Guard. 2007. *2006 Summary of Great Lakes Ballast Water Management Exams.* Ninth District.

Vander Zanden, M. J. 2007. *Surveillance and Control of Aquatic Invasive Species in the Great Lakes.* University of Wisconsin, Madison, June 15.

APPENDIX A

COMMITTEE MEETINGS AND OTHER ACTIVITIES

FIRST COMMITTEE MEETING

May 23–24, 2006, Washington, D.C.

The following presentations were made to the committee by invited speakers and individual committee members:

Sponsor Expectations for the Project
David Rankin, *Great Lakes Protection Fund*

Shipping on the Great Lakes St. Lawrence Seaway and Current Ballast Water Regulations
Phil Jenkins, *committee member*

Vectors for Introduction of Nonindigenous Aquatic Species into the Great Lakes
Hugh MacIsaac, *committee member*

Current Status of Ballast Water Treatment
Tom Waite, *committee member*

Natural Resources Panel

Panelists were asked to discuss their perspectives on the impact of aquatic invasive species (AIS) on the natural resources of the Great Lakes region.

John Dettmers, *Great Lakes Fishery Commission*
Anthony Earl, *Quarles and Brady Law Firm*

David Lodge, *University of Notre Dame*
Chuck O'Neill, *National Aquatic Nuisance Species Clearinghouse*

Seaway Users Panel

Panelists were asked to outline their organization's stake in the Great Lakes St. Lawrence Seaway (GLSLS) system and to describe any actions their organization is taking to prevent further AIS introductions into the Great Lakes by vessels transiting the seaway.
Steve Fisher, *American Great Lakes Ports Association*
Ray Johnston, *Chamber of Maritime Commerce*
Ivan Lantz, *Shipping Federation of Canada*
Georges Robichon, *Fednav*

Seaway Management and Infrastructure Panel

Panelists were asked to outline their organization's role and responsibilities vis-à-vis the GLSLS system and to describe any actions their organization is taking to prevent further AIS introductions into the Great Lakes by vessels transiting the seaway.
Peter Burgess, *St. Lawrence Seaway Management Corporation*
Marc Fortin, *Transport Canada*
Kevin O'Malley, *St. Lawrence Seaway Development Corporation*
David Wright, *U.S. Army Corps of Engineers*

Ocean Shipping in the Great Lakes: Transportation Cost Increases That Would Result from a Cessation of Ocean Vessel Shipping

Presentation of report prepared for the Joyce Foundation
John Taylor, *Grand Valley State University*
Jim Roach, *JL Roach, Inc.*

Discussants
David Kriger, *iTRANS Consulting, Inc.*
Jerry Fruin, *University of Minnesota*
Hazem Ghonima, *Chartered Institute of Logistics and Transport in North America, and TAF Consultants*
Jim McClellan, *independent consultant*

SITE VISITS

Visit to Hamilton Port Authority, Hamilton, Ontario, August 28, 2006.

Visit to St. Lawrence Seaway Management Corporation, St. Catharines, Ontario, and tour of Welland Canal, August 28, 2006.

SECOND COMMITTEE MEETING

August 29–30, 2006, Toronto, Ontario

The following presentations were made to the committee by invited speakers:

Multimodal Freight Movements in the Great Lakes Region
Rod Taylor, *independent consultant*

Freight Movements by Rail in the Great Lakes Region: Current Status and Future Opportunities
Malcolm Cairns, *Canadian Pacific Railway*

Highway H2O
Richard Corfe, *St. Lawrence Seaway Management Corporation*

New Opportunities to Optimize the Great Lakes Maritime Transportation System
Richard Stewart, *University of Wisconsin, Superior, and Great Lakes Maritime Research Institute*

New Ballast Water Treatment Technologies
Junko Kazumi, *University of Miami*

Shipboard Ballast Water Treatment Systems
Richard Everett, *U.S. Coast Guard*

Ballast Water Treatment Technology Requirements for Vessels Operating on the Great Lakes
Chris Wiley, *Fisheries and Oceans Canada and Transport Canada*

THIRD COMMITTEE MEETING
February 4–6, 2007, Irvine, California

The following presentations were made to the committee by the authors of its commissioned papers:

Map of Vectors and Pathways for Nonindigenous Aquatic Species
David Kelly, *University of Windsor*

Ballast Water Treatment Technologies and Their Application for Vessels Operating on the Great Lakes
Junko Kazumi, *University of Miami*

Surveillance and Control of Invasive Species in the Great Lakes
Jake Vander Zanden, *University of Wisconsin, Madison*

Institutional Mechanisms for More Stringent Ballast Water Standards
Richard Stewart, *University of Wisconsin, Superior*

Global Climate Change and Great Lakes International Shipping
Frank Millerd, *Wilfrid Laurier University*

Environmental Footprint of Surface Freight Transportation
John Lawson, *Lawson Economics Research, Inc.*

Carrots and Sticks: Opportunities to Accelerate the Development and Adoption of Ballast Water Treatment Technologies
Richard Hodgson, *Hodgson and Associates*

FOURTH COMMITTEE MEETING
May 7–9, 2007, Toronto, Ontario

On May 7, 2007, the committee hosted a public meeting to gain a better understanding of stakeholder views about possible approaches to meeting the two project criteria. The agenda for this public meeting and a list of participants are provided in Appendix C.

FIFTH COMMITTEE MEETING

July 30–31, 2007, Washington, D.C.

The following presentations were made to the committee by invited speakers and individual committee members:

It's Not Just About Ballast Water: Opportunities and Successes
Doug Jensen, *University of Minnesota Sea Grant Program*

Report on Investigation of Shipboard Technologies for Monitoring Ballast Water Operations
Hugh MacIsaac, *committee member*

APPENDIX B

COMMISSIONED PAPERS AND AUTHORS

Ballast Water Treatment Technologies and Their Application for Vessels Entering the Great Lakes via the St. Lawrence Seaway. Junko Kazumi, Office of Technology Transfer and Industry Research, University of Miami, Florida, May 2007.

Carrots and Sticks: Opportunities to Accelerate the Development and Adoption of Ballast Water Treatment Technologies for Vessels Operating into the Great Lakes. J. Richard Hodgson, Hodgson and Associates, Marine Policy Consulting, Halifax, Nova Scotia, April 17, 2007.

Do Institutional Mechanisms Exist to Set and Enforce Standards for the Great Lakes That Exceed the Ballast Water Performance and Exchange Standards Established by the International Maritime Organization? Richard D. Stewart, Transportation and Logistics Research Center, Department of Business and Economics, University of Wisconsin, Superior, June 11, 2007.

The Environmental Footprint of Surface Freight Transportation. John Lawson, Lawson Economics Research, Inc., Ottawa, Ontario, June 2007.

Global Climate Change and Great Lakes International Shipping. Frank Millerd, Department of Economics, Wilfrid Laurier University, Waterloo, Ontario, May 2007.

Retroactive Evaluation of International Maritime Organization Ballast Water Standards. David W. Kelly, Landcare Research, Dunedin, New Zealand, and Junko Kazumi, Office of Technology Transfer and Industry Research, University of Miami, Florida, September 10, 2007.

Surveillance and Control of Aquatic Invasive Species in the Great Lakes. M. Jake Vander Zanden, Center for Limnology, University of Wisconsin, Madison, June 15, 2007.

Vectors and Pathways for Nonindigenous Aquatic Species in the Great Lakes. David W. Kelly, Landcare Research, Dunedin, New Zealand, June 2007.

NOTE: The commissioned papers are available at www.trb.org/news/blurb_detail.asp?id=9281.

APPENDIX C

PUBLIC MEETING AGENDA AND PARTICIPANTS

Aquatic Invaders and Global Trade: Options for the Great Lakes Region

Trinity Ballroom
Marriott Toronto Downtown Eaton Center
525 Bay Street
Toronto, Ontario M5G 2L2

Monday, May 7, 2007

AGENDA

8:30–9:00 a.m.	Meeting Registration
9:00–9:15 a.m.	**Welcome and Meeting Objectives** *Jerry Schubel, Aquarium of the Pacific, committee chair*
9:15–9:30 a.m.	**Establishing the Information Base** *Reds Wolman, Johns Hopkins University, committee member*

This talk will outline the committee's approach to gathering the information needed to identify and explore options meeting the two project criteria, namely, enhance the potential for global trade in the Great Lakes region and eliminate further introductions of non-indigenous aquatic species into the Great Lakes by vessels transiting the St. Lawrence Seaway.

9:30–10:15 a.m.	**COMMISSIONED PAPERS, PART 1**
	Introduction to Expert Papers Commissioned by the Committee *Jerry Schubel, committee chair*
9:30–9:45 a.m.	**Vectors and Pathways for Nonindigenous Aquatic Species**
	Context and purpose of paper *Hugh MacIsaac, University of Windsor, committee member*
	Paper highlights *David Kelly, Landcare Research, Dunedin, New Zealand, paper author (presented by Hugh MacIsaac)*
9:45–10:00 a.m.	**Ballast Water Treatment Technologies and Their Application for Vessels Operating on the Great Lakes**
	Context and purpose of paper *Tom Waite, Florida Institute of Technology, committee member*
	Paper highlights *Junko Kazumi, University of Miami, paper author*
10:00–10:15 a.m.	**Surveillance and Control of Invasive Species in the Great Lakes**
	Context and purpose of paper *Joy Zedler, University of Wisconsin, Madison, committee member*
	Paper highlights *Jake Vander Zanden, University of Wisconsin, Madison, paper author*
10:15–10:35 a.m.	Break

10:35–11:35 a.m.	**COMMISSIONED PAPERS, PART 2**
10:35–10:50 a.m.	**Global Climate Change and Great Lakes International Shipping**
	Context and purpose of paper *Frank Quinn, consultant, committee member*
	Paper highlights *Frank Millerd, Wilfrid Laurier University, paper author*
10:50–11:05 a.m.	**Environmental Footprint of Surface Freight Transportation**
	Context and purpose of paper *Trevor Heaver, University of British Columbia, committee member*
	Paper highlights *John Lawson, Lawson Economics Research, Inc., paper author*
11:05–11:20 a.m.	**Carrots and Sticks: Opportunities to Accelerate the Development and Adoption of Ballast Water Treatment Technologies**
	Context and purpose of paper *Steven Popper, Rand Corporation, committee member*
	Paper highlights *Dick Hodgson, Dalhousie University, paper author*
11:20–11:35 a.m.	**Institutional Mechanisms for More Stringent Ballast Water Standards**
	Context and purpose of paper *Phil Jenkins, Philip T. Jenkins and Associates, Ltd., committee member*

Paper highlights
Richard Stewart, University of Wisconsin, Superior, paper author

11:35 a.m.–12:15 p.m. **COMMENTS FROM MEETING PARTICIPANTS, PART 1**

Participants should limit their comments to a maximum of 5 minutes.

Participants are invited to suggest approaches to meeting the two project criteria, namely,

- Enhance the potential for global trade in the Great Lakes region, and
- Eliminate further introductions of nonindigenous aquatic species into the Great Lakes by vessels transiting the St. Lawrence Seaway.

Suggested approaches should focus on actions that can be taken on the basis of current knowledge, rather than on further studies of the issue.

12:15–1:45 p.m. Lunch

1:45–2:30 p.m. **Possible Actions,** *Jerry Schubel, committee chair*

To further stimulate comment and discussion, this talk will add to the list of possible actions identified by meeting speakers by drawing on suggestions from a variety of sources. The actions presented will *not* represent the committee's recommendations, which have yet to be developed.

2:30–3:15 p.m. **COMMENTS FROM MEETING PARTICIPANTS, PART 2**

Participants should limit their comments to a maximum of 5 minutes.

Participants are invited to suggest approaches to meeting the two project criteria, namely,

- Enhance the potential for global trade in the Great Lakes region, and

- Eliminate further introductions of nonindigenous aquatic species into the Great Lakes by vessels transiting the St. Lawrence Seaway.

Suggested approaches should focus on actions that can be taken on the basis of current knowledge, rather than on further studies of the issue.

3:15–3:35 p.m.	Break
3:35–4:15 p.m.	**COMMENTS FROM MEETING PARTICIPANTS, PART 2 (continuation)**
4:15–5:15 p.m.	**Group Discussion**
5:15–5:30 p.m.	**Meeting Wrap-Up,** *Jerry Schubel, committee chair*

WORKSHOP PARTICIPANTS

Marilyn Baxter*
Hamilton Port Authority

Mark Burrows
International Joint Commission, Great Lakes Regional Office

Jennifer Caddick*
Save the River

Richard Corfe*
St. Lawrence Seaway Management Corporation

Rich Everett
U.S. Coast Guard

Dennis Fortune
Consultant

Jim Galloway
U.S. Army Corps of Engineers

Jennifer Gerardi
Trojan Technologies, Inc.

Caroline Gravel
Shipping Federation of Canada

Ken Haagsma
Trojan Technologies

Erica Heintz
New York State Assembly, Legislative Commission on Water Resource Needs

Jim Houston
International Joint Commission, Ottawa

Marc Hudon
Nature Québec

Ray Johnston*
Chamber of Maritime Commerce

Neil Kochhar
Transport Canada

Klaus Koehler
Canadian Food Inspection Agency

Ivan Lantz*
Shipping Federation of Canada

Carrie Mann
St. Lawrence Seaway Development Corporation

Bob Matthews*
Hamilton Port Authority

Michael Morencie
Ontario Ministry of Natural Resources

Ralph Moulton
Environment Canada

Mary Muter*
Georgian Bay Association

Jennifer Nalbone*
Great Lakes United

John Nevin
International Joint Commission, U.S. Section

Karen Phillips*
U.S. Coast Guard Ninth District

Jim Roach
JL Roach, Inc.

Georges Robichon
Fednav Limited

Dennis Schornack
International Joint Commission, U.S. Section

John Taylor*
Grand Valley State University

Russell Van Herik
Great Lakes Protection Fund

Raymond Vaughan
New York State Attorney General's Office

Chris Wiley
Transport Canada and Fisheries and Oceans Canada

John Wilson
Georgian Bay Association

David Wright
U.S. Army Corps of Engineers

*Indicates participants who presented prepared remarks during the public comment sessions.

Written comments were received from the following individuals who were unable to attend the meeting:

Margaret Dochoda
Ann Arbor, Michigan

Richard Smith
Lucky 7 Charters, Dunkirk, New York

APPENDIX D

ECONOMIC BENEFITS OF TRANSOCEANIC SHIPPING THROUGH THE ST. LAWRENCE SEAWAY

Estimating the economic benefits of transoceanic shipping through the St. Lawrence Seaway is a challenging task. On the assumption that closing the seaway to transoceanic vessels would change the costs of shipping goods from points outside the seaway into the Great Lakes and vice versa, the challenge is to quantify the changes in these costs. One would need to determine, for example, whether break-bulk import cargoes arriving on transoceanic vessels could be transshipped from Quebec City or Montreal to interior destinations in Canada and the United States via road or rail without a significant increase in delivered cost and without straining the capacities of the alternative modes. A conclusive assessment would require access to a computable general equilibrium (CGE) model[1] linked to the transportation network in such a way that all flows between origins and destinations would be mapped onto this network.[2] In addition, one would need assessments of the capacity

[1] A CGE model essentially captures the circular flow of demand–production (supply)–income in an economy. On the basis of typical assumptions about the behavior of producers, consumers, and government, the impacts of changes in demand or supply and the effects of government policy (tariff reduction, new taxes, or deregulation) on the economy can be traced.

[2] Most CGEs assume that the transportation cost is determined by the shipper (someone interested in moving a commodity from *a* to *b* or purchasing a commodity from *b* to be moved to *a*). In only a few models have there been attempts to "map" the transportation flows onto multimodal networks, and even in those few cases attention is usually only on road and rail. Thus, CGE models in their present form, while more flexible than other models, fail to capture the peculiarities of the transportation network.

limitations of all links (i.e., their ability to absorb additional demands without straining capacities) and a further assessment of the diversion possibilities. For the latter, one would need to know whether, absent an ability to use the seaway, an exporter (importer) has an alternative market (source) in the event that the alternative transportation mode proved too expensive. As discussed in the following paragraphs, a review of the literature suggests that partial answers are available to some of the relevant questions, but the comprehensive analysis needed to quantify with confidence the economic impacts of closing the seaway to transoceanic vessels is lacking.

The study by Taylor and Roach (2005) probably comes closest to an overall assessment (see Box D-1). To the committee's knowledge, it is the only study to date that offers an estimate of handling and transportation cost savings attributed to transoceanic vessels transporting cargoes via the seaway. The study's principal conclusion is that a cessation of transoceanic shipping on the Great Lakes would result in a transportation cost penalty of approximately US$55 million annually.

The committee notes that the Taylor and Roach estimate does not include the transportation cost savings associated with coastal vessels that move goods between Great Lakes ports and coastal ports within the Canadian and U.S. exclusive economic zones (EEZs). These vessels are also a possible source of aquatic invasive species (AIS), as discussed in Chapter 4.[3] The vessel traffic data from the seaway corporations include coastal vessels within the "laker" category, but the coastal component of the laker traffic cannot be readily extracted. Thus, assessing the transportation cost savings for coastal vessels using the seaway is problematic.

The methodology of Taylor and Roach is analogous to that of earlier researchers who have faced similar questions, and consequently the study has shortcomings often attributed to these types of efforts. In particular, these analyses fail to consider a spatial

[3] Contrary to recent evidence, Taylor and Roach state that "aquatic invasives are introduced by oceangoing vessels, and not by lakers that remain within the North American EEZ" (2005, p. 6).

BOX D-1

Analysis of Transportation Cost Increases That Would Result from a Cessation of Transoceanic Shipping in the Great Lakes

A 2005 study sponsored by the Chicago-based Joyce Foundation, which supports efforts to protect the natural environment of the Great Lakes, analyzed the transportation cost benefits to Canada and the United States resulting from the movement of freight cargoes into and out of the Great Lakes via the St. Lawrence Seaway on transoceanic vessels (Taylor and Roach 2005). The methodology used, a comparative shipper cost approach, involved (*a*) identifying the current level and type of transoceanic vessel traffic on the GLSLS system and estimating its "door-to-door" transportation and handling costs, (*b*) identifying alternative modes and routings for commerce identified in (*a*) and estimating associated door-to-door transportation and handling costs, and (*c*) estimating quantities moving by alternative modes and routings and calculating the cost for the most likely alternative mode and routing. The analysis centered on an estimated 12.3 million tonnes (Mt) of transoceanic vessel cargo that transited the Montreal–Lake Ontario (MLO) section of the seaway in 2002. During the same year an estimated 17.7 Mt of laker cargo also moved through the MLO section. The transoceanic vessel cargo included 4.1 Mt of grain exports, 4.6 Mt of imported steel, and 3.6 Mt of other commodities. On the basis of the outlined methodology and commodity handling cost and transportation rate data collected from various sources, the annual cost savings associated with use of transoceanic vessels entering the Great Lakes was estimated at US$54.9 million. Closure of the seaway to transoceanic vessels was estimated to divert 2.97 Mt to lakers, 5.98 Mt to railroads, 1.18 Mt to barge, and 2.16 Mt to truck. It was assumed that the diverted traffic would not increase the transportation rates of the involved modes.

equilibrium framework and require the researcher to select alternative routes and modes arbitrarily, without consideration of related trade flow patterns and associated costs. Criticism also often centers on various assumptions made by researchers with regard to the effect of diverted traffic on transportation rates and the routings of other modes.[4, 5]

A more recent study estimated the transportation cost savings for all Great Lakes St. Lawrence Seaway (GLSLS) shipping, rather than merely the transoceanic shipping through the seaway considered by Taylor and Roach (Transport Canada et al. 2007). The estimated savings of $2.7 billion per year were calculated in terms of the transportation and handling costs that GLSLS shippers would have incurred had they used other modes of transportation. The methodology was based on a rate analysis and shipper survey, but no further details are provided in the report. No attempt was made to explore the impact on cost savings of alleviating possible congestion on other modes through use of the GLSLS. The committee notes that a more detailed evaluation would need to explore the costs of maintaining the GLSLS system to realize the estimated savings and then to evaluate the benefits and costs of this choice vis-à-vis other transportation investments.

In contrast to the Taylor and Roach study, Martin Associates (2001a) provided a more traditional assessment of the economic impact of the GLSLS system. That analysis was based on assessment of public data supplemented by interviews with approximately 400 firms at the U.S. Great Lakes ports. (No Canadian data or ports were surveyed.) The analysis identified (*a*) the direct impact from the employment, income, and revenue of firms

[4] Comparing transportation rates does not take into account the costs associated with changes in transportation and logistics systems. These changes can be significant for the people and firms affected and for the economy.

[5] The Taylor and Roach study estimates alternative costs of transporting goods by modes and routes other than transoceanic vessels through the seaway. While the transportation rates and associated service levels are the characteristics on which shippers base their traffic allocation decisions, these rates are not the same as the economic costs to society. Such economic costs would measure (and compare) the future value of resources consumed under the alternative transportation scenarios.

associated with the maritime community at each port and (*b*) induced impacts resulting from these direct impacts including supplier chain linkages and the expenditures from wages and salaries. The employment estimate for 2000 was that "152,508 jobs are in some way related to the 192 million tons of cargo moving on the Great Lakes St. Lawrence Seaway system in 2000" (p. E-2). About 44,000 are the direct jobs, which implies a crude multiplier or ripple effect of 3.4: for every direct job, there are 2.4 additional jobs. There is concern whether the number of jobs entirely centered on shipping activities on the Great Lakes is an overestimate. Furthermore, the analysis estimates that the direct job increases were larger (by 50 percent) than the national increase in employment over the period 1991–2000. A companion study (Martin Associates 2001b) assessed the cost savings associated with the GLSLS system at $1.2 billion for 2000. However, the methodology was not detailed, so what alternatives were explored is not clear. The report also claims that 37,000 jobs might not have located in the region without the Great Lakes as a navigable system—an assertion that does not appear to be based on any formal economic assessments.

A report from the Midwest Regional University Transportation Center (2006) provides a more detailed assessment of the transportation system for the region comprising the states of Minnesota, Iowa, Wisconsin, Illinois, Indiana, Michigan, and Ohio. Valuable data and perspectives are provided, but the focus is on the anticipated effects of increasingly congested road and rail networks. The authors put forward ideas about coordination among networks and the notion that water-based transportation systems could play an increasing role in meeting the future needs of the region. The analysis does not, however, provide the type of integration with a CGE model that would be necessary to evaluate fully the impacts and savings associated with seaway closure.

Cangelosi and Mays (2006) have provided a scoping report for the analysis of the potential impacts of commercial vessels on the GLSLS that would be free of invasive species. As befits a scoping study, the economic analysis in this report relies on other documents, such as the Taylor and Roach study (2005) and Martin Associates reports (2001a; 2001b). Good examples of supply chains are presented, thereby providing the basis for consideration of disruptions of reroutings. However, the report does not provide the formal analysis that would be required to assess the economic impacts of seaway closure to transoceanic vessels.

Finally, an ongoing investigation of the Midwest is being conducted by the Brookings Institution (Austin and Affolter-Caine 2006); to date, the project is at the stage of reporting trends and the spatial distribution of economic activity and of positing some policy initiatives. No formal economic model underlies the report.

In assessing the results of its literature review, the committee observed that the Taylor and Roach estimate of the cost benefit of transoceanic shipping on the Great Lakes (US$55 million annually) has been widely cited. Clearly, this initial estimate has contributed to the discussion of closure of the seaway to transoceanic vessels as a possible means of preventing further ship-vectored introductions of AIS into the Great Lakes. The committee notes, however, that a single estimate with recognized limitations and imperfections is not a robust basis for informing a major transportation policy decision—whether to close the seaway to transoceanic vessels. In the case of deregulation of the U.S. airline industry, for example, numerous analyses by experts with varying perspectives and areas of specialization explored the likely implications of deregulation. The results of these analyses were available to inform the public policy decision to proceed with deregulation. As the committee's literature review indicates, current analyses do not provide a comparable level of understanding about the likely economic impacts of any decision to close the seaway to transoceanic vessels. Analyses of the environmental and quality-of-life impacts would also be needed to inform any such decision.

REFERENCES

Austin, J., and B. Affolter-Caine. 2006. *The Vital Center: A Federal–State Compact to Renew the Great Lakes Region.* Brookings Institution, Washington, D.C. www.brookings.edu/metro/pubs/20061020_renewgreatlakes.pdf.

Cangelosi, A., and N. Mays. 2006. *Great Ships for the Great Lakes? Waterborne Trade Free of Invasive Species in the Great Lakes–St. Lawrence Seaway System: A Scoping Report for the Great Ships Initiative.* Northeast-Midwest Institute, Washington, D.C. www.nemw.org/scopingreport.pdf.

Martin Associates. 2001a. *Economic Impact Study of the Great Lakes St. Lawrence Seaway System.* Prepared for the U.S. Saint Lawrence Seaway Development Corporation, Washington, D.C. www.greatlakes-seaway.com/en/pdf/impact_study_en.pdf.

Martin Associates. 2001b. *Economic Impact Study of the Great Lakes St. Lawrence Seaway System, Transportation Cost Savings.* Prepared for the U.S. Saint Lawrence Seaway Development Corporation, Washington, D.C. www.greatlakes-seaway.com/en/pdf/impact_costanalysis_en.pdf.

Midwest Regional University Transportation Center. 2006. *Upper Midwest Freight Corridor Study.* University of Wisconsin, Madison, and Intermodal Transportation Institute, University of Toledo, Ohio.

Taylor, J. C., and J. L. Roach. 2005. *Ocean Shipping in the Great Lakes: Transportation Cost Increases That Would Result from a Cessation of Ocean Vessel Shipping.* Grand Valley State University, Grand Rapids, Mich., Aug. www.gvsu.edu/cms3/assets/C6D78A67-0AEF-0264-A38619EC6FB0793A/OceanShippingReport091105.pdf.

Transport Canada, U.S. Army Corps of Engineers, U.S. Department of Transportation, St. Lawrence Seaway Management Corporation, Saint Lawrence Seaway Development Corporation, Environment Canada, and U.S. Fish and Wildlife Service. 2007. *Great Lakes St. Lawrence Seaway Study.* Final Report. www.glsls-study.com/Supporting%20documents/GLSLS%20finalreport%20Fall%202007.pdf.

Study Committee Biographical Information

Jerry R. Schubel, *Chair,* is president and chief executive officer of the Aquarium of the Pacific in Long Beach, California, and directs the aquarium's Marine Conservation Research Institute. He was president and chief executive officer of the New England Aquarium in Boston from 1994 to 2001 and dean and director of the Marine Sciences Research Center at the State University of New York at Stony Brook from 1974 to 1994. Under his leadership, the center became known for excellence in fundamental research in coastal oceanography and for the development of innovative strategies allowing humans to live in harmony with their coastal environments. In 2005, an endowed Jerry R. Schubel graduate fellowship was created by the center in recognition of Dr. Schubel's contributions to the evolution of the institution. Dr. Schubel has published more than 200 scientific papers in academic journals and has written extensively for general audiences. He chairs the Ocean Research and Resources Advisory Panel and is a member of the Science Advisory Team for the California Ocean Protection Council. He is past chair of the National Sea Grant Review Panel and has served on the National Science Foundation's Education and Human Resources Advisory Council and the U.S. Environmental Protection Agency's Science Advisory Board. In 1998, Dr. Schubel was awarded an honorary DSc degree by the Massachusetts Maritime Academy, and in 2004 he was named a National Associate of the National Academies. He is a former chair and vice chair and a current member of the Marine Board, and he chaired the Phase 1 Committee on the St. Lawrence Seaway: Options to Eliminate Introduction of

Nonindigenous Species into the Great Lakes. Dr. Schubel earned a BS in physics and mathematics from Alma College, Michigan, a master's degree from Harvard University, and a PhD in oceanography from the Johns Hopkins University.

Richard M. Anderson is assistant professor of environmental systems analysis at Duke University's Nicholas School of the Environment and Earth Sciences. He previously held visiting scientist and research associate positions at the Johns Hopkins University Department of Geography and Environmental Engineering, was a research associate with the National Weather Service, and worked as a nuclear safety analyst for Westinghouse Electric Corporation. Dr. Anderson recently spent a year with the U.S. Department of Agriculture's Office of Risk Assessment and Cost–Benefit Analysis on a fellowship from the American Association for the Advancement of Science. His research interests focus on environmental systems analysis, decision analysis, and watershed management. He is particularly interested in bringing together many types of scientific data and incorporating decision-making models to enable environmental resource managers to make decisions that balance the competing interests of different stakeholders. His work on protecting the walleye fish population in Lake Erie has sought to apply these concepts. Dr. Anderson earned a BS in engineering mechanics, an MS in mechanical engineering, and a PhD in geography and environmental engineering, all from the Johns Hopkins University.

Stephen W. Fuller is Regents Professor in the Department of Agricultural Economics at Texas A&M University, where he has been a faculty member since 1974. His responsibilities include development of an agricultural marketing program with emphasis on transportation research. Dr. Fuller's principal research interests are agricultural transportation, marketing, and international trade. His recent publications have addressed grain transportation on the upper Mississippi and Illinois Rivers and the effects of improving transportation infrastructure on competitiveness in world grain markets. Dr. Fuller has received awards from the Transportation Research Forum for outstanding papers in rural transportation, and in 2002 he received the Southern Agricultural Economics Association lifetime achievement award. He has served on two National Research Council (NRC) study committees, the Committee on Freight Transportation Needs for the 21st Century and the Committee to Review the U.S. Army Corps of Engineers Restructured Study of the Upper Mississippi and Illinois Waterways. He recently served on an expert panel charged with reviewing a report prepared for the Joyce Foundation on transportation cost increases that would result from a cessation of ocean vessel shipping in the Great Lakes. Dr. Fuller earned a BS and an MS in agricultural economics and a PhD in economics, all from Kansas State University.

Trevor D. Heaver is professor emeritus in the Operations and Logistics Division of the Sauder School of Business at the University of British Columbia (UBC). He is also a visiting professor at the University of Antwerp, Belgium. Dr. Heaver held a variety of positions at UBC between 1960 and 1997, including UPS Foundation Professor of Transportation, Director of the Center for Transportation Studies, and Chair of the Transportation and Logistics Division in the Faculty of Commerce. His research interests focus on maritime and international logistics, maritime policy, and transportation economics, and his publications include 12 books and monographs and more than 100 journal articles. Dr. Heaver is a former president of the World Conference on Transportation Research Society and of the International Association of Maritime Economists. He has served on a number of advisory committees addressing transportation, logistics, and trade issues, including the Canadian Federal Transportation Services Sectoral Advisory Group on International Trade and the Multimodal Council of the Transportation Association of Canada. He has appeared before the House of Commons Standing Committee on Transport on a number of occasions as well as before the Canadian Transport Commission. Dr. Heaver recently authored two papers commissioned by the Canada Transportation Act Review Panel. He also provided economic input for a study for the International Joint Commission on the effects of different water level and flow conditions on vessel operations in the Lake Ontario–St. Lawrence River section of the Great Lakes St. Lawrence Seaway system. Dr. Heaver received a BA from Oxford University, England, and a PhD from Indiana University.

Geoffrey J. D. Hewings is professor in the Departments of Geography, Economics, and Urban and Regional Planning and director of the Regional Economics Applications Laboratory (REAL) at the University of Illinois at Urbana–Champaign. REAL is a joint venture between the Federal Reserve Bank of Chicago and the University of Illinois. His major research interests lie in the field of urban and regional economic analysis with a focus on the design, implementation, and application of regional economic models for use in policy formation and analysis. In addition to continuing development of regional econometric input–output models for a number of U.S. states and metropolitan areas, he is engaged in modeling projects in Brazil, Argentina, Austria, Colombia, Japan, and Indonesia. His recent work on the Midwest regional economy has focused on the estimation of interstate trade flows as a prelude to the construction of a Midwest impact and forecasting model that is linked with a transportation network model. Dr. Hewings has published nine books and more than 100 articles. In 2003, he received the Walter Isard Award for distinguished scholarly achievements in the field of regional science and an honorary doctorate from the University of Bourgogne, France. In 1995, the Regional Science Association International established the Geoffrey J. D. Hewings Junior Scholar Award, which is awarded annually to an exceptional scholar less than 10 years from completion of his or her PhD. Dr. Hewings serves on the Board of Directors of the Environmental Law and Policy Center in Chicago and on the Technical Advisory Committee of the Northeastern Illinois Planning Commission. He earned a BA from the University of Birmingham, England, and an MA and a PhD from the University of Washington, Seattle.

Philip T. Jenkins is president of Philip T. Jenkins and Associates, Ltd., a marine consulting and management services company in

Fonthill, Ontario. Captain Jenkins has been active in the Great Lakes marine community in both the public and private sectors for more than 25 years. As chief, Marine Services, for the St. Lawrence Seaway Authority in the early 1980s, he was responsible for the establishment and administration of regulations, procedures, and standards for safe ship operation through the international waterway; the conduct of inspections and accident investigations; and liaison with the marine industry in North America and overseas. Before forming his own consulting company in 1989, Captain Jenkins was vice president, Fleet Operations, for Misener Shipping, Ltd., in St. Catherines, Ontario. In that position he was responsible for the operation and technical management of the company's Canadian-flag inland and deep-sea bulk carriers, as well as its foreign-flag bulk carriers. In recent years, Captain Jenkins has worked on a number of projects to monitor ballast water management and develop practical alternatives to ballast water exchange. He was a member of the Phase 1 Committee on the St. Lawrence Seaway: Options to Eliminate Introduction of Nonindigenous Species into the Great Lakes. Captain Jenkins is a member of the Association of Marine Arbitrators of Canada and the Company of Master Mariners of Canada, as well as the Nautical Institute and the Royal Institute of Navigation in London. He holds Master Foreign Going certification from both Canada and the United Kingdom.

Hugh J. MacIsaac is professor of biology and Department of Fisheries and Oceans Invasion Biology Research Chair at the Great Lakes Institute for Environmental Research, University of Windsor, Ontario. He is also director of the Canadian Aquatic Invasive Species Network. His research focuses on biological invasions and aquatic community ecology, with particular emphasis on the Great Lakes, and uses genetic probes, mathematical modeling, and field studies to explore the importance of invasion vectors. Because many of the invasive species found in the Great Lakes come from Europe, Dr. MacIsaac's research includes collaborative investigations with researchers working on the Baltic, North, Black, and Caspian Seas. He has published more than 80 refereed papers on topics related to biological invasions and is an associate editor of the journals

Aquatic Ecosystem Health and Management and *Diversity and Distributions.* Dr. MacIsaac received the University of Windsor Research Excellence Award in 2000, 2001, 2002, 2003, and 2006 and the Premier's Research Excellence Award in 2000. He is a member of the Great Lakes Invasive Species Task Force and the International Joint Commission's Science Advisory Committee. He was also a member of the Phase 1 Committee on the St. Lawrence Seaway: Options to Eliminate Introduction of Nonindigenous Species into the Great Lakes. Dr. MacIsaac earned a BSc from the University of Windsor, an MSc from the University of Toronto, and a PhD from Dartmouth College.

Steven W. Popper is a senior economist with the Rand Corporation and professor of science and technology policy in the Rand Graduate School. From 1996 to 2001, he was associate director of Rand's Science and Technology Policy Institute, where his work provided research and analytic support to the White House Office of Science and Technology Policy and other agencies of the executive branch. His recent projects include work on technical barriers to international trade, critical technologies, national innovation systems, and federal R&D portfolio decision making. Dr. Popper is currently active in projects of the new Rand Pardee Center for the Longer-Range Global Policy and the Future Human Condition. He was coauthor of the flagship study *Shaping the Next Hundred Years,* which provides a new methodological framework for considering problems raised by future uncertainty. Dr. Popper has conducted research and has served as consultant to several governments and multilateral international organizations, such as the Organisation for Economic Co-operation and Development, on issues of regional economic development, industrial restructuring, and technology planning. Before joining Rand, he worked as a researcher in physical chemistry and enzymology; as country account officer for Czechoslovakia, Hungary, Romania, and Yugoslavia at Bank of America; and as consultant to the World Bank on issues of industrial restructuring in East Europe. Dr. Popper is a fellow of the American Association for the Advancement of Science and a charter member of the Pacific Council on International Policy. He earned a BS in biochemistry from the University of Minnesota and a PhD in economics from the University of California, Berkeley.

Frank H. Quinn is a consulting research hydrologist. In 2001, he retired from the National Oceanic and Atmospheric Administration's (NOAA's) Great Lakes Environmental Research Laboratory (GLERL) in Ann Arbor, Michigan, where his positions included senior research hydrologist and head of the Physical Sciences Division. In addition to conducting his own research on Great Lakes hydrology, hydraulics, and climate, Dr. Quinn worked with oceanographers, ecologists, biologists, and atmospheric scientists on a variety of multidisciplinary Great Lakes environmental projects. Before joining NOAA's Lake Survey Center (later GLERL) in 1970, he was a hydraulic engineer with the Lake Survey District of the U.S. Army Corps of Engineers in Detroit. Dr. Quinn has been actively involved in Great Lakes water resource issues and lake level research for more than 40 years and has authored more than 100 publications. He has also lectured extensively on Great Lakes water quantity issues. He is a former president of the International Association for Great Lakes Research and has served on several boards, task forces, and committees of the International Joint Commission, the Great Lakes Commission, and other Great Lakes organizations. He was the U.S. chair of the binational program to assess potential impacts of climate change on the Great Lakes–St. Lawrence basin. In 1987, Dr. Quinn was awarded the U.S. Department of Commerce Silver Medal for outstanding contributions toward the management of natural resources. Other honors include the Department of the Army Commanders Award for Public Service in 2001 and the Great Lakes Commission Outstanding Service Award, also in 2001. Dr. Quinn earned a BS and an MS in civil engineering from Wayne State University and a PhD in civil engineering from the University of Michigan.

Thomas D. Waite is F. W. Olin Professor of Engineering and Dean of the College of Engineering at Florida Institute of Technology in Melbourne. He was previously professor of environmental engineering and associate dean of research and graduate studies at the University of Miami. From 2002 to 2004, he also served as program director of environmental engineering and technology in the Division of Bioengineering and Environmental Systems at the National Science Foundation in Arlington, Virginia. His research interests include disinfection of wastewater effluents and sludge and the use of innovative treatments for the remediation of hazardous wastes. Much of his recent work has focused on technologies for treating ships' ballast water. Dr. Waite has served as a technical expert to the International Maritime Organization (IMO) for establishing global ballast water standards and as a consultant to the U.S. Coast Guard and Carnival Cruise Lines on ballast water treatment. In 1999, while on sabbatical at the Nanyang Technological University in Singapore, he was a member of the Singapore delegation to the IMO Ballast Water Working Group. He advised NOAA on the emergency treatment of ballast water during the grounding of the MS *Igloo Moon* off the Florida Keys in 1996. Dr. Waite has published three books and more than 50 refereed papers in the technical literature. He served on the NRC committees on ships' ballast operations and on shipboard pollution control and was a member of the Phase 1 Committee on the St. Lawrence Seaway: Options to Eliminate Introduction of Nonindigenous Species into the Great Lakes. Dr. Waite earned a BS and an MS in civil engineering from Northeastern University and an MS and a PhD from Harvard University.

M. Gordon (Reds) Wolman is the B. Howell Griswold Professor of Geography and International Affairs at the Johns Hopkins University, where he has been a faculty member since 1958. His research interests include environmental policy; the interaction of human activities and natural processes in altering the environment; and surficial earth processes with emphasis on erosion, sedimentation, and landform evolution. His recent publications address a variety of topics in environmental policy, including human and ecosystem health, water quality management, and the application of systems analysis in natural resources management. Dr. Wolman was elected to the National Academy of Sciences in 1988 and to the

National Academy of Engineering in 2002. He received the National Council for Science and the Environment's Lifetime Achievement Award in 2004, the Abel Wolman Award from the Chesapeake Water Environment Federation in 2003, and the Horton Medal from the American Geophysical Union in 2000. His other awards include the Penrose Medal from the Geological Society of America and the John Wesley Powell Award from the U.S. Geological Survey. Dr. Wolman has served on numerous NRC committees, including the Phase 1 Committee on the St. Lawrence Seaway: Options to Eliminate Introduction of Nonindigenous Species into the Great Lakes. He is a National Associate of the National Academies and a former member of the Transportation Research Board's Executive Committee. He earned a BA from the Johns Hopkins University and an MA and a PhD from Harvard University, all in geology.

Joy B. Zedler is the Aldo Leopold Professor of Restoration Ecology at the University of Wisconsin, Madison, Arboretum and Botany Department. She was professor of biology at San Diego State University from 1980 to 1998. Her research interests include wetland ecology, the structure and functioning of wetlands, restoration ecology, interactions of native and exotic species, and the use of scientific information in the management of wetlands. Her numerous publications address various topics in wetland ecology. They include a book chapter on prospects for the integrity of aquatic ecosystems and articles on the causes and consequences of invasive plants in wetlands and on the need for a regional restoration strategy for coastal mitigation in Southern California. Dr. Zedler is a member of the Boards of Trustees of Environmental Defense (formerly the Environmental Defense Fund) and the Wisconsin Chapter of the Nature Conservancy and served on the Nature Conservancy Governing Board from 1995 to 2004. She has received a variety of awards for her teaching, research, and conservation activities, including the first award for achievements in regional wetland conservation from the Southern California Wetlands Recovery Project in 2000 and the National Wetlands Award for Science Research from the Environmental

Law Institute and the Environmental Protection Agency in 1997. Dr. Zedler has served on several NRC committees and chaired the Committee on Wetland Mitigation; she is a former member of the Water Science and Technology Board. She earned a BS in biology from Augustana College and an MS and a PhD, both in botany, from the University of Wisconsin, Madison.

Ann P. Zimmerman is professor in the Department of Zoology at the University of Toronto and former director of the Koffler Scientific Reserve at Jokers Hill, a university research station. She teaches courses in limnology, lake ecosystem conservation, and global change ecology. She was the founding director of the university's Division of the Environment and served as cochair of the university's Environmental Protection Advisory Committee for 10 years. Her research focuses on freshwater ecosystems, and she is involved in cooperative efforts with ecologists both inside and outside the university in efforts to develop practically oriented, holistic models of lake ecosystems that might prove useful in both rehabilitation and efforts to conserve aquatic community biodiversity. Dr. Zimmerman is also interested in participatory research, cross-cultural technology transfer, and application of appropriate technology, with particular reference to the Nishnawbe-Aski of northwestern Ontario and other Canadian First Nations. Her involvement in a large lake acidification survey project of Ontario lakes and an effort to provide equitable, appropriate technologies for water supply and wastewater treatment in remote locations afforded her firsthand experience of the politics attendant to environmental issues. Dr. Zimmerman earned a BA in zoology from Ohio Wesleyan University and a PhD in biogeochemistry from the University of Georgia.

Great Lakes Shipping, Trade, and Aquatic Invasive Species

Since its opening in 1959, the St. Lawrence Seaway has provided a route into the Great Lakes not only for trade but also unfortunately for aquatic invasive species (AIS), which have had severe economic and environmental impacts on the region. Prevention measures have been introduced by the governments of Canada and the United States, but reports of newly discovered AIS continue, and only time will tell what impacts these species may have. Pressure to solve the problem has even led to proposals that the seaway be closed. At the request of the Great Lakes Protection Fund, the National Research Council assembled a committee of experts to identify and explore options that would both enhance the potential for global trade in the Great Lakes region and eliminate further introductions of AIS from ships transiting the St. Lawrence Seaway. The report concludes that trade should continue on the St. Lawrence Seaway but with a more effective suite of prevention measures that evolves over time in response to lessons learned and new technologies.

THE NATIONAL ACADEMIES™

Advisers to the Nation on Science, Engineering, and Medicine

The nation turns to the National Academies—National Academy of Sciences, National Academy of Engineering, Institute of Medicine, and National Research Council—for independent, objective advice on issues that affect people's lives worldwide.

www.national-academies.org

ISBN 978-0-309-11313-7