Report from the Great Lakes Ballast Water Collaborative Meeting

The Delta Hotel (the Opus 2 room)
475 Avenue Du President-Kennedy
Montreal, Quebec, H3A 1J7
(514) 286-1986
18 May 2010

Prepared for: Wisconsin Department of Natural Resources, Bureau of Watershed Management

Prepared by: Sharon Moen*

Final Version 6-25-10

***Sharon Moen, Science Writer; Duluth, Minnesota**
smoen@umn.edu
218-624-5735 (office)
218-591-2568 (cell)

Preface

The Great Lakes Ballast Water Collaborative Meeting took place on May 18, 2010 at the Delta Hotel in Montreal, Quebec. The International Joint Commission and The Saint Lawrence Seaway Development Corporation hosted the meeting. The proximate purpose of the meeting, which involved 48 attendees and nine phone-in participants (numbers varied throughout the day), was to share information that would assist Wisconsin Department of Natural Resources staff as they draft the Wisconsin Ballast Water Treatment Assessment Report. The ultimate purpose of the meeting was for leaders in the shipping industry, regulatory agencies, and ballast water treatment research to advance an ongoing discussion about realistically achieving the goal of protecting the Great Lakes from aquatic invasive species spread through ballast water while maintaining shipping safety and preserving the ability of coastal communities to conduct business on the Great Lakes.

There were two main parts to the meeting, which are reflected in this document. The morning presentations and discussions (Part 1) covered general topics pertinent to managing ballast water on the Great Lakes. Dr. David Reid moderated the afternoon panel presentations and ensuing discussions (Part 2), which were organized to synthesize information for the Wisconsin Ballast Water Treatment Assessment Report.

Brief Overview of Ballast Water Management

In 1992, the United Nations (U.N.) challenged the International Maritime Organization (IMO, the U.N. agency responsible for the international regulation of ship safety and the prevention of marine pollution) to actively address the transfer of harmful organisms by ships. (Agenda 21 of the Conference on Environment and Development, Rio de Janeiro). Ten years later at The World Summit on Sustainable Development in Johannesburg, South Africa, the IMO was urged to accelerate the development of measures to address invasive species in ballast water and to finalize the IMO Ballast Water Convention, which became *The International Convention for the Control and Management of Ships Ballast Water & Sediments (The Convention),* adopted by consensus at a Diplomatic Conference in London in 2004.

The Convention will enter into force 12 months after 30 nations representing at least 35% of world merchant shipping tonnage ratify it. At this time, 24 nations representing 25% of world merchant shipping tonnage have ratified *The Convention*.

The Convention includes three items particularly germane to the discussions at the 2010 Montreal meeting, and therefore this report:

- The Ballast Water Exchange Standard - Ships performing ballast water exchange shall do so with an efficiency of 95% volumetric exchange of ballast water.
- The 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 in minimum dimension, and less than 10 viable organisms per milliliter between 50 micrometers and 10 micrometers in minimum dimension; and discharge of the indicator microbes (toxicogenic *Vibrio cholerae*, *Escherichia coli*, intestinal enterococci) shall not exceed specified concentrations.
- Approval – Any Party to the IMO that approves a Ballast Water Treatment system agrees to do so in accordance with IMO Ballast Water Convention, including guidelines relevant to systems using chemicals or biocides, organisms or biological mechanisms, or that alter the chemical or physical characteristics of the ballast water.

The group of people and entities that assembled in Montreal, on 18 May 2010, was similar to those attending the Forum on Ballast Water on 24 September 2009 in Detroit, Michigan (see appendix: Great Lakes Ballast Water Collaborative Update). These included the U.S. Saint Lawrence Seaway Development Corporation and the International Joint Commission (IJC), which co-hosted the information-sharing forum on ballast water issues in the Great Lakes St. Lawrence Seaway System. As at the Detroit meeting, Minnesota Sea Grant and Great Lakes Commission facilitated that discussion and attendees included representatives from State and Provincial Governments; U.S. and Canadian regulatory agencies; senior executives from the U.S.-flag Laker, Canadian-flag Laker, and international fleets; leading ballast water researchers; and ballast water treatment system vendors. The goals of the meetings were to share relevant information among the participants, to increase dialogue among stakeholders involved in ballast water management in the Great Lakes, and to discuss ways to further reducing the risk of introduction and spread of invasive species through ballast water.

At the Montreal meeting, Joe Comuzzi, chair of the Canadian section of the IJC, welcomed participants to "the 2nd Great Lakes Ballast Water Collaborative Meeting". He remarked that the control of sea lamprey was "a bit of a scientific miracle" and that the development of that control could inspire those working toward ballast water treatment goals. Comuzzi noted the success of ballast water exchange regulations. He said that almost 98% of all oceangoing vessels entering the Great Lakes carrying ballast water are in compliance with the ballast water exchange regulations and that the ballast portals of non-compliant ships are sealed. No new ballast-borne foreign aquatic invasive species have been reported in the Great Lakes in over four years.

Terry Johnson, Administrator of the St. Lawrence Seaway Development Corporation, also welcomed participants, saying that Craig Middlebrook (Deputy Administrator of The Seaway) inspired this meeting with important contributions from Jeff Stollenwerk (Minnesota Pollution Control Agency). He pointed out that three fleets were involved in the discussions occurring throughout the day: an international saltwater fleet, the Canadian fleet that traverses both fresh and saltwater, and the U.S. carriers' Great Lakes-only fleet.

Middlebrook commented on the activities of the Ballast Water Collaborative saying that the ad-hoc collaborative grew from the need to be more intentional about communicating and sharing information as ballast water management became more complicated in the face of multiple layers of regulation imposed by the U.S. Coast Guard, the Canadian government, the U.S. Environmental Protection Agency, and the U.S. Great Lakes states. Middlebrook said that the Collaborative seeks to mitigate the gaps that make it difficult to coordinate ballast water treatment regulations among these various governing entities. Collaborative discussions started in 2009 continued in Ann Arbor, Michigan, (December) and in Toronto, Ontario (January 2010)(see appendix: Great Lakes Ballast Water Collaborative Update). Middlebrook stated that the point of the meeting in Montreal was to help refine the questions that would inform the Wisconsin Ballast Water Treatment Assessment Report at the request of Susan Sylvester.

PART 1

Interim Measures for Ballast Water Treatment

Noel Bassett, Vice President of the American Steamship Company (ASC), and Phyllis Green, Superintendent of Isle Royale National Park, explained how they are cooperating to ensure that Isle Royale and National Park Service (NPS) marine parks are protected from ballast water discharge, should a ballast-bearing vessel potentially contaminated with invasive species, need to seek a safe harbor in the park in the event of a grounding or need to release ballast within NPS jurisdictional waters.

Their goals are to:

- Establish emergency ballast water treatment options and solutions.
- Continue to explore interim ballast water treatment possibilities until a unified federal strategy is in place.

The ASC provided a vessel for testing treatment protocols, equipment, and dosing agents. ASC's cooperation ensured that the potential treatments would be feasible on a working ship. The partnership has been testing several biocide introduction schemes and is establishing an emergency delivery system for biocide treatment for ships needing to release ballast within NPS jurisdiction. The research team has resolved major biocide delivery issues and has recently obtained funding to develop a biocide targeted for freshwater applications. The emergency treatment involves applying lye (sodium hydroxide) to raise the pH of the water from 7 to lethal levels between pH 11.5 and pH 12. The internal dosing is done through several means, including a perforated hose and treated water is not released until it falls to pH 9 after neutralization, a level the EPA accepts with regard to the Clean Water Act. To neutralize the water, vessel crew need to dilute the basic water with ambient lake water ("neutralization by dilution"). Introducing carbon dioxide will also lower the pH level.

Researchers conducted land-based testing of pH-based ballast treatment and reported that lye (sodium hydroxide, NaOH) can be an effective biocide (The Great Ships Initiative 2009 report, www.nemw.org/GSI/outcomes.htm). Studies suggest that applying slaked lime [calcium oxide,

$Ca(OH)_2$] might also be an acceptable way to raise the pH of ballast water to lethal levels. Bleach (sodium hypochlorite, NaOCl) is another biocide of merit, but it has corrosion issues at the higher toxicity levels. Since corrosion rates drop precipitously at pH levels of 10 and higher, meeting participants suggested that elevating pH might reduce corrosion to the uncoated steel found in Great Lakes-locked ships. Compared to salt water trials, scientists found that pH dosing is tremendously more effective in fresh water (a pH of 11.5 kills 100% of aquatic bacteria within 48 hours). This was the first reference of many that occurred throughout the day that ballast water treatment options may need to be very different depending on the water in which they are expected to perform.

Investigations continue into mixing schemes for dispersing biocides into ballast water. Computer modeling, scale modeling, and full-scale shipboard dye testing are addressing questions about how quickly a biocide could mix into a ship's ballast tanks. Reports from the Naval Sea Systems Command (NAVSEA) and the U.S. Geological Survey suggest complete mixing can occur in less than 60 minutes for a million gallons in a full tank situation by enhancing the mixing with an airlift or educter system.

In practice, there are concerns about how to safely store enough NaOH and CO_2 onboard ships to treat the ballast water. On a typical Laker, estimates for the materials required per ballast dosing to a pH of about 11 hover around $3000. If the pH target were raised further (given the pH scale is logarithmic), costs would be about $10,000 to reach a pH of 12. There would be significant additional costs for installation of treatment and neutralization equipment.

Toxicology research continues along with efficacy reviews at lower pH levels. Regulatory reviews are also ongoing as shipboard-specific installation, dosing procedures, and storage units are designed. Phyllis Green commented on the exceptional success of the National Park Service's collaboration with the ASC, saying, "We could not have answered the questions raised in the 1990s when the Igloo Moon was treated without the Steamship Company's collaboration."

References:

Emergency Response Guide for Handling Ballast Water to Control Non-Indigenous Species. 21 January 2010. Prepared for the National Park Service, Isle Royale National Park. http://www.nps.gov/isro/upload/High_Risk_Ballast_Water_First_Response_Guide_January2010.pdf.

In ballast water treatment systems relying on deoxygenation and reoxygenation, researchers should monitor the microbe population living within ballast tanks. The species composition might change.

The discussion also made it clear that the ballast water treatment systems used on Lakers may be very different than those used on Salties. The cost-effectiveness and concerns are different between environments. Issues concerning ballast water treatment in freshwater include minimizing the spread of invasive species and minimizing corrosion.

Allegra Cangelosi, a ballast treatment researcher with the Northeast Midwest Institute and director of the Great Ships Initiative, responded to a question regarding the lethality of pH. When asked why systems were aiming for a pH of 11.5 when a pH of 12 was more effective in GSI bench tests, she replied that although bench-testing with resistant microorganisms showed that pH 12 without a doubt created lethality within 2 days, a pH of 11.5 performed well enough to be potentially useful and cost-effective.

Bassett concluded by saying, “We need to pick our battles. What’s the alternative? There is nothing else out there. Nothing. Nothing can work at the pump rates the ships use. Dosing ballast water to a pH of 11.5 might be the best we can achieve within the Great Lakes System.”

State Activities Update: Discussion of Information Needs (Dave Adams and Jeff Stollenwerk)

See appendix: Great Lakes Ballast Water Collaborative: 2010 State Updates

The resounding message was that: The Great Lakes states would prefer a strong, environmentally protective Federal ballast water management program that is well coordinated throughout the Great Lakes, as soon as possible.

State governments (Michigan, Minnesota, New York, Ohio, and Wisconsin) have created their own ballast water regulations based on state legislation and associated regulations and/or state certification of the EPA Vessel General Permit. States feel a responsibility to achieve their individual state water quality standards and to meet the public’s expectations for environmental health. However, state-generated rules have resulted in regulatory inefficiencies and inconsistencies throughout the Great Lakes region. The states strongly encourage the U.S. Coast Guard and EPA to work in a collaborative manner as they finalize national standards for ballast water discharge in U.S. waters. While it is recognized that the state-based regulatory system that has recently developed will be hard to dismantle once acceptable federal regulations are in place, the states understand the challenges, and are committed to protecting their natural resources.

Canadian Federal Regulatory Activities Update (Chris Wiley and Paul Topping)

Canadian ballast water discharge regulations have been iterative and informed by bi-national science (Department of Fisheries and Oceans, Canada, National Oceanic and Atmospheric Administration, U.S.) since 1989. The arrival of Eurasian Ruffe in the Duluth-Superior Harbor precipitated the mid-ocean ballast water exchange rule for oceangoing ships intending to enter the Great Lakes seaway. Ships are in compliance and according to *research appearing in Freshwater Biology, 2009, none of the eight invasive species tested in the Great Lakes would have survived in ballast water if mandatory ballast water exchange began 25 years ago.

The Canadian Government ratified the U.N. IMO's Ballast Water Convention on 8 April 2010. The presenters feel The Convention currently reflects science and will reduce the risk of introducing more non-native species into the Great Lakes in particular. Canada chairs the IMO Ballast Water Review Group-MEPC 61 and the group expects the IMO Ballast Water Convention to become fully ratified within a few years. Science (**Bailey et al. and others) supports the IMO discharge standards for the Great Lakes and suggests that treatment to these standards will decrease invasions of high-risk zooplankton.

References:

***Effect of osmotic shock as a management strategy to reduce transfers of nonindigenous species among low-salinity ports by ships.** Santagata, S., Z.R. Gasiūnaite, E. Verling, J.R. Cordell, K. Eason, J.S. Cohen, K. Bacela, G. Quilez-Badia, T.H. Johengen, D.F. Reid, and G.M. Ruiz (2008). Aquat. Inv. 3(1), 61-76.

http://www.aquaticinvasions.ru/2008/index1.html

*__Salinity tolerance of Great Lakes' invaders.__ 2009. Ellis, S. and H.J. MacIsaac. Freshwater Biology 54:77-89. (www.caisn.ca/ContentFiles/ContentPages/Documents/Ellis_MacIsaac.pdf)

**__Estimating establishment probabilities of Cladocera introduced at low density: an evaluation of the proposed ballast water discharge standards.__ 2009. Bailey, S.A., Vélez-Espino, L.A., Johannsson, O.E., Koops, M.A., Wiley, C. J. Canadian Journal of Fisheries and Aquatic Sciences 66(2): 261-276.

An important point brought up throughout the day: It is unclear how "available" ballast water treatment systems and alternatives are at this time for use in the freshwater of the Great Lakes..

At this time, 9 ballast water vendors have type approval (and are thus available to be purchased in the marketplace.) Of those, only one system (SEDNA) has been tested in fresh water. Another system, RWO has received final approval from the IMO, and has been tested in fresh water. However, it is currently awaiting type approval.

Transport Canada and the Department of Fisheries and Oceans intend to conduct tests on using exchange plus use of a ballast water treatment system type tested to IMO Standards in partnership with Germany. Scientists estimate that using exchange plus treatment may provide protection for the Great Lakes exceeding the IMO Standard alone by 10 to 100 times. Continued use of exchange will also provide extra risk reduction in case of ballast water treatment system failure. Full-scale trials as well as research into the efficacy of ballast water exchange in conjunction with ballast water treatment, sampling protocols, consistency, and tools to analyze DNA and RNA are planned. The presenters feel that at this time, ballast water is sliding to the lower end of the risk scale as a vector for introduction of non-native species into the Great Lakes.

When questioned about whether Canada wants ballast water treatment exemption for Lakers, Chris Wiley of DFO/TC indicated that Canada had done a three year study as to the role of Lakers. He indicated the BW Convention requires all ships to install treatment systems. Any exemption would have to be based on the science, and currently the science suggests that Lakers are not a high risk to introduce invasive species into the Great Lakes. The science does suggest that they do pose a role in spreading aquatic invasive species (AIS) if introduced from another vector. If introduction from the other vectors could be minimized, the role of Lakers would be a lower risk. At this point, we are doing the risk analysis and currently do not have enough science to make a decision.

Wiley addressed a concern about why, if mid-ocean ballast water exchange is working so well at keeping new non-native species out of the Great Lakes, regulators are posed to require additional technology at huge costs. He replied that because ballast water is also an issue in Canadian saltwater ports where mid-ocean exchange wouldn't be as effective, and that since Canada signed the IMO

Convention, the nation agreed to require onboard ballast water treatment for all vessels as the Convention mandates, once it is fully ratified.

Wiley was given credit for applying science to ballast water challenges. Eurasian Ruffe populations have expanded along the south shore of Lake Superior and to several ports in Lake Michigan, but the predicted ruffe take-over and a resulting die-off of native species was never observed, even in impacted bays and harbors.

The location of Eurasian ruffe populations in the Great Lakes (USGS map, 2010).

See: A Guide to Canada's Ballast Water Control and Management Regulations TP 13617 E. Jan 14, 2010 (**http://www.tc.gc.ca/eng/marinesafety/tp-tp13617-menu-2138.htm**)

U.S. Federal Regulatory Activities Update (Gary Croot and Ryan Albert)

The Environmental Protection Agency requirement for vessel discharge permits by 2009 (www.epa.gov/npdes/pubs/vessel_vgp_factsheet.pdf) occurred within 13 months following a protracted court battle between the States and EPA to require EPA to regulate ballast water discharges under the Clean Water Act. The U.S. Coast Guard, the agency responsible for creating ballast water treatment standards and protocols, supports the EPA requirement, which reflects the Clean Water Act and uses organism-based limits. In early summer of 2011 the National Academy of Science (NAS) plans to issue a report on the use of numeric limits for living organisms in ballast water discharge with respect to ballast water treatment. This NAS report and the results of the Aquatic Nuisance Species Working Group meeting in early June 2010 should move discussions toward more nationally consistent ballast water regulations. Great Lakes Restoration Initiative funding through the EPA is committing money toward ballast water regulation and technology over the next two years.

The U.S. Coast Guard is working to create a national policy. Gary Croot said, “I can’t tell you the publication date of the final rule but we’re currently wading through about 3,000 public comments.” He said that, at a minimum, by law, the USCG needs to reexamine the draft ruling’s preamble, economic analysis, and environmental impact statement before a final ruling can be made.

At a national level, ballast water treatment research and development is ongoing. The USCG intends to apply Great Lakes Restoration Initiative funds toward a practicability review to investigate the pros and cons of raising the IMO ballast water discharge standards. The Great Ships Initiative is using federal money to study ballast water treatment protocols and environmental protocol testing. The USCG has issued a request for proposals regarding ballast water treatment calibration and is involved in an onboard feasibility study that will take from 18 – 24 months to complete. The U.S. Government plans to fund research to explore how different ballast treatment systems influence corrosion rates in freshwater. Initial evidence suggests that deoxygenation systems might accelerate corrosion but ballast water treatment researcher Mario Tamburri said, “In defense of deoxygenation, it’s as good as anything if done correctly.”

Panel Discussion: USCG Ballast Water Treatment Evaluation Activities and Enforcement Issues (led by Gary Croot, panelists: Mario Tamburri, Lisa Drake, and Allegra Cangelosi)

This session reviewed the infrastructure and functions of the ballast water treatment testing facilities in the United States. The three panelists in this session all commented on the importance and difficulties of achieving a reasonable level of quality assurance and quality control. Their comments had several elements in common on issues surrounding sampling methodologies and working with massive volumes of water required for proper testing. Their conclusions were:

- *Keep working to ensure scientifically rigorous and statistically sound standardized testing*
- *Don’t extrapolate current testing and data to different systems and environments*
- *Methods and approaches will continue to evolve*
- *Monitoring for vessel compliance will be as challenging as the certification testing they are conducting but with much greater logistic constraints and less control. They suggest that*

developing indirect measures of ballast water characteristics will be a useful tool to incorporate into a monitoring framework.

Gary Croot, chief of the environmental standards division of the USCG, introduced the session by pointing out that minimizing and ultimately preventing the spread of aquatic nuisance species is an international goal. He followed with, "Can we actually put ballast water treatment systems on ships and verify that the equipment works?" Using a life raft analogy, he asked rhetorically, "What level of statistical certainty that a life raft will open are you comfortable with?" Since ballast water treatment technologies will be operating onboard ships, the USCG is responsible for regulating them and their use in U.S. waters.

Allegra Cangelosi reported on the Great Ships Initiative (GSI) activities. This ballast water treatment testing facility is the only one operating in a freshwater environment in the world. To date, GSI has conducted bench- and land-based testing for many type of ballast water treatment technologies for use in freshwater including the Siemens' SiCure™ Ballast Water Management System (tested in 2009), and Alfa Laval's PureBallast System, version 1 (IMO-approved) and 2 (experimental) and an experimental lye/CO_2 system. GSI will initiate its program of ship-scale testing in late 2010, anticipating adequate ballast water treatment technology advances. Cangelosi then directed her remarks to the global and domestic framework in which ballast test facilities operate. Globally, there are currently three third party facilities domestically through the Marad program, and the USCG/USEPA Environmental Technology Verification Program. They collaborate internationally informally and through IMO GloBallast (globallast.imo.org/index.asp) effort, among others. Intercollaboration helps assure testing at all of these facilities will be equivalently rigorous and credible.

Lisa Drake, a researcher at the Naval Research Laboratory Key West: Center for Corrosion Science and Engineering, reported that the Navy's ballast water facility provides technical advice to help the USCG and EPA address ballast water management. Technical challenges of treating, evaluating, and regulating ballast water include:

- Sampling statistics
- Volumes of water

- Assessing protist viability
- Assessing zooplankton viability

Commenting that the Maritime Environmental Resource Center (MERC) is in some ways a sister program to the Great Ships Initiative, Mario Tamburri, the director of MERC, discussed testing ballast water treatment options in brackish and salt water in Maryland's Chesapeake Bay. Since there is a large range of salinities in the Bay, the ballast water treatment systems used there must perform under diverse conditions. MERC's foci are:

- Evaluating the mechanical and biological efficacy of ballast water treatment systems.
- Assessing the economic feasibility of installing these systems.
- Facilitating green ship technologies (biofouling, air emissions).
- Supporting an online Port Discharge Database (Google Earth, Google Maps).

When asked, if any of the researchers have worked with the State of California on their 1000 X IMO ballast discharge standards, Tamburri had the most interaction through a shipboard test funded by California and offered advice about compliance. Drake has not worked with California and Cangelosi's interactions with California ballast water treatment have been informal.

When asked if the technology could be developed more quickly, Drake said, "You really need to do the initial tough validations to make sure the equipment works." Tamburri supported this idea further by saying, "A level of rigor is required to even get into compliance, let alone reach a level of certification." Cangelosi thought an integrated systems approach to type approval and compliance monitoring using a combination of rigorous screening in type approval combined with a risk-based hierarchy of compliance monitoring steps might make ballast water treatment systems more immediately workable. "Maybe the Coast Guard could regulate systems like it regulates other parts of ships. They could be more rigorous with ships already cited for non-compliance on other issues, or in high risk situations. Effort to find violators should be targeted. Don't vigorously try to shake down a ship that has a low probability of violating the standards. Instead substitute a less costly monitoring method most of the time for those ships." Croot finished the session by saying that achieving compliance is a Coast Guard goal at this point.

References:

Publications authored or coauthored by Mario Tamburri, including: King, D.M. and M.N. Tamburri. 2010. **Verifying Compliance with Ballast Water Discharge Regulations 2010**. Ocean Development and International Law 41(2): 152 – 165

Publications authored or coauthored by Lisa Drake, including: Lemieux, E.J., S. Riley, T. Wier, C. Scianni, S. Smith, N. Welshmeyer, D. Anderson, K. Burns, D. Kulis, L. Drake, B.N. Nelson, and P. Herring. 2009. **Phytoplankton Enumeration and Evaluation Experiments**. Report by the Naval Research Laboratory Key West, Fla. 123 pages.

Publications authored or coauthored by Allegra Cangelosi, including: Cangelosi AA, Mays NL, Balcer MD, Reavie ED, Reid DM, Sturtevant R & Gao X (2007). **The Response of Zooplankton and Phytoplankton from the North American Great Lakes to Filtration.** Harmful Algae, 6 (2007) iv: 547-566.

Reavie E, Cangelosi AA & Allinger LE (In prep.). **Assessing Ballast Water Treatments: Evaluation of Viability Methods for Ambient Freshwater Microplankton Assemblages.** Journal of Great Lakes Research. Accepted for publication April 16, 2010.

Bain MB, Cornwell ER, Hope KM, Eckerlin GE, Casey RN, Groocock GH, Getchell RG, Bowser PR, Winton JR, Batts WN, Cangelosi A & Casey JW (2010). **Distribution of an Invasive Aquatic Pathogen (Viral Hemorrhagic Septicemia Virus) in the Great Lakes and Its Relationship to Shipping**. PLoS ONE, 5(4): e10156.

Cangelosi A & Mays N (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. www.nemw.org/scopingreport.pdf

Facilitated Discussion: A Common Understanding of Ballast Water Treatment Concepts and Terms (facilitator: Dale Bergeron)

Since the understanding, language, and points of meaning might differ among industry, science, and regulators, participants were asked which words related to ballast water treatment challenges they would most like to have defined. Dave Knight, special projects manager with the Great Lakes Commission (GLC), began the list by saying, "Defining the meaning of these two words will be a measure of our success: *Protective and Practical."*

Participants felt the following words need to be defined and understood more fully:

- *Protective (Protection)*
- *Practical (Practicable)* – The USCG has a list of factors to consider including: safety of vessel and passengers is first. What is the "footprint" of the ballast water treatment system? These systems must fit on a ship. There needs to be an economic equation that accounts for the installation and operational life of both the product and the ship. The life of the vessel needs to be compared to the life of the system. Will there be a grandfathering clause? What is a reasonable "grandfathered-in" timeframe? What do we do with ships that get an early system that might be obsolete in 5 years? Are there enough engineers and engineering technology to design

and install the systems in the given timeframe? Are dry docks needed? What are the costs to install and costs to operate the system(s)?

- *Commercially available* – This is a subset of practicability. The researchers said that certification testing is different from what they are doing, which is more-or-less prototype testing. They caution that just because a system is called "commercially available" by vendors does not mean that it has been tested and vetted. From the industry perspective, even if a system is commercially available it might not be suitable for a particular ship; it could clog operations or be a fiscally irresponsible investment. Has it been tested? Is it affordable? Is it cost effective? Does it diminish a vessel's safety?
- *Feasible* – Is the system technically, economically, legally, etc., possible?
- *Threat* – What poses a threat? Have risk assessments been conducted?
- *Risk* – What is the economic transfer risk for different species? For instance, a zooplankton compared to a fish.
- *Approval* – Will this be defined by "compliance"?
- *Compliance* – From a regulatory standpoint, what does this mean and how will it be evaluated?
- *Scientific evidence, scientific uncertainty, credible* – Is the goal of testing to achieve a level of precision or to describe and predict what will work on a ship? More science is becoming available. "Credible" by means of what?
- *Compatible regulations*
- *Viability* – What is a viable organism? How do you count this? For zooplankton are the numbers including living adults AND resting eggs, which are potentially viable)? Lisa Drake commented that the IMO refers to "living" organisms, so at present the Naval Research Laboratory quantifies living things.
- *Treatment, Interim treatment*
- *Confidence* – How do we define a working system? Consider both statistical and public confidence. What is success? 90%, 99%, 100%?

Update Ballast Water Treatment System Manufacturers: Pathway for Approval of Experimental Ballast Water Treatment Systems in the Great Lakes

Georges Robichon, senior vice president of Fednav, Ltd., put a ballast water treatment vendor perspective on making and ushering a ballast water treatment technology (the *OceanSaver System*) through testing. An experimental system was designed in Norway in 2003 using filtration and deoxygenation to clean ballast water. A third method (caviation/pulsation) was added a little later, but was prohibitively expensive. FedNav offered one of their vessels as a platform for the *OceanSaver* prototype and acquired a minority interest in the company in 2005. Although the *OceanSaver System* won IMO Final Approval in 2008, the system has not sold and might only be a reasonable option on very large oceangoing vessels. It is not effective in fresh water without adding quantities of salt to a concentration that would place the resulting discharge in violation of water quality standards in the Great Lakes.

Vadim Zolotarsky introduced SiCure™ by SIEMENS, which uses in-line filtration, and a biocide (sodium hypochlorite, i.e. bleach) to clean ballast water. The system is now being tested onboard ships. The company expects to share the results of this testing in September 2010 at the 5th International Conference and Exhibition on Ballast Water Management (ICBWM) in Singapore (www.ballast2010.com/).

The company attempted to follow all IMO guidelines in their thick application dossier for basic and final approval. The process began in 2006 and the company projects that the system will be given final approval by the IMO by the end of 2011. SiCure™ tested well at GSI in Lake Superior, and the MERC facility in Maryland is running further tests in brackish water. SiCure™ seems to have no ecological ramifications but vessel corrosion rates in fresh water might be more like corrosion in seawater.

Performance to IMO: A Case Study on *What it Means in the Great Lakes* (Allegra Cangelosi)
Allegra Cangelosi, ballast treatment researcher and director of the Great Ships Initiative, reported on IMO certification testing in 2009 at the GSI land-based facility in Lake Superior for the German administration, and how the results pertained to treatment performance in the Great Lakes. She indicated that the SiCure™ system met IMO standards for regulated size-classes of zooplankton in ballast discharge (>50 microns, and 10-50 microns). It also met the EPA criteria for residual chlorine and conventional WET tests revealed no serious problems for use in fresh water.

However, Cangelosi pointed out that one peculiarity of freshwater systems is that often zooplankton in the Great Lakes can fall below 50-micron limit, especially rotifers. “Rotifers were what was left (after treatment)," said Cangelosi. Although the larger zooplankton counted were well below the IMO standard of 10 living organisms per cubic meter, if smaller zooplankton (< 50 micron) were included in the count, the number of living organisms exceeded 10 per cubic meter.

SiCure's toxicity declined over 5 days, but remained higher than EPA criterion on day 4, and higher than Wisconsin discharge standards on day 5. The toxicity of the effluent from the system does not decrease as rapidly in cold water, but the vendor asserts that, in practice, the system's smart technology would compensate by reducing the initial treatment dosage.

Finally, while operationally the SiCure system is compatible with the salty fleet that visits the Great Lakes and possibly Canadian Lakers, corrosion issues could make SiCure incompatible with U.S. Lakers. Further research and development of the SiCure system is underway to make it operationally compatible for most Great Lakes ships. These modifications include making the system effective and environmentally sound within typically short voyage durations.

References:

Cangelosi A, Allinger L, Balcer M, Mays N, Markee T, Polkinghorne C, Prihoda K, Reavie E, Reid D, Saillard H, Schwerdt T, Schaefer H & TenEyck M (2010). **Report of the Land-Based Freshwater Testing by the Great Ships Initiative of the Siemens SiCURE™ Ballast Water Management System for Type Approval According to Regulation D-2 and the Relevant IMO Guidelines**. Great Ships Initiative. http://www.nemw.org/GSI/GSI-LB-F-A-1.pdf

Cangelosi A (2010). **A Great Lakes Relevancy Preamble to the GSI Report on Land-Based Testing Outcomes for the Siemens SiCURE™ Ballast Water Management System.** Great Ships Initiative. http://www.nemw.org/GSI/GLPreamble.pdf

The discussion following the three presentations included rotifers of a size range between 10 and 50 microns and their survivorship, the potential industry challenges with ballast water treatment systems that create backflushing, and the USCG approval process for ballast water treatment options, which includes four steps:

1) The EPA conducts an environmental impact assessment.
2) The USCG consults with the U.S. Fish and Wildlife Service.
3) If a biocide is used, it needs to be registered by the EPA through the FIFRA (*Federal Insecticide, Fungicide, and Rodenticide Act: http://agriculture.senate.gov/Legislation/Compilations/Fifra/FIFRA.pdf*) process.
4) Applications need to go through coastal zone approval by each state.

Even after IMO type approval, it will take the USCG 2.5-3 years to give final approval to a ballast water treatment system. This is assuming it would take a year for shipboard testing, another year for making the final rule, and six more months before the certification process was complete. Questions were raised about streamlining the USCG's approval process with respect to different state standards.

PART 2

Dr. David Reid, Moderator

State Implementation Challenges – Wisconsin "Scope of Work" for Ballast Water Treatment Efficacy and Availability (Opportunities for "Collaborative Input") (Susan Sylvester)

The EPA issued a Vessel General Permit (VGP) that requires states to manage ballast water discharge under the Clean Water Act (401). Because of the ballast water discharge mandate and the lack of numerical standards associated with the VGP, states felt forced into a rapid 401 certification process. In Wisconsin, the National and Wisconsin Wildlife Federation challenged the state to cover ships, including both Lakers and Salties. For now the Wisconsin standard, which is 100 times more stringent than the IMO discharge standard, does not apply to Lakers. The Wisconsin DNR needs to finish a review of ballast water treatment systems for use in the Great Lakes by 31 December 2010 and is grateful for the Ballast Water Collaborative's support and help in this matter. For details, refer to the appendix handout, *Scope of Work: Wisconsin Ballast Water Treatment Technology Assessment Report (5/18/10)*.

The Wisconsin Dept. of Natural Resources (DNR) is interested in the answers to the following questions:

1. Are there ballast water treatment technologies and systems available for use in the Great Lakes? (topic leader: Susan Sylvester, chief of permits section for the Bureau of Watershed Management, Wisc. DNR)
2. What are the barriers to getting systems operating onboard ships, both in designing new ships and retrofitting older ones? (topic leader: Paul Novak, environmental manager, Ohio EPA)
3. How do we know that the ballast water treatment systems are working? (topic leader: Dave Adams, regulatory coordinator for the Office of Invasive Species Coordination, New York Dept. of Environmental Conservation)

Other reports regarding ballast water management options are due out in 2011 (including one produced by the National Academy of Science), but these will not help Wisconsin meet the December 31 deadline. Note that the State of California has its own 1000 X IMO standard. Please refer to the Lloyd's Register Ballast Water Treatment Technology report (Feb 2010) and the related tables from Lloyd's in the Appendix. Sylvester commented that even though ballast water exchange has reduced the likelihood of new aquatic invasive species introductions, researchers still think that onboard treatment is necessary. She also expressed interest in possible interim measures for ballast water treatment options that might be practicable onboard vessels while the USCG is engaged in the process of approving a system over the next three years (at a minimum).

PANEL 1: Identification of "Available" Ballast Water Treatment Systems "Rated" to Meet or Exceed 100 X IMO [Panelists: Chris Wiley, Gary Croot, and Maurya Falkner (by phone)]

Maurya Falkner, environmental program manager for the California State Land Commission, sent four tables to Susan Sylvester as an example of how the State of California is handling ballast water treatment system data (Attached as an appendix to this report). In California, regulators are NOT required to APPROVE any particular ballast water treatment system, only to evaluate the various systems' potential to meet California standards with respect to shipboard or land-based data. According to California, eight systems have this potential: Alfa Laval, Ecochlor (which was denied IMO final approval), Hamworthy Greenship, Hyde Marine, OceanSaver, OptiMarine, Qungdao Headway Tech, and Techcross. The regulators cannot guarantee that any of these systems will work on all ships. New vessels operating in California waters need to have systems onboard by 2011; statute requires that all vessels must meet performance standards by 2016.

Chris Wiley, manager of environmental issues for Transport Canada, and Fisheries and Oceans Canada, presented information about the IMO ballast water treatment approval process. At this time 24 countries representing 25% of the world's vessel tonnage have ratified the ballast water convention. He presented a slide indicating the compliance dates for installation of ballast water treatment systems under the Convention and what date they would be incorporated into new ships. Although there are nine ballast water treatment systems that have been given type approval by IMO, only one has been tested in fresh water, SEDNA. However, SEDNA was bought out and is no longer in business. RWO has been tested in fresh water and is currently awaiting type approval. Other firms (e.g., Siemans) are doing testing at GSI in Superior, WI and are in the process of approval. About 40 ballast water management systems are at or in an advanced state of development (i.e. nearing type approval), or waiting shipboard testing. Most commonly, the systems couple filtration with another treatment method (including electrolysis, coagulation, flocculation, hydrocyclone, biocides, cavitation and ozone). “The reality,” said Wiley, “is that currently mid-ocean ballast water exchange is the best way to remove unwanted species from ballast water for the majority of ships until ballast water treatment systems come online in 2016.” He cited remaining safety issues, documentation challenges, and the regulatory regimes starting in many parts of the world.

Gary Croot said that although there are many ballast water treatment systems being developed, the USCG is not confident that any of them can meet IMO and USCG Phase I standards in the Great Lakes. None could meet standards 100 times more stringent than the IMO standard. The USCG studied three treatment system dossiers for type-approval and found that based on 84 criteria, the systems could meet these criteria roughly 25% of the time. The USCG is concerned that the ballast treatment guidelines are not being approached in a consistent manner and that testing might not be scientifically rigorous. The USCG’s main concerns are:

1. Quality Assurance/Quality Control: In 2 out of 3 dossiers, evidence of QA/QC plan was missing.
2. Test Methodologies: 2 out of 3 dossiers used approved test methodologies but there was some question about whether the methodologies and results are repeatable.
3. Data Validation: In 1 of the 3 dossiers, there was no evidence that the data had been validated.

Croot commented that the USCG does not have confidence in the ballast water treatment system validation testing that has been done so far by other flag-administrations. Effectively, an audit was done on three ballast water treatment systems that were awarded IMO type approvals. Testing methods and results are supposed to be transparent but this needs to be verified when accepting results from testing facilities overseen by other flag-administrations. For example, nothing in the documents indicates that these tests have ever been done. Why is that data missing? “We don’t believe, given the available information, it is useful to have a treatment standard that is higher than the IMO,” he said, since verifying treatment to the IMO standard is still not a routine and consistent process.

The ensuing discussion made it clear that test methodologies for sampling and statistical validity are critical. A report due out at the end of June will incorporate database information on vessel pump capacity since this factor has ramifications for onboard treatment systems. Wiley explained the differences among the four IMO approval statuses in a handout [see appendix: Table (1) – (4)]. He said that the world's toxicological experts (GESAMP) received thick dossiers from manufacturers, which they used to evaluate safety concerns, evaluate whether the system proposed has the potential to treat ballast water, consider toxicological effects, etc. Only after receiving advice from GESAMP on the Safety of the proposed treatment system to the environment and to ships and crew, do they receive approval. Then, as part of the type test process, the systems are tested for efficacy. Type approval currently requires tests in two out of three conditions: salt water, brackish water, and fresh water.

When asked why mid-ocean ballast water exchange isn't enough, Wiley replied that saltwater has its own set of potentially invasive organisms should the ballast be released in saltwater ports. Experimental systems are working on some ships at this time with the expectation (USCG and IMO) that ballast water discharge standards will come into effect and that type-approved systems will be fully operational on vessels in 2012, 2014, or 2016, depending on the application date in the convention.

When David Reid reminded the participants that their task was to identify criteria for Wisconsin, they developed this list:

Criteria 1: For systems that have gotten through type approval from IMO, was the testing adequate?
Criteria 2: How were standards formed? How were standards applied?
Criteria 3: Test methodologies…were they available? Adequate? Was there an acceptable level of quality assurance and quality control during the testing?
Criteria 4: Evidence of how things were validated (QA/QC)
Criteria 5: Can this system be applied on actual ships given the constraints of space, power, and pumping capacity?
Criteria 6: Has the system been tested in fresh water? (So far it seems that only 2 of 9 IMO-approved technologies have been tested in fresh water; and those that received freshwater evaluation received it in the shipboard context with limited controls, or at a non-independent vendor operated testing site.) Researchers cautioned that aquatic environments are not universally similar so data gathered in systems outside of the Great Lakes needs to be used carefully.
Criteria 7: Is the temperature at which the test was conducted similar to Great Lakes conditions?

Sources of information:

California tables

Type approval list

EPA science advisory board (report out by end of the year)

U.S. Coast Guard review (out later also)

PANEL 2: Evaluating Factors Affecting the Installation of Specific Ballast Water Treatment Systems on the Applicable Fleets and Vessels within the Designated Timeframes (Panelists: John Stubbs, Errol Francis, Noel Bassett, and Eric McKenzie)

John Stubbs, manager of technical services for FedNav, offered a shipping industry perspective on applying ballast water treatment systems onboard working vessels. He said, “The USCG approval accreditation is what we look at. For our trade, the starting point is USCG type approval, which apparently is at least 3 years away from today according to the earlier presentation made by the USCG.” Like the researchers and USCG, shipowners and carriers are leery of the IMO approval process after hearing the results of the initial USCG audit of the approval results.

For onboard installation and operations, the biggest issues are:

- Safety (Risk to crew that need to manipulate chemicals, risk to vessel, risk to crew).
- Backpressure that slows the ballast evacuation capacity. (Are the tested pumping rates realistic? Many systems have been tested at a pumping rate of less than 200 metric tons per hour but onboard working vessels, the pumping rate can be 700 - 5000 metric tons per hour.)
- Space (Ballast water treatment systems start with a footprint that is about 50% of the size of the main engine; space is a major issue, especially when retrofitting ships.)
- Power (A retrofitted ship might be unable to accommodate the additional power needs of a ballast water treatment system without access to other power sources.)
- Air pollution (With more power, and more greenhouse gas emissions and potentially volatile chemicals, will the air quality sacrifices be worth the water quality benefits?)
- Timing (The lead time required for installing ballast water treatment systems on vessels will be a major issue. Where are the shipyards and are there enough of them to accommodate retrofitting

ballast water treatment systems on existing ships? Where are the engineers for outfitting ships? Ship repairs are currently done in China for the majority of ocean-going vessels. For new ships, their first dry-docking can be in 5 years; will new ships have a 5-year window for retrofitting?

- Costs (To put a ballast water treatment system onboard a vessel costs in the order of $1-2 million (U.S.). To put the issue of ballast water management into perspective, a modern Laker vessel main engine costs about $2 million (U.S.). Ship repair market charges will increase the cost even further.)
- Does system work in fresh water? Cold water? Did a reputable national authority approve it? What are the risks for the ship-owner?

Errol Francis, vice president of operations for Canfornav Inc., said Canfornav was excited to put a proto-type BWTS onboard one of their vessels, especially since the supplier/vendor claimed that they were successful in solving the system's efficacy in fresh water; the system has final and type approval. However, testing in Lake Ontario, with Sarah Bailey's research group, indicated the particular ballast water treatment system failed miserably. This supplier has subsequently stated that they will not spend any more time on research in this connection. Canfornav has had technicians from two other companies inspect their ships to develop plans for retrofitting ships with their ballast water treatment systems. Several months have gone by, but Canfornav still does not have a comprehensive plan from these companies. Francis said "We're open to almost any system that could work on our ships. We'd like to know the cost of these ballast water treatment systems". He estimated a 500 m^3 unit would cost $400,000 and a system could have a footprint ranging from $3m^2$ to $20m^2$ depending on the size and capacity of the unit, restating that these factors are important (cost and space)".

After crediting Susan Sylvester's proactive role in sharing information, Noel Bassett of the American Steamship Company, made comments specific to Great Lakes vessels. "We're like the perfect storm of ballast water challenges," he said, referencing the big vessels without protective ballast tank coatings using extreme pumping rates and making extremely short trips in cold freshwater. "Ignoring the dollars," he said, "treatment rates are a show-stopper; many ships must be capable of pumping ballast at rates of 60,000 gallons a minute!" He foresaw serious physical and economic problems if ballast treatment systems slowed pumping. The footprint of ballast water treatment systems (maybe 1,700 square feet for the largest Great lakes ships) could be a problem along with a system's power needs (maybe 1,200 kilowatts). Short hops, such as Chicago to Milwaukee, would make some treatment options difficult to implement. Bassett said that there are three types of ballasting systems on vessels in the Great Lakes:

1. Common ballast header in the engine room with separate piping in each tank.
2. Each ballast tank has its own sea chest and pump.
3. A main sea chest and pumps in the engine room, then a large header with branch lines to individual tanks (most common).

He thought large ships would require two of the largest ballast water treatment systems currently manufactured by Hyde Marine, made for about $3 million each. He said that the industry is interested in solutions and interim ballast water treatment measures but it is essential to keep physical and economic reality in mind. Very large systems, for that matter any equipment additions to a ship, should require a structural and stability analysis to determine what impact the proposed modification has on the structure, stability, and cargo capacity of the vessel. Structural foundations, materials, welding, vibration analysis would be considered by a naval architect.

Eric McKenzie, vice president of technical development for Seaway Marine Transport, added that voyages taken by the Great Lakes fleet average 4-5 days and some happen within less than 2 days. The average age of the 30 ships in the fleet is 35 years and space is at a premium on existing ships. Retrofitting Lakers with ballast water treatment systems would require major structural redesign given the massive amount of piping running into the engine room, as well as switchboard complexity. He said most of the power a ship can generate is allocated for unloading and that the power required to operate a ballast water treatment system would slow unloading.

The discussion following the panel presentations included questions about retrofitting ships. “You don’t always use all of the ballast water capacity, why do you need all this room,” said a participant. The industry representatives replied by explaining that ships still need a certain amount of physical space for ballast water in order to “ballast down” during particularly rough weather. For Salties, they said there is no spare ballast capacity. “Salties need it to get their propellers down into the water and some need 13,000 tons of water just to do this. Sometimes we even use cargo holds to take on extra ballast water in bad weather.” The carriers thought that finding enough space to install ballast water treatment technologies would more likely take space from the cargo capacity. Should ballast tanks need to be modified, they pointed out that sometimes that might require modifying 16 tanks on one ship, bringing vessel economics, productivity, and a host of other factors into question.

Sources of information:
The shipping industry
Ship engineers/naval architects

Useful criteria to consider when evaluating the practicability of ballast water treatment systems are:

- Reliability and expected reliability. (What do you do when the system breaks down? How long will a system last?)
- Do you need to specially train staff to apply and operate system?
- What are the consumables of the system?
- What is the power draw of the system?
- How does the system impact the ship's safety and the safety of the crew? ("What we must have at the end of the day is safety. Will there be enough ballast capacity and enough pumping capacity to remain safe?)
- Financing (Is it worth retrofitting a Laker that will retire within 10 years?)
- How many systems could a vendor supply in a year?

The carriers pointed out that the classification of a ship is very important and that insurers will not insure ships that are not classed. It is not an option for ship owners or operators to violate the rules of the insurance policies.

Shipowners wonder how they would go about picking a ballast water treatment system for their ships and how they might handle non-delivery. They agreed that USCG type approval will be meaningful to them when it happens. They made it clear that the fact that two of the three IMO approved systems the USCG examined were found to be questionable was alarming. Great Lakes carriers want to be sure they have Transport Canada and USCG type approval before going to the expense of installing a ballast water treatment system. "Would any of you go out and buy a car without taking it for a test drive?"

The 2016 IMO and state deadlines have the shipping industry reevaluating ballast water carried by the Great Lakes fleet along with ocean-going vessels. However, many meeting participants believe that the USCG and Transport Canada are in the "lynchpin position" for deciding the future of ballast water treatment on the Great Lakes. Water quality regulations in the Great Lakes mean that any ballast water discharge will probably need to fall within sewage effluent guidelines. Storing and using chlorine as a treatment option gives rise to safety issues for the crew safety.

Susan Sylvester indicated that Wisconsin plans to reconcile the absence of USCG type approval for ballast water treatment systems by requiring a 3rd party approval (not necessarily a USCG approval). Shipowners indicated that they "won't do what the USCG doesn't tell us to do." Gary Croot, the USCG representative said, "If the state has a requirement to treat, we're not prohibiting installation. However, ballast water exchange is still the only federally accepted method of treatment according to USCG. Then…in all likelihood, carriers would have to treat that water again according to state legislation."

PANEL 3: Review and Assess Current Verification Capability for Treatment Systems to Comply with a Discharge Standard of 100 x IMO Frames [Panelists: Hugh MacIsaac (on phone), Mario Tamburri, and Allegra Cangelosi]

Clearly the biggest hurdles to testing ballast water treatment systems are the large volumes of water and the proper analysis of these volumes. Test methodologies and approaches are evolving. Mario Tamburri (researcher and director of MERC) explained that there is currently no standardized testing protocol. "The way my group has been collecting data has changed and I expect it will continue to change," he said. He also said with a nod to regulators, "Ballast water treatment system vendors want to kill everything. They can't. They're doing the best they can. They're shooting for zero. You don't necessarily need to make a target for them to shoot for, they're shooting for zero. But I haven't ever seen a consistent line of zeros."

Allegra Cangelosi (researcher and director of Great Ships Initiative) added, "We'll go crazy giving a full discharge quality work-up to all vessels applicable to 100 x IMO standards." She suggested developing other ways to evaluate systems to these tougher standards by seeking information from other industries and statisticians for quality assurance and quality control (QA/QC). She thought that the question of “can you monitor to 100 x IMO?” sometimes gets muddled with “do we care about this level of protection?” She said, “These are two questions…the easier one being “can you monitor to this level?” If you care enough about it, you can monitor for it. The tougher question is “is treating to and monitoring for discharge at that stricter level worth the effort? Do the benefits outweigh the costs?”

Hugh MacIsaac, a senior researcher at the University of Windsor, identified three issues of concern. First, treating the volume of water is problematic but not insurmountable. We need to treat large volumes of water quickly. Technology is evolving quickly here. Secondly, there is the aforementioned volume issue. At a 100 x IMO standard, “Wisconsin will truly be trying to find a needle in a haystack,” he said. The National Academy of Sciences will be evaluating propagule pressure in their upcoming report (both MacIsaac and Cangelosi are members of the NAS panel.) Wisconsin’s stringent standard is possibly based on an assumption that reducing propagule pressure affects population establishment risk. However, to test this hypothesis properly, we need to conduct experimental additions to mesocosms or ecosystems on both sides of the proposed standard, and then check the establishment success rate. Nobody has been able to devise suitable experimental studies to address this issue. The third issue is validation that treatment has been successful. Empirical validation poses an enormous challenge because most of our studies have been done on very small volumes of water. The risk of false negatives (i.e., incorrectly stating that water meets the standard) is very high, if treatment is moderately to largely successful - with some live organism remaining – if small volumes of water are surveyed. MacIsaac suggested that discerning living organisms from dead ones is a further complicating problem. FloCam™ can detect the presence of an intact organism and compares it to entries in a database, but is probably not well suited to distinguishing zooplankton species in ballast water discharge since copepods will be dominant and FloCam is highly unlikely to be able to resolve these organisms. Using DNA/RNA technologies may be complicated for validation of treated ballast water since it is possible that killed organisms will release both RNA and DNA into the water and thus generate false positives (i.e. conclude ballast water fails when in fact it may be passable). MacIsaac noted that DNA remains discernable for up to 48 hours, leading to possible inaccurate results. RNA is more reactive and less persistent, and may prove a better tracer. MacIsaac thinks that techniques for surveillance will probably revolve around one or both of these genetic probe technologies.

Since the relationship between propagule pressure and risk is still vague, someone commented, “Instead of boiling the ocean, maybe we should look at species likely to invade?” MacIsaac replied that these types of studies have been done, especially for European source ports from which most shipping to the Great Lakes originates.

Criteria for evaluating ballast water treatment system:

- Are there scientifically sound, available testing protocols?

Lisa Drake added to the discussion about volume. “I don’t see a way around the sample volume issue. I don’t see that it’s possible to analyze 200 cubic meters of water (for the 100 x IMO standard) in a reasonable timeframe at this time. Looking for 10 zooplankton in a cubic meter of water, the IMO standard, is like looking for 10 golf balls in 27 empire state buildings. There are many people talking about the sampling issue, there is not just one voice but many voices in this choir.”

The researchers thought that *validating* ballast water treatment system efficacy onboard vessels required to meet IMO standards would not be possible. Certification testing wouldn’t work. “The volume of water is too great,” said Tamburri. “We can’t certify (*verify*) these systems.” Only threshold compliance could be possible. Regulators could catch gross violators, not precision violators. At the 100 x IMO standard Wisconsin is mandating (0.1 zooplankton per cubic meter); a testing protocol would require a minimum of 10 cubic meters of water.

One participant commented that there are over 60 non-ballast water vectors that could move aquatic species around and that the cost of this discussion is crazy. David Reid replied, “That while there are many vectors for introduction, ballast water has proven, by far, to be the most significant, and it is the vector regulators have chosen to address first.”

Jim Houston revisited an idea dismissed years ago suggesting that the regulators and ports provide pre-treated water from ports. “The economics of this makes it seem like we should talk about this,” he said. Wisconsin is conducting a pilot project in Milwaukee on this proposal but it would be difficult to provide pre-treated ballast in all ports and impossible to do while a ship was underway.

Participants thought there was a need to continue discussions about the huge difference between compliance testing and type approval testing and to clearly differentiate between the two. Croot talked about a paper that involved statistical analyses of compliance testing. It would appear to the USCG and others that type approval testing for standards higher than IMO standards is and will continue to be very problematic.

Tamburri commented that no treatment system that is currently available can meet the Wisconsin standard. Proving a ballast treatment system's and therefore a ship's non-compliance will be easier than showing compliance.

Phyllis Green explained that if you determine a technology standard of dosing to a certain toxicity level and neutralization to a standard prior to release you can create coarse measures of scale then measure whether the treatment is conducted properly to reduce the risk. For the Ranger III, the dose was to a level to kill VHS and zebra mussel measures. When they use the coarse measure of effectiveness used to test drinking water, heterotrophic plate counts, it comes back like distilled water, but without testing protocols she cannot prove it meets 100 x or 1000 x IMO, but she is confident she's enhanced the protection of Isle Royale National Park.

Although there are problems with the use of toxic substances in treating ballast water, Terry Johnson cautioned, "The perfect is the enemy of the good."

Chris Wiley hoped that this exact discussion will happen at the next IMO ballast water discharge meeting. "The world's toxicological experts have expressed considerable concern about standards higher than IMO standards," he said. From a toxicological perspective, he commented that it is critical to ensure toxic water is neutralized before pumping it out. "If you poison the next port, you've got a seriously bad problem," he said. Others agreed.

<u>Sources of information</u>

IMO R&D symposium—report from technology report from Sweden.

Next Steps (Susan Sylvester)

"I bring the paradigm shift to the table," said Sylvester about the afternoon discussions focused on Wisconsin's ballast water treatment regulations. "If this (applicable ballast water treatment options for use in the Great Lakes) doesn't work by December of this year -- to allow ships of 2012 to be built with standards and retrofit ships by 2014 -- then at least we've set a pace for the future. I am in a legal challenge and I need this information for this legal challenge. I appreciate the dialogue based on science and logic; reality over emotion."

Closing

Craig Middlebrook invited participants to take this opportunity to help make legislation rational. "I know everyone is busy," he said. "But, I urge you to get just a little bit busier. Your expertise is desperately needed. We are asking for your further participation in the designated working groups.

Summary

Participants agreed that a promising ballast water treatment technology for use in the Great Lakes and other fresh waters might be raising the water's pH from 7 to 11.5 by dosing ballast water with lime or sodium hydroxide. Hydroxide treatment might be best described as <u>a promising approach</u>, but remains to be developed into a system that can work on ships. After an estimated 48 hours, the pH would need to be lowered back to near neutral (pH 7), or at least to pH 9 (the standard for wastewater discharge from urban centers) and pumped out of the ship. Deoxygenation was also discussed as a promising technology for treating ballast water in freshwater environments.

However…participants almost unanimously agreed that significant challenges separate regulatory targets for ballast water discharge in the Great Lakes from available technologies and the physical constraints of existing ships.

Research discussions suggested that the onboard ballast water treatment systems approved by the International Maritime Organization (IMO) for use in marine environments might be ineffective and/or environmentally unsound and/or corrosive in freshwater systems. Researchers questioned the ability of any currently available system approved for operating in fresh water to exceed the IMO standard for ballast water discharge. Unlike marine environments, the suite of freshwater zooplankton includes rotifers, organisms mostly in the 10-50 micron range that survive ballast water treatment efforts in sufficiently high enough numbers to challenge the IMO standard, and exceed Wisconsin's proposed standard of 100 x IMO. Methods for testing whether ballast water treatment systems can attain better-than-IMO standards are not available at this time; the volume of water or number of replicates required could outstrip capacity at the three ballast water treatment testing facilities operating in the United States, though this remains an open question. Researchers think that it would be exceedingly difficult at this time to prove a ship is compliant with proposed Wisconsin standards. Given the sampling statistics and the state-of-the-art methods at the current time, it seems possible to show only that a ship's ballast water is grossly violating 100 x IMO standards.

With regard to installing and operating ballast water treatment systems onboard ships in the Great Lakes, shipping industry professionals and U.S. Coast Guard regulators remain concerned about crew and ship safety, space constraints, installation timing, long and short-term costs, indirect costs, and ballast water treatment system lifetime and reliability. Aside from several prototype trials that have or are taking place, Great Lakes shipping industry representatives indicated that they are seriously reluctant to install ballast water treatment systems onboard ships before the U.S. Coast Guard gives final approval for a system. The final approval process for a system will take at least 2.5 years.

Above and beyond the criteria of meeting basic purification and safety standards, participants offered the following critical questions for evaluating a ballast water treatment system's practicability in Great Lakes conditions:

- For systems that received type approval, is the testing adequate?
- Has the system been tested in freshwater?
- Was the temperature at which testing was conducted reflective of Great Lakes conditions?
- Is there evidence of how data were validated (quality assurance and quality control)?
- Will the system(s) compromise ship or seaman safety once they are installed?
- Will the system(s) fit on existing ships in the Great Lakes?

- How reliable is the system? (What happens if the system breaks down?)
- Will ships need specially trained staff to apply and operate system?
- What and how much will the system consume?
- What are the power needs of the system while operating?
- Can the manufacturer produce enough of these systems to meet projected timeframes of demand?
- What sort of expertise, engineering, and lay-up will be required for system installation?
- Is this expertise and space available in the current timeframe?
- How affordable is the system to purchase, install, and operate?
- Once the system is operating onboard a vessel, are there scientifically sound, available testing protocols for ensuring it is performing?

RESOURCE LIST

- *Saint Lawrence Seaway Development Corporation (U.S.A.)*
- *St. Lawrence Seaway Management Corporation (Canada)*
- **Port of Milwaukee Onshore Ballast Water Treatment Feasibility Study Report**. October 12, 2007. *Prepared for the Wisconsin Department of Natural Resources.* dnr.wi.gov/org/water/greatlakes/projects/WDNROnshoreBallastWaterTreatmentStudy_FinalReport.pdf
- **Emergency Response Guide for Handling Ballast Water to Control Non-Indigenous Species.** 21 January 2010. *Prepared for the National Park Service.* www.nps.gov/isro/upload/High_Risk_Ballast_Water_First_Response_Guide_January2010.pdf.
- **Great Ships for the Great Lakes**?
- **GSI Findings on Siemens SiCure System and Great Lakes Preamble**

APPENDIX: Meeting Handouts

- Meeting Agenda
- State Updates Spring 2010
- Great Lakes Ballast Water Collaborative Update, Spring 2010
- Outline for Wisconsin's Data and Assessment Discussions
- Scope of Work: Wisconsin Ballast Water Treatment Technology Assessment Report. May 18, 2010
- National Ballast Regulations, by Janenne Irene Pung. Reprinted from *Great Lakes/Seaway Review* 38(3).
- 2009 Summary of Great Lakes Seaway Ballast Water Working Group. Report from Feb. 2010
- Ballast Water Treatment Technology: Current Status. 3rd Edition. Lloyd's Register with contributions from the Institute for the Environment at Brunel University, February 2010.
- Density Matters - Review of Approaches to Setting Organism-Based Ballast Water Discharge Standards
- Agenda June 28, 2010, Meeting of California State Lands Commission
- California Lands Commission 2010 Assessment: Assessment of the efficacy availability and environmental impacts of ballast water treatment systems for use in California Waters, June 2010
- Tables provided by California May 2010
- Canada's Regulatory Regime for the Great Lakes, Chris Wiley.
- IMO Ballast Water Update 2010 follow-up, Chris Wiley.
- IMO BWMS Approvals (April 2010).

Great Lakes Ballast Water Collaborative Meeting

Tuesday, May 18, 2010
The Delta Hotel, Room: Opus 1
475 Avenue Du Président-Kennedy
Montréal, Quebec, H3A 1J7
(514) 286-1986

AGENDA

Morning Session (8AM-NOON)

- 8:00 – 8:15 Introductory Remarks (IJC and Seaway)
- 8:15 – 8: 30 Update on Ballast Water Collaborative Activities (Craig Middlebrook)
- 8:30 – 8:50 Update on interim measures activities (Phyllis Green and Noel Bassett)
- 8:50 – 9:05 State Activities Update: Discussion of their individual information needs (Jeff Stollenwerk and Dave Adams)
- 9:05 – 9:15 Canadian Federal Regulatory Activities Update (Chris Wiley and Paul Topping)
- 9:15 – 9:45 U.S. Federal Regulatory Activities Update (Gary Croot and Ryan Albert)
- 9: 45 – 10:00 BREAK
- 10:00 – 11:00 Panel Discussion led by Gary Croot: "USCG Ballast Water Treatment Evaluation Activities & Enforcement Issues" (participants to include Mario Tamburri, Lisa Drake, and Allegra Cangelosi).
- 11:00 – 11:40 Facilitated discussion to develop a common understanding of key BWT concepts and terms (work to be completed as a follow-up to the meeting, based on USCG/EPA efforts).
- 11:40 – 12:00 Start of LUNCH

Noon/Lunch Session *(One Hour for both Lunch and Presentations)*

- 12:00 – 12:15 Update Ballast Water Treatment System Manufacturers: Pathway for Approval of Experimental BWT Systems in the Great Lakes (Georges Robichon).
- 12:15 – 12:30 Pathway for Approval of Experimental BWT Systems in the Great Lakes (Vadim Zolotarsky).
- 12:30 – 12:45 Performance to IMO: A Case Study on what it means in the Great Lakes (Allegra Cangelosi).
- 12:45 – 1:00 Discussion

Afternoon Session (1PM – 5PM)
Moderator – Dr. David Reid

- 1:00 – 1:20 Introduction: State Implementation Challenges - Wisconsin "Scope of Work" for Ballast Water Treatment Efficacy and Availability: Opportunities for "Collaborative Input".
- 1:20 – 2:20 Identification of "available" ballast water treatment systems "rated" to meet or exceed 100 X IMO (Chris Wiley, Gary Croot, and Maurya Falkner).
- 2:20 – 3:20 Evaluating factors affecting the installation of specific ballast water treatment systems on the applicable fleets and vessels within the designated time (John Stubbs, Errol Francis, Noel Bassett, and Eric McKenzie).
- 3:20 – 3:30 Break
- 3:30 – 4:30 Review and assess current verification capability for treatment systems to comply with a discharge standard of 100 X IMO frames (Allegra Cangelosi, Mario Tamburri, and Hugh MacIsaac) .
- 4:30 – 4:50 Wrap-up and Next Steps
- 4:50 – 5:00 Closing Remarks

Evening reception hosted by FedNav (5PM – 7PM)
Symphonie Room at The Delta Hotel

Great Lakes Ballast Water Collaborative: 2010 State Updates

Michigan:
1) NWF challenged the MDNRE 401 certification of EPAs Vessel General Permit in December/2008. The litigation is ongoing.
2) Michigan joined with New York, California, Wisconsin, Connecticut, and New Jersey in submitting comments on the USCGs proposed standard for ballast water discharges.
3) Michigan challenged EPAs Vessel General Permit in April/2009. The other parties in the EPA lawsuit include: NRDC; NWF; Northwest Environmental Advocates; Canadian Shipowners Assoc.; American Waterways Operators; and Lake Carriers Assoc. EPA settlement discussions are continuing. A motion is being filed to hold litigation proceedings in abeyance until June 25, 2010.
4) MDNRE has issued 172 permits for oceangoing vessel operators to conduct port operations since Michigan's ballast water law went into effect in 2007.
5) MDNRE continues to support a universal ballast water discharge standard for the Great Lakes.

Minnesota:
1) Continue to administer the state ballast water discharge permit that includes the IMO performance standard by 2016.
2) Continue efforts to support a national ballast water discharge standard that is protective of state waters and eliminates the need for a direct regulatory program at the state level. This work includes:

- -Pursuit of technical solutions through contracts with experts at GSI and USGS;
- -Finding regulatory solutions through review and comment on USCG proposed regulation, and support of EPA strategy for VGP reissuance;
- -Seeking resources through GLRI to support transitional work from state to federal regulations;
- -Promote communication through the BW Collaborative, GSI Advisory Committee, and routine GL states conference calls.

New York:
1) New York State successfully defended a multiparty challenge to the State's EPA VGP letter of cert. conditions in both the State Supreme Court and the Appellate Division. Litigants have filed a request to appeal to the Court of Appeals.
2) If you have coverage for vessels under EPA’s Vessel General Permit (VGP) and are seeking an extension to condition(s) 2, 4 and/or 5 of New York's Water Quality Certification (WQC) to the VGP (Section 6.22 of the VGP), requests must be made no later than June 30, 2010.
3) Coastal Zone Management Program staff are reviewing USCG request for a consistency determination.

Ohio:
1) Continue to administer the VGP and state 401 certification conditions.
2) Review of studies/reports on new treatment systems to maximize the kill/removal of exotic species.

3) Support R&D on treatment methods applicable to the unique characteristics of laker ballast discharges.

Pennsylvania:

1) Continues to administer the VGP and state 401 certification conditions.
2) In December 2009 Pennsylvania DEP replied to 182 shipping companies representing over 9,300 vessels that requested an extension of time to comply with Pennsylvania's 401 certification conditions numbers two and three and granted an extension to comply until the current VGP expires.
2) In December 2009 Pennsylvania DEP requested EPA to delete state 401 certification conditions one, two and three. EPA is expected to act on this deletion request in July 2010.
3) Pennsylvania will reevaluate the need to establish additional 401 certification conditions when the current VGP expires at midnight December 19, 2013. PA DEP also advised the 182 shipping companies mentioned above that PA DEP reserves the right to establish similar or identical conditions when the new VGP is issued.

Wisconsin:

1) Ballast Water Discharge GP permit effective date February 1, 2010.
2) Both salties and lakers are covered by this permit for BMPs and reporting.
3) If vessel has coverage under EPA Vessel GP, then covered under our permit until July 31, 2010 when NOI must be submitted, or vessels will be illegally discharging ballast water into state waters. Must have coverage under state permit by July 31, 2010.
4) Fees for permit application and annual fee have not been invoiced, waiting for staffing decision for new positions to implement permit.
5) Feasibility Determination due by December 31, 2010 must be made on commercial availability of treatment systems to meet Wisconsin Standards by January 1, 2012 (new salties) and 2014 (existing salties).

Dear All,

It has been several months since we have communicated to you regarding what has become known as the “Ballast Water Collaborative.” We are writing to give you an update, because over the past several months, you have participated in or expressed an interest in the work of the “BWC.” Since our initial meeting in Detroit on September 24, 2009, there have been concerted efforts to further build on the progress of the Detroit meeting.

At its most basic level, the BWC is an effort to share relevant, useful, and accurate information and foster better communication and collaboration among the key stakeholders engaged in the effort to reduce the risk of introduction and spread of aquatic nuisance species. A particular emphasis of the Collaborative has been to bring state representatives together with marine industry representatives and respected scientists to find workable and effective solutions to the ANS challenge as they relate to the Great Lakes St. Lawrence Seaway System. The aim of the BWC is not to take away from any preexisting efforts in this regard, but rather to complement those efforts.

September 24, 2009 Meeting in Detroit, Mich.

On September 24, 2009, the Saint Lawrence Seaway Development Corporation (SLSDC) and the International Joint Commission (IJC) co-hosted an information-sharing forum on ballast water issues in the Great Lakes St. Lawrence Seaway System. The forum was held in Detroit, Michigan, facilitated by representatives from the Minnesota Sea Grant and Great Lakes Commission and attended by representatives from State and Provincial Governments (Minnesota, Wisconsin, Illinois, Ohio, Michigan, New York, and Ontario), U.S. and Canadian federal agencies (U.S. Coast Guard, U.S. Environmental Protection Agency, U.S. National Park Service, National Oceanic and Atmospheric Administration, U.S. Geological Survey, Transport Canada, Fisheries and Oceans Canada), senior executives from the U.S.-flag laker, Canadian-flag laker, and international fleets; and the leading academic ballast water researchers from Canada and the United States. In all, 51 individuals attended the one-day meeting. The meeting’s goals were to share relevant information among the participants, increase dialogue among the key stakeholders involved in this issue, and to discuss ways of further reducing the risk of introduction and spread of invasive species through ballast water.

December 9-11, 2009 Great Lakes ANS Panel Meeting in Ann Arbor, Mich.

After the larger meeting in Detroit, key representatives from the stakeholder groups decided to continue talking and to participate in a series of follow-up calls to discuss how to build on the discussions and ideas shared at the Detroit meeting. Among the entities involved in this smaller group were the IJC, the SLSDC, the States of Minnesota, New York, and Wisconsin, Wisconsin and Minnesota Sea Grant, the USCG, the National Park Service (NPS), the National Oceanographic and Atmospheric Administration (NOAA), the Great Lakes Commission (GLC), American Steamship Company (ASC), the Lake Carriers Association (LCA), and the Canadian Shipowners Association (CSA).

This smaller group communicated (often electronically) on several ideas, including identifying research priorities. Dr. Phil Moy, Fisheries and Invasive Species Outreach Specialist with

Wisconsin Sea Grant, suggested that a practical next step was for Collaborative members to attend the Great Lakes ANS panel meeting in Ann Arbor, Michigan, in December 2009 to present these research priorities and also to discuss them with the Panel's academic and NGO-community representatives. Representatives from the IJC, SLSDC, USCG, NOAA, NPS, State of Minnesota, ASC, LCA, and CSA attended the meeting in Ann Arbor.

During the Great Lakes ANS Panel meeting, Collaborative members were invited by Panel members to participate in the Panel's Research Coordination Committee meeting. At the Committee's working meeting, the BWC's research-priority ideas were reviewed and extensively discussed. This discussion led to revisions of the BWC's original priorities. The Committee decided to include these revised priorities among its 2009 Aquatic Invasive Species Research Priorities for the Great Lakes. The Committee's list can be accessed at http://www.glc.org/ans/pdf/2010-01-04-GLP%20RCC%20Priorities_for%20distribution.pdf. The BWC's original priorities and the revised language are attached below.

During the Ann Arbor meeting, the non-federal members of the Ballast Water Collaborative decided to prepare a proposal in response to the Great Lakes Restoration Initiative Request For Proposals (GLRI RFP). The funds requested would provide support for the BWC to convene at least three plenary meetings for all participants, convene focused committees and/or expert panels and implement measures to reduce spread of ballast-borne AIS in the Great Lakes.

January 14 Meeting in Toronto, Ontario

In early January, a third session brought the smaller group together to discuss how the BWC effort will complement, not compete with, existing efforts to find, support, and implement effective ANS risk-mitigation measures in the immediate and longer term. The non-federal members finalized their GLRI proposal, which was submitted to the EPA by the University of Minnesota Sea Grant Program at the end of January. To date, a determination by EPA on the proposal has not been made. A copy of the proposal is attached.

During the January meeting in Toronto, Susan Sylvester (who represented the Wisconsin Department of Natural Resources (WI DNR) at the September Detroit meeting) requested assistance from the Collaborative. WI DNR is in the process of developing the Ballast Water Treatment Technology Assessment Report which is a requirement of the Wisconsin Pollution Discharge Elimination System (WPDES) permit. Over the past two months, members of the key BWC stakeholder groups have discussed how the Collaborative's members can provide assistance to WI DNR in this effort. A series of working groups has been proposed to compile information related to each component of the final report. A Ballast Water Collaborative Steering Committee (key representatives from each stakeholder group) would oversee this activity. Ownership and responsibility for the Ballast Water Technology Report and identified Scope of Work, is wholly Wisconsin's. However, the Collaborative members who have been working with Susan Sylvester to date feel that all members of the Collaborative will benefit from participating in this process. By voluntarily providing their expertise, Collaborative members will be able to contribute to the success of this effort being undertaken by WI DNR, and all participants will better understand the issues, opportunities, and obstacles that impact regulatory realities in the current environment.

The Federal (USCG) rule-making process is underway and as mentioned at our initial meeting in Detroit, influencing that process is not the goal of the BWC's efforts. However, a new awareness is developing in the broader regulatory community of how complicated and time consuming the process of formally evaluating ballast water treatment systems actually is.

Next Steps

The members of the BWC who have been conferring since the September Detroit meeting are looking to convene a meeting of the entire Collaborative in the next two to three months to discuss progress being made towards finding interim solutions as well as to address the specifics of how the Collaborative will provide assistance to WI DNR. As a possible date and agenda take shape, we will share them with you.

Thank you for your continued interest and efforts in this vitally important activity.

Sincerely,

Craig Middlebrook
Deputy Administrator
Saint Lawrence Seaway Development Corp.

Mark Burrows
Physical Scientist Secretary
Council of Great Lakes Research Managers
International Joint Commission

Attachment

Proposed amendments arising from initiatives proposed by the Ballast Water Collaborative:

Original:
Test ballast water treatment systems for their efficacy with fresh water ballast and over the range of temperature conditions typical for the Great Lakes shipping season.

Revised
Test efficacy of ballast water treatment systems for fresh water ballast over the range of environmental conditions (temperature, salinity) typical for the Great Lakes shipping season, considering physical and operational limitations of saltwater vessels, in order to prevent new AIS introductions from foreign freshwater ports and/or prevent secondary spread between Great Lakes ports by saltwater vessels.

Test efficacy of ballast water treatment systems for fresh water ballast over the range of environmental conditions (temperature, salinity) typical for the Great Lakes shipping season, considering physical and operational limitations of Great Lakes vessels, in order to prevent secondary spread between Great Lakes ports by Great Lakes vessels.

Original
Continue efforts to purchase or lease vessels for full-scale ballast water treatment technology testing platforms. Make full-scale ballast water treatment test platforms available in the form of shore-based facilities or U.S. Department of Transportation - Maritime Administration (MARAD) vessels and conduct full-scale demonstrations of ballast water treatment technologies on shore or ship under actual operating conditions.*

Revised
Continue efforts to purchase or lease vessels for full-scale ballast water treatment technology testing platforms. Make full-scale ballast water treatment test platforms available in the form of shore-based facilities or U.S. Department of Transportation - Maritime Administration (MARAD) vessels and conduct full-scale demonstrations of ballast water treatment technologies on shore or ship under actual operating conditions. Evaluate on-board treatment systems on Lakers consistent with or as part of the US Coast Guard STEP program, to verify treatment performance standards across the range of environmental (temperature) conditions typical for the Great Lakes shipping season, and operational constraints of the Great Lakes shipping fleet.

New
Continue to evaluate the risk of secondary spread of AIS associated with Lakers and their trade routes.

Develop and evaluate practices (ballast water management tools) for reducing the risk of inter/intra lake transport of non-indigenous species by Lakers for immediate implementation.

Note: *The current Wisconsin Scope of Work will only consider impacts and issues concerning "ocean-going vessels" (new builds 2012, and retrofits 2014) in the following meeting sessions, for incorporation into the "2010 Wisconsin Ballast Water Treatment Technology Assessment Report." However, this is also an opportunity for "Lakers" to evaluate and prepare their information needs for potential inclusion in future permit requirements by Wisconsin and other Great Lakes States. This is also an opportunity to begin to collect and frame essential information to assist ballast water treatment vendors in designing BWT systems to meet the unique needs of Great Lakes only vessels and routes.*

Outline for Wisconsin's Data and Assessment Discussions

Montreal Ballast Water Collaborative Meeting, May 18th, 2010

1) Identification of "available" ballast water treatment systems "rated" to meet or exceed 100 X IMO.

The Wisconsin ballast water permit requires new oceangoing vessels to meet the Wisconsin Standard (100xIMO) by January 1, 2012 and existing oceangoing vessels to meet the standard by January 1, 2014. A panel discussion, and subsequent work group, will focus on compiling information available on all treatment systems into a matrix that would identify the treatment system, if rated, to what level, when, by whom, whether it works in freshwater or saltwater, estimated cost of system, manufacturing status, availability year.

Discussion leaders: Chris Wiley, Gary Croot, Maurya Falkner (via phone).

A. What are the critical factors or elements of the issue that must be evaluated?

Information has been collected but it needs to be compiled into one matrix. Define the elements needed for the matrix and fill-in all the information which is currently available.

B. What are the sources of information?

For each of the data elements, obtaining information already available from IMO, Lloyds', California, federal agencies, as well as technology testing facilities or other information collected on ballast treatment systems.

C. How should the information be assembled and evaluated?

What is the most efficient method to compile information on each critical factor? Can these factors be interpreted differently by others? If so, describe the logic that should be used in evaluating and interpreting the information provided, ie. explain why a particular requirement was included.

D. Who are the topic experts that are willing to help assemble data/information (who are potential members of this work group)?

2) Evaluating factors affecting the installation of specific ballast water treatment systems on the applicable fleets and vessels within the designated time frames.

The Wisconsin ballast water permit requires new oceangoing vessels to meet the Wisconsin Standard (100xIMO) by January 1, 2012 and existing oceangoing vessels to meet the standard by January 1, 2014. A panel discussion and subsequent work group will focus on the physical limitations affecting capacity of vessels to accept various treatment system types from relatively minor modification to support chemical dosing systems to installation of stand-alone package treatment systems. The discussion / work group will also address administrative requirements for installing treatment systems.

Discussion Leaders- John Stubbs, FedNav; Errol Francis, CanForNav; Noel Bassett, ASC; Eric McKenzie, SMT.

A. What are the critical factors or elements of the issue that must be evaluated?

Assuming 100xIMO systems are available (whenever that may be), define the critical factors that affect practicability and timing for installation on new and existing oceangoing vessels. Factors may include space, time to treat, pump rate, electric power supply, safety (chemical exposure, etc), financing, USCG and other regulatory approvals, class society approvals, operations and maintenance capacity, . . .

B. What are the sources of information?

For each of the factors identified in Item A above, specify the sources of data or other information can be found to support a statement regarding the time necessary to fulfill the factor requirement.

C. How should the information be assembled and evaluated?

What is the most efficient method to collect information on each critical factor? Can the time requirements of these factors be interpreted differently by others? If so, describe the logic that should be used in evaluating and interpreting data. Basically, begin to explain how and why a particular time requirement was selected.

D. Who are the topic experts that are willing to help assemble data/information (who are potential members this work group)?

3) Review and assess current verification capability for treatment systems to comply with a discharge standard of 100 X IMO.

The Wisconsin ballast water permit requires new oceangoing vessels to meet the Wisconsin Standard (100xIMO) by January 1, 2012 and existing oceangoing vessels to meet the standard by January 1, 2014. A panel discussion, and subsequent work group, will focus on determining the capacity to evaluate treatment system efficacy at both land-based testing facilities and ship-board. The discussion will also address issues pertaining to verification of treatment systems.

Discussion Leaders: Allegra Cangelosi, Mario Tamburri, Hugh MacIsaac (via phone).

A. What are the critical factors or elements of the issue that must be evaluated?

Define the elements needed to assess verification capability of treatment systems with the potential to meet 100 x IMO via land-based testing facilities. Factors may include protocols, environmental conditions, biological requirements and statistical issues, ie. salinity, organism concentrations, trials/ replicates, water volumes, and statistical confidence limits.

B. What are the sources of information?

For each of the elements, especially the critical factors identified in Item A above, specify sources of data and/ or other information necessary to support a statement regarding the ability to meet necessary verification requirements.

C. How should the information be assembled and evaluated?

What is the most efficient method to compile information on each critical factor? Can these factors be interpreted differently by others? If so, describe the logic that should be used in evaluating and interpreting the information provided, ie. explain why a particular requirement was included.

D. Who are the topic experts that are willing to help assemble data/information (who are potential members this work group)?

SCOPE OF WORK
May 18, 2010

Wisconsin Ballast Water Treatment Technology Assessment Report

History

On November 18, 2009, WDNR issued a General Permit for vessels discharging ballast water into Lake Michigan, Lake Superior or other waters where a vessel may transit located within the boundaries of Wisconsin. The permit effective date is February 1, 2010.

This general permit requires new built oceangoing vessels to meet the Wisconsin Discharge Standard (IMO x 100)by January 1, 2012. Existing oceangoing vessels must meet this standard by January 1, 2014. As indicated in the Wisconsin General Permit and permit fact sheet, Wisconsin DNR will conduct a treatment feasibility review by the end of 2010.

Ballast Water Treatment Technology Assessment Report

The focus of this report is limited to ocean going vessels (salties): new builds only in 2012 and retrofitting existing ocean going vessels in 2014.

Treatment system manufacturers, researchers, and vessels owners covered under the permit are encouraged to submit information to the Department to assist in this treatment feasibility determination.

The treatment feasibility determination must be completed by December 31, 2010. A report to be developed as an internal document will be used to determine whether existing technologies are available to meet the discharge standards. If it is determined that treatment technologies are not commercially available, then the permit will be modified. Several options exist:

1) Require IMO standards to be met by the permit timeframe instead of the Wisconsin standard.
2) Change the compliance schedule and/or the implementation date.

Note: If it is deemed that technology exists, but is not commercially available, IMO x 100 standards may remain in the permit and the implementation date may be extended. For Wisconsin's purposes, the assessment of availability will focus on whether systems are available for purchase on the commercial market.

Wisconsin's General Permit specifically invites interested parties to provide information that will assist in the treatment feasibility determinations (Permit Part 4.1.1.) The Great Lakes Ballast Water Collaborative[1] (Collaborative) has expressed interest in helping Wisconsin achieve this goal in determining the assessments needed for the General Permit. While other states have different discharge standards or time frames for implementation of their standards, Wisconsin is the only state currently conducting a technical feasibility analysis to achieve the IMO x 100 standard. We anticipate that Wisconsin's evaluation will be useful for all other Great Lake States as they move towards implementation of their ballast treatment water standards.

Scope of Work

The Department intends to rely on others to approve ballast water treatment systems, such as the US Coast Guard, US EPA, and other applicable organizations. Within the Permit, the burden of responsibility is ultimately on the vessel owners to ensure that vessel discharges comply with the Wisconsin Discharge performance standards for ballast water and applicable water quality laws, permits, and regulations. Therefore, the Wisconsin treatment technology assessment report is structured to assess the availability of ballast water treatment systems to meet Wisconsin's standards. The final assessment report will provide no guarantee that a system will meet Wisconsin's standards, as all vessels operate on different routes under different biological, chemical, and physical conditions that may influence ballast water treatment system operation. Our approvals are not a guarantee of performance; they approve compliance with state codes.

The General Permit lists the criteria the Department will consider in the assessment but does not provide a detailed scope of work or define any terms. Therefore, the Department is charged with interpreting the permit and defining terms and the scope of work prior to preparing the assessment report. The assessment report will be limited to an evaluation of each criterion listed in the General Permit (Part 4.1.1.) based on existing data and information:

a) Treatment technologies are able to meet the Wisconsin standard in Table A of the General Permit;
b) The technologies are commercially available:
c) It is feasible to install the technologies onboard both new and existing vessels, and;
d) That sufficient time exists to comply with the discharge standard's effective dates.

For each criterion the assessment report will include:
1) Overview and description of the criterion;
2) Definition of key terms;
3) Identification of existing data or information sources;
4) Assessment of data/information; and
5) Recommendation for Department determination.

The primary review consists of treatment system efficacy and availability. Efficacy, in this context, is defined as the ability of a system to treat ballast water to a level compliant with Wisconsin's performance standards.

The assessment of availability should focus on whether systems are available for purchase on the commercial market. Since Wisconsin does not perform a technical review of treatment systems, but does require systems to have third party approvals from appropriate federal or international organizations or governments, "availability" hinges on approved systems that are available for purchase and installation on a vessel for use in the Great Lakes.

It is anticipated that the Collaborative and other interested parties will provide unique expertise and perspective to assist in the development of the final assessment report. The Department will use the final assessment report to make the decision in the Treatment Feasibility Review. The General Permit Fact Sheet has an outline for the Treatment Feasibility Review (included at the end of this document).

The Department invites the Collaborative to participate in evaluating the technical and scientific information available to help Wisconsin compile its assessment report. The Collaborative can help the Department bring to the table "key" experts to weigh in on the discussion and on the recommendations.

System Assessment
The report shall gather information on ballast water treatment systems. The Collaborative is invited to help to collect information in three key areas: Identification of "available" ballast water treatment systems rated to meet or exceed 100 x IMO; Evaluation of factors affecting the installation of specific ballast water treatment systems on applicable fleets and vessels within the designated time frames; and Review and assessment of current verification capability for treatment systems to comply with a discharge standard of 100 x IMO.

Benefits of Approach to Technology Assessment
We believe that given the available resources and information on treatment system development and operation, support from the Collaborative provides the most productive and cost-effective approach to collecting critical data for our technology assessment. A wide range of information is available in third party testing reports, the scientific literature, government white papers, and even in commercial brochures and advertising materials. Follow-up discussions with Collaborative and technical experts will be incredibly valuable in assessing information pertinent to decisions on implementation of Wisconsin's performance standards. The variety of approaches for verifying system performance may result in having systems that work in salt water environments but not in the freshwater environments, of the Great Lakes. We will need to move forward using the current best available information and data.

Next steps
Wisconsin has committed to finalizing a Treatment Feasibility Determination decision by December 31, 2010, in anticipation of the January 1, 2012 implementation of the performance standards for new built vessels. Wisconsin will participate in the May 18th Great Lakes Ballast Water Collaborative meeting in Montreal to bring the process of collecting data and information for its assessment report concerning the efficacy and availability or unavailability of treatment systems that will meet the Wisconsin standard (IMO x 100) by the timelines indicated in the General Permit.

[1] The Great Lakes Ballast Water Collaborative is an informal working group that resulted from the Great Lakes Regulatory Forum on Ballast Water Action (Forum) held September 24, 2009, in Detroit, Michigan. The Forum brought together for the first time a number of senior executive officers of the U.S. and Canadian-flag commercial Great Lakes fleets, and representatives of U.S. State and Canadian provincial regulatory agencies, as well as U.S. and Canadian federal regulators and leading U.S. and Canadian ballast water researchers, to initiate a direct dialogue on potential voluntary, immediate ballast treatment and/or management measures the Great Lakes shipping industry could take to minimize the spread of AIS. The Forum was hosted by the U.S. St. Lawrence Seaway Development Corp. and the International Joint Commission, and facilitated by Minnesota Sea Grant and the Great Lakes Commission.

(From Wisconsin's General Permit Fact Sheet Attachment)
Treatment Feasibility Review
Scope of Work

Subsection 4.1.1 of the WPDES general permit requires the Department to make a determination on whether ballast water treatment technologies are available that meet the four criteria in the permit to comply the Wisconsin ballast water discharge standard. To assist the Department in making this important determination, a "Technical Advisory Committee" or TAC may be formed to provide a forum for reviewing technical information on ballast water treatment. The TAC would consist of stake holders as well other interested parties who have technical expertise to offer.

The Department intends to invite those willing to provide technical advice from a cross section of groups to help the Department reach an unbiased decision. The TAC may include some or all of the following:

- Transoceanic shipping interests
- Environmental groups
- Port authorities
- US Environmental Protection Agency
- Great Lakes organizations
- Great Lakes shipping interests
- University academics
- Great Ships Initiative researchers
- US Coast Guard

Once these groups express their availability and interest to participate on a broad based TAC, the Department will conduct TAC conference calls or meetings. The Department intends to hold one or two sessions, but will hold more if necessary to make its determination. Each invited group will be asked to give a presentation and provide any relevant documentation they have in support of their technical knowledge on whether the four criteria below are met.

1. Treated effluent will comply with the Wisconsin Standard in Table A.
2. A compliant treatment system is commercially available.
3. Onboard installation is feasible for existing vessels and new vessels.
4. Sufficient time exists to comply with the discharge standard effective dates.

After the TAC completes its task, the Department will take under advisement all the information received from the TAC. Additional sources of information besides the TAC may also be taken into consideration by the Department. A decision on the treatment feasibility determination will be made by the Department no later than December 31, 2010.

National ballast regulations

Looking into aspects of the U.S. Coast Guard's proposed rulemaking

During the public comment period for the Notice of Proposed Rulemaking for the U.S. Coast Guard Ballast Water Discharge Standard, which closed December 4, 2009 the Coast Guard received about 2,500 comments. The comments are now being reviewed, a step in moving toward ultimately establishing a national discharge standard.

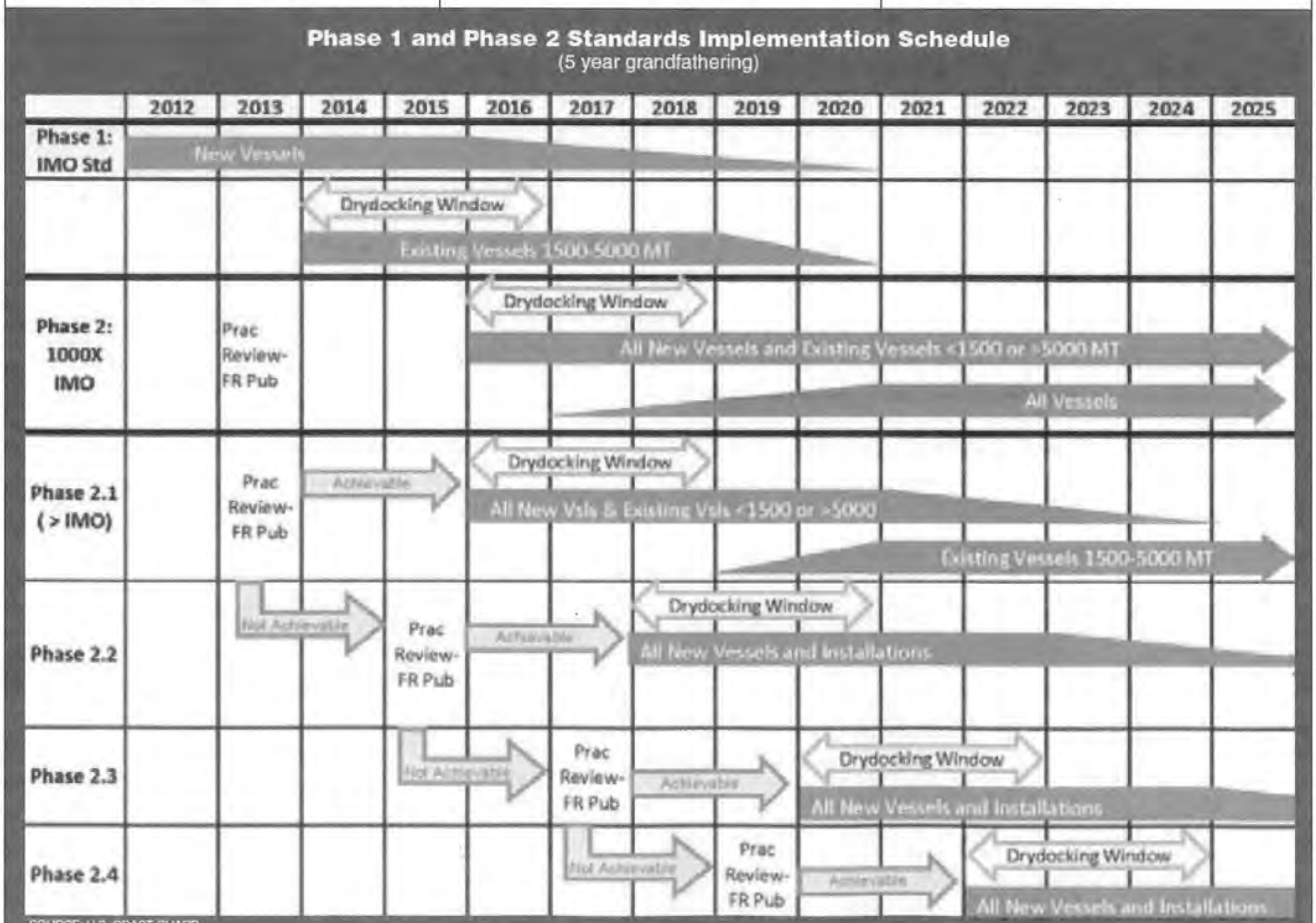
The Coast Guard has developed a schedule to provide stakeholders with a process for integrating Phases 1 and 2 of the proposed standard. (See schedule below). As it stands, Phase 1 involves new vessels meeting the International Maritime Organization (IMO) standard in 2012 and existing vessels complying in 2014, with a drydocking window extending to December 31, 2016.

"The discharge standard provides a concrete code for system manufacturers to meet," said U.S. Coast Guard Commander Gary Croot, Chief of the Environmental Standards Division in Washington, D.C.

However, Croot said the 2012 timeline as a first deadline for compliance is aggressive because ballast water treatment systems—most of which are still being developed and tested—will need to undergo U.S. federal type approval, a process that will involve review by independent labs that have yet to be certified by the Coast Guard. The type approval process is Phase 2 of the Coast Guard's plan—in addition to integrating a release standard 1,000 times more stringent than IMO.

"The IMO standard is extremely low, meaning really good," Croot said. "It's like one drop of water in 20 Olympic swimming pools or one second in 32,000 years."

Deadlines in flux. Installation deadlines are a being considered flexible because the technology to meet the IMO standard is still developing, said Allegra Cangelosi, Director of Environmental Projects for the Northeast-Midwest Institute and Principal Investigator of the Great Ships Initiative. Depending on when the system designers can prove that their systems work and can begin to make them available will impact the deadlines.



"There's a real race going on right now among treatment vendors to get their systems approved and on the map so that the deadline for ships to install is not delayed," she added.

Amid the lack of treatment systems, ship operators are using ballast water exchange—also known as flushing—as a form of treatment. Bi-national ballast tank inspections are showing the approach to be an effective option, however, treatment systems are expected to expedite ships' journey rather than have them stopped while undergoing a complete release and reload of ballast while more than 200 miles offshore.

Cangelosi sees another advantage to the developing technology.

"With ballast water treatment, we can know in advance to what extent we're treating, and then we can monitor to determine how that treatment is working," she said.

As the U.S. Coast Guard continues establishing the national standard, it has planned reviews along the way. In 2013, a practicability review will determine if technology can meet the criteria. A similar review is scheduled for 2016.

"It's much more important to establish a Phase 1 standard that's achievable as apposed to establishing a pie-in-the-sky standard," Croot said. "If the final standard comes out and Phase 1 was 10 times more stringent than IMO, it's been our experience that none of the systems that have been type approved by foreign administrations would meet the criteria. And, even if there was a system 10 or 100 times more stringent than IMO, we're not confident that we could verify it."

Testing and validation. There are currently upwards of 40 different treatment systems being developed, from rudimentary stages to having received IMO certification. About eight systems have received type approval, a credential for use, from foreign administrations. However, before being approved by the U.S., the systems will need to undergo review and approval at U.S.-certified labs.

"There's going to be a difference between what has been approved by foreign administrations," Croot said. "The U.S. will review each system's specifications."

There are three labs in the U.S. at this time that have shown interest in becoming certified by the Coast Guard to work as independent laboratories in reviewing and validating ballast treatment systems: Great Ships Initiative (GSI), Maryland Environmental Research Center and the Pacific Northwest Naval Lab.

According to Croot, the first two labs are much farther along in their development than the Pacific Northwest Naval Lab, but all labs seeking certification must meet a variety of quality assurance and quality control criteria. An important factor will be a lab's willingness to fully disclose its findings, something that GSI already practices.

Details of the certification process is something that will be done congruently with preparing the Coast Guard's final rule and something that Croot said extends outside the Coast Guard's, and the federal government's, purview.

To aid in meeting the fast-approaching deadlines, the GSI is stepping up to help provide independent freshwater testing and validation for new treatment technologies, a cooperative effort between ports in the Great Lakes system, environmental groups and federal, state and local governments.

"The first order of business for the Great Ships Initiative has been to set up an integrated set of demonstration services that could be deployed to help validate, as a third party, performance of proposed ballast treatments," Cangelosi said.

To aid in meeting the fast-approaching deadlines, the GSI is stepping up to help provide independent freshwater testing and validation for new treatment technologies, a cooperative effort between ports in the Great Lakes system, environmental groups and federal, state and local governments.

Besides validating systems for freshwater use, the initiative services are also available to provide testing for companies with technologies that are deemed promising by independent review. She said, "We're willing to meet them wherever they are and provide them with bench-scale, land-based or shipboard research services, and then they can take those findings back to the drawing board to improve their systems. They can also call on us to demonstrate for governments that they're performing to some preordained level, so these services can either be R&D or actual validation testing."

The systems that have received IMO final approval use a variety of technologies to treat ballast water. Some of the most common are:

• Filtration - A physical-separation system that strains out living and nonliving particles. Typical filters have pore sizes of 40-50 microns (40-50 micrometers). Anything smaller may mean slowing the filtration process, as the water has to travel through a finer mesh.

• Ultraviolet Light - A biocide that either alters the DNA of living organisms or literally cooks the organisms. Either way, the organisms die. This system works well in clear water, because the UV light can penetrate the water to greater distances. Companies have to design UV systems so that everything in the water gets close to a lamp.

• Ozonation - A technique that adds the gas ozone to water to destroy bacteria and other microorganisms.

• Electrolytic Chlorination - A system that generates chlorine from brine and water. The chlorine serves as a biocide.

• Cyclonic Separation - A technique using a vortex to either destroy particles in the water or to separate and remove them.

• Cavitation - A system that harnesses the same pressure differential that exists in the normally damaging bubbles that form around shippropellers and uses it to destroy organisms in the ballast water.

• Biocides - Applying any number of chemicals, such as peroxide, that kill organisms in the water.

"Each of these technologies has strengths and weaknesses, but the companies try to combine them to optimize their strengths," Cangelosi said, noting that although much work remains to be done, the stage is set for success. "I think that the sophistication curve is on an exponential growth rate right now. We've gone from people trying to solve it in their minds and putting a gizmo together, to big corporations taking on ballast treatment development, to sophisticated validation testing and awareness of what can and cannot happen in terms of treatment. We're gaining the capacity and the knowledge required to make a real success of this R&D effort."

Standards: G9 and G8. There is more than just one guideline to determine system validity. The G9 guidelines were developed to address ballast treatment systems that use active substances, or chemical treatments. They provide a process by which to identify if the system's active substances are safe to use onboard and if they are safe to use for the environment.

The G9 standard was developed by the group known as GESAMP, or the Group of Experts on Scientific Aspects of Marine Environmental Protection, which is sanctioned by the United Nations. The process for approval involves a system manufacturer approaching an administration for type approval. With the endorsement of the administration, the manufacturer applies to GESAMP for basic approval, which means that the chemicals are safe to use onboard the vessel.

Following basic approval, more lab testing is conducted and information provided to GESAMP to review and determine whether the system is functioning properly and the discharge is safe for the environment. If GESAMP determines this to be true, it gives the system final approval.

"The approval does not say how effective the system is," Croot said.

At this time, the manufacturer goes back to the administration to request type approval process.

The shipboard and land-based testing that is conducted for G9 is based on G8 guidelines. However, administrations have interpreted those guidelines differently, according to Croot, because the guidelines are not specific as to how sampling and testing is to occur. If a system uses filtration or ultraviolet technology, it does not need to go through the G9 process.

Once type approval is given by a flag state, the system can be put on ships and considered IMO compliant.

Getting systems on ships. As the U.S. seeks to establish its federal regulation for ballast discharge, shipowners are expressing a feeling of being held hostage to build new ships and install treatments systems. If they purchase a system today, will they need to replace it in a few years to meet newer standards?

Some of the comments received by the Coast Guard prior to December 4 asked whether grandfathering would be part of the final rulemaking.

"We're still in the comment-review process," Croot said. "We've received comments from environmentalists who want short grandfathering, or none, and from shipowners and operators who want at least a 10-year grandfathering period."

"It's not a democratic process," he added. "We don't add up the number of people who are in favor and opposed. We have to make that determination based on additional data, such as the cost to the industry and the benefits of having a more stringent treatment system on ships."

As it moves the process forward in a timetable that is expected to extend into the deadline for complying with IMO standards, the Coast Guard is conducting a cost-benefit analysis to address whether—and for how long—grandfathering may be part of the final ruling.

"We don't want to do anything to discourage people from putting equipment on early and a short grandfathering period would do that," Croot said. "The shipowners are the wildcard here."

Janenne Irene Pung ■

State-by-state regulations

Appeal loses in New York, new rules introduced in Wisconsin

As a coalition of shipping groups was handed a defeat by the New York State Supreme Court in February in response to an appeal filed over a New York State Supreme Court ballast water decision, industry attention is focusing on Wisconsin's new ballast rules.

The latest New York ruling meant the shippers have lost another round in their battle to keep states from passing individual ballast rules. Parties involved in the appeal include the Port of Oswego, New York; Port of Albany, New York; American Great Lakes Port Association (AGLP); Canadian Shipowners Association; Federal Marine Terminals and Lake Carriers' Association.

In Wisconsin, some new rules took effect in February, but they are not expected to have immediate impact beyond best management standards and reporting requirements on vessels trading into Wisconsin ports until 2012 and beyond.

"For 2010 there's no change from 2009 (for lakers and salties)," said Wisconsin Department of Natural Resources' (WDNR) spokeswoman Susan Sylvester.

Steve Fisher, AGLP Executive Director, agreed. Wisconsin's plan should have no immediate impact on shipping bound for ports such as Milwaukee, Superior or Green Bay.

"There's a requirement for 2012 for new ships, but nobody is really building new ships right now so the relevant deadline is 2014 for existing ships, he said" By January 2014, they will have to have installed ballast water treatment technology to meet either the standard crafted by the IMO or 100 times stronger than that, depending on a review the state is going to do between now and then."

The AGLP has been pushing for a unified federal approach to the protection of the Great Lakes—and all U.S. waters—from invasive species via ballast water and has been urging Congress to adopt such an approach. The Wisconsin Department of Natural Resources has been doing the same.

"Wisconsin has always favored a strong national standard and without that, we were required to issue our own standard," Sylvester explained.

The shipping industry has long feared that states acting unilaterally will create a patchwork of regulations that could be difficult to navigate. Fisher said those fears may be coming true, at least for now.

"We've always advocated for a uniform rule/requirement from state to state and all over the United States," he said. "Now that's not what we're going to get. The Coast Guard is developing a regulation, but that regulation specifically allows states to implement their own, tougher regulations. So we're still potentially looking at a hodgepodge of rules from state to state."

Wisconsin's new ballast rules include:

- February 1, 2010, large commercial vessels are prohibited from discharging ballast tank sediment, seawater and certain other substances. They must adopt best management practices for handling these substances to reduce the risk of releasing new invaders into the Great Lakes. Oceangoing ships and lakers must both meet these requirements.
- By the end of 2010, the WDNR, with advice from a stakeholder committee, will determine if commercial treatment technology is available to meet the states numerical ballast water discharge standards that will apply to oceangoing ships. Wisconsin's standard is proposed to be 100 times more restrictive than the proposed standard for the International Maritime Organization. If the technology is not feasible, the Wisconsin standard will change to the IMO standard.
- January 1, 2012, any oceangoing vessel built on or after that date must treat ballast water to reduce the number of live plants, animals and organisms in it to meet numerical standards that WDNR regards as appropriate protection against introducing new invasives.
- January 1, 2014, existing oceangoing ships must meet these same standards before discharging.
- Lakers will not be required to treat their ballast water to meet standards under the current general permit, which will be valid for five years.
- If the U.S. Coast Guard or the U.S. Environmental Protection Agency adopts numerical standards that Wisconsin regards as adequately protective, Wisconsin will examine whether a state permit is still necessary.

Fisher said he is skeptical if any commercial treatment technology will be available to meet Wisconsin's ballast water discharge standards.

"For those of us who follow technology, I can tell you we are unaware of any technology that can meet 100 times the IMO standards," Fisher said. "Keep in mind that the companies that are developing these environmental technologies are doing it for the international market. How many companies out there are going to develop a product that meets the needs of ships that just happen to trade into Wisconsin, which is a pretty small subset of international shipping?"

Sylvester remains optimistic.

"There are several treatment systems that are still undergoing testing to see if they are effective in freshwater systems," she said. "That's what we're waiting for, a system that will meet the discharge standards."

Even though Wisconsin's rules won't have any immediate impact on shipping, Fisher said the state is potentially playing with fire.

"In the end, ships don't have to go to Wisconsin, and if they chose to go to nearby states instead, all Wisconsin is doing is chasing commerce and jobs away from its ports," he said.

The National Wildlife Federation and its state partner, the Wisconsin Wildlife Federation, have filed a legal challenge that claims the state's new rules are not stringent enough. **Roger LeLievre** ■

Reprinted from Great Lakes/Seaway Review, Volume 38 Number 3, January-March 2010 © 2010 Harbor House Publishers Inc., www.greatlakes-seawayreview.com

2009 Summary of Great Lakes Seaway Ballast Water Working Group

February 2010

TABLE OF CONTENTS

Chapter 1 – Executive Summary

The 2009 Summary of Great Lakes Seaway Ballast Water Management report was compiled by the Great Lakes Seaway Ballast Water Working Group (BWWG), comprised of representatives of the United States Coast Guard (USCG), the U.S. Saint Lawrence Seaway Development Corporation (SLSDC), Transport Canada - Marine Safety (TCMS), and the Canadian St. Lawrence Seaway Management Corporation (SLSMC). The group's mandate is to develop, enhance, and coordinate binational enforcement and compliance efforts to reduce the introduction of aquatic invasive species via ballast water. The BWWG is actively engaged and providing an energetic response to calls for tougher ballast water regulation of ocean-going vessels transiting the Seaway.

In 2009, 100% of vessels bound for the Great Lakes Seaway received a ballast tank exam. A total of 5450 ballast tanks, onboard 295 vessels, were sampled and had a 97.9% compliance rate. Vessels that failed to properly manage their ballast tanks were required to either retain the ballast water and residuals on board, treat the ballast water in an environmentally sound and approved manner, or return to sea to conduct a ballast water exchange. In addition, 100% of ballast water reporting forms were screened to assess ballast water history, compliance, voyage information and proposed discharge location. The BWWG anticipates continued high vessel compliance rates for the 2010 navigation season.

Today, ballast water management requirements in the Great Lakes and the St. Lawrence Seaway System are among the most stringent in the world. Mandatory ballast water regulations that include saltwater flushing, detailed documentation requirements, increased inspections, and civil penalties provide a comprehensive regulatory enforcement regime to protect the Great Lakes Seaway System. USCG regulations, and the Seaway no ballast onboard (NOBOB) regulation, require all vessels destined for Seaway and Great Lakes ports from beyond the exclusive economic zone (EEZ) to exchange all their ballast tanks at sea. As a result, the risk of a ballast water mediated introduction of aquatic invasive species into the Great Lakes has been mitigated to extremely low levels.

Chapter 2 – Joint Ballast Water Management

Ballast Water Management on the Great Lakes Seaway System

Regulations protecting the Great Lakes Seaway system include Ballast Water Control and Management Regulations under the Canada Shipping Act, USCG ballast water regulations pertaining to vessels equipped with ballast tanks, Best Management Practices for NOBOB vessels entering the U.S., and the St. Lawrence Seaway's NOBOB requirements. These regulations apply to all vessels entering waters under Canadian and U.S. jurisdiction from outside the Canadian EEZ and apply to vessels on both oceanic and coastal voyages. Loaded vessels with residual sediments are required to flush their tanks with water of a salinity equivalent to ballast exchange. Federal regulations call for vessels to conduct mid-ocean ballast water exchange during ballast laden voyages in an area 200 nautical miles (nm) from any shore. For vessels unable to conduct mid-ocean ballast exchange due to stability concerns, they are asked to conduct saltwater flushing of their empty ballast water tanks in an area 200 nm from any shore whenever possible. Salt water flushing is defined in U.S. policy as the addition of mid-ocean water to empty ballast water tanks; the mixing of the flush water with the residual water and sediment through the motion of the vessel; and the discharge of the mixed water, such that the resultant residual water is as high salinity as possible, preferably greater than 30 parts per thousand (ppt).

St. Lawrence Seaway NOBOB Requirement

The U.S. and Canadian St. Lawrence Seaway agencies enacted new requirements effective at the start of the 2008 navigation season that require vessels to conduct saltwater flushing of ballast tanks that contain residual amounts of ballast water and/or sediment in an area 200 nm from any shore before entering waters of the Seaway. Vessels must also maintain the ability to measure salinity levels in each tank onboard so that final salinities of at least 30 ppt can be ensured.

The overall goal of the inspection program was to inspect each vessel entering the system from outside the EEZ on every transit and increase the number of tanks tested. All four agencies committed resources to accomplishing the additional work required to carry out the increased tank inspection program.

Transport Canada Requirements

Transport Canada (TC) Quebec region monitors all traffic entering the Gulf of St. Lawrence from outside the Canadian EEZ bound for regional ports as well as the St. Lawrence Seaway/Great Lakes Ports on a 12 month basis.

Challenges experienced by TC in achieving ballast water management compliance for the Seaway/Great Lakes related to changes in vessel crews, exchange of information with vessels, vessel agents and/or owners, reviewing over 3335 ballast water reports from 2169 vessels and addressing vessel deviations from coastal vessels in order to meet Great Lakes ballast water management regulations.

All information collected by TC was forwarded to the University of Windsor for analysis and support of ongoing ballast water compliance projects.

U.S. Coast Guard Discharge Standard

The Coast Guard is proposing a two-phase standard for the allowable concentration of living organisms in vessels' ballast water discharged in U.S. waters. This rulemaking is being carried out under the Non-indigenous Aquatic Nuisance Prevention and Control Act of 1990 (NANPCA), as reauthorized and amended by the National Invasive Species Act of 1996 (NISA). These statutes authorize the Coast Guard to approve alternative ballast water management systems (BWMS) that are found to be at least as effective as mid-ocean ballast water exchange (BWE) in preventing non-indigenous species introductions. As the effectiveness of ballast water exchange varies from vessel to vessel, the Coast Guard believes that setting a performance standard is the most effective way for approving BWMS that are environmentally protective and scientifically sound.

The public comment period has been completed; the Coast Guard is drafting responses to comments and preparing the final rulemaking for publication.

This proposed rulemaking and all submitted comments can be found at: http://www.regulations.gov. In Search, enter docket number USCG-2001-10486.

Chapter 3 – Results of Ballast Management Exams

Ballast Water Reporting Form

Vessels bound for the Great Lakes from outside the EEZ are required to submit a ballast water reporting form before entering Canadian waters and again 24 hours prior to entering the St. Lawrence Seaway. The vessel lists voyage information, ballast water usage/capacity, ballast water management method, ballast water sources, ballast water management practices, and proposed discharge location.

- ***100% of ballast water reporting forms were screened to assess ballast water history, compliance, and intentions.***

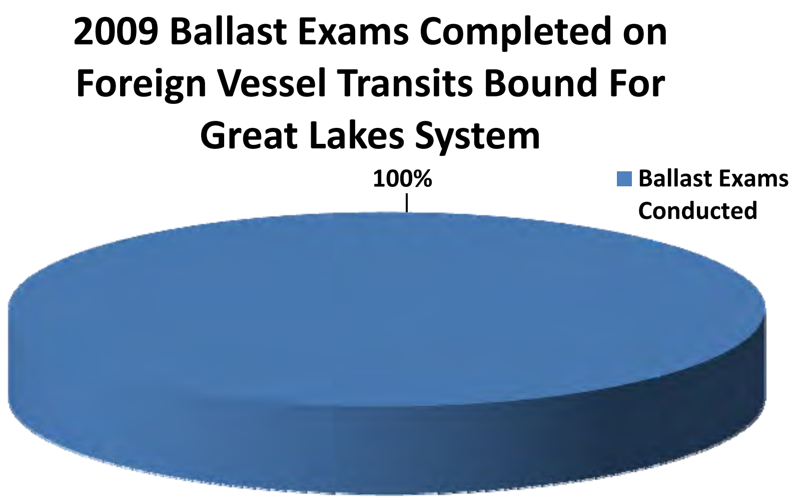
Ballast Water Management Exams

The Joint Ballast Water Management Exam Program uses a comprehensive approach to vessel inspections. The inspection begins with a detailed review of ballast water reports, logs, records and ballast water management plans. The crew is interviewed to assess their understanding of the requirements of the vessel's Ballast Water Management Plan as well as answer questions on actual practices. Finally, ballast tanks are sampled for salinity or the presence of mud that would suggest a satisfactory management practice was not employed.

Vessel Inspection Totals

- ***295 (100%) of vessels bound for the Great Lakes Seaway from outside the EEZ received a ballast tank exam, compared with 99% in 2008 and 74% in 2007.***

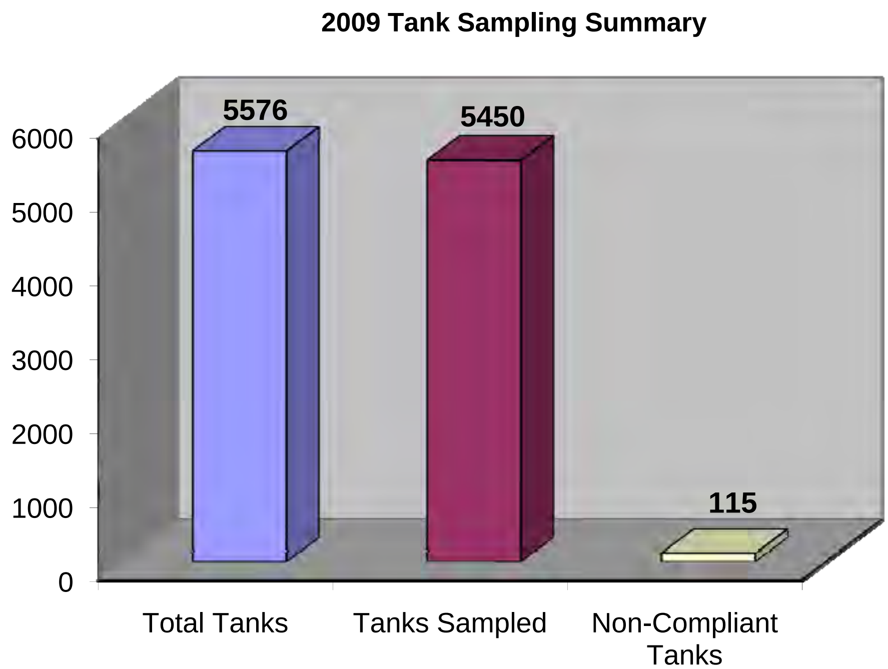
The chart below summarizes the total exams completed in 2009 by at least one of the four BWWG agencies.



Ballast Tank Sampling

Ballast water is typically found in wing tanks, double bottom tanks, peak tanks, and cargo holds. Access to these tanks is normally gained through vents, sounding tubes or hatches. Normal procedure calls for the inspector to utilize the sounding tube or vent for primary access. Manhole covers and hatches may be used if access cannot be gained access via a primary means. Ballast water salinity is checked using a hand held salinity refractometer or with an electronic meter. The results of the sampling are captured on a sampling report form created by the BWWG.

- ***Total ballast tanks assessed via sampling or administrative review 100%***
- ***Total tanks capable of carrying ballast water 5576***
- ***Total tanks physically sampled 5450***
- ***Total tanks evaluated by administrative measures 126***
- ***Total tanks tested satisfactorily 5335***
- ***Total non-compliant tanks 115 (53 vessels) all issued a Letter of Retention***
- ***Total compliant tanks 5461 representing 97.9%***



Chapter 4 – Enforcement and Regulatory Action

Regulatory Actions

Regulatory action is limited to the jurisdiction of each agency. Information exchanged between agencies ensures appropriate action is taken to address discrepancies. The various tools commonly used for discrepancies include education, a Letter of Warning, a Letter of Retention or a fine issued through a Notice of Violation.

Letters of Warning

A Letter of Warning is issued by U.S. Coast Guard or Transport Canada when a vessel is found with discrepancies in its ballast water management plan, records or reports. It is used for minor first time offenses with a warning of possible assessment of a fine if not corrected.

- ***Transport Canada issued 7 Letters of Warning.***

Letters of Retention

Vessels with noncompliant tanks that choose to retain, in lieu of another management option, are issued a Letter of Retention. When the vessel departs the system, compliance is verified and the Letter is rescinded. It is important to note that Letters of Retention were issued for some tanks that are not actually used for ballast water, but are listed in their system such as potable or cooling water tanks.

- ***BWWG agencies issued a Letter of Retention for 53 vessels.***
- ***Rather than retain non-compliant ballast water, 1 vessel chose to conduct an exchange in an approved alternate zone.***

Verification Boardings

Verification boardings are conducted on every outbound vessel issued a Letter of Retention. In 2009 all vessels issued a Letter of Retention were in compliance. Therefore, no unmanaged ballast water or sediment was released into the Great Lakes/Seaway system.

Notice of Violation

A Notice of Violation imposes a fine on a vessel for failure to comply with regulations. For example, U.S. Coast Guard fines associated with ballast water vary from $500 to $1000 for the first offense and may reach $6,000 for repeated offenses. This year no Notices of Violation were issued.

Chapter 5 – Conclusion

For any regulatory regime to be effective, all the Great Lakes and the St. Lawrence Seaway must be treated as a single system. The only way to ensure consistent ballast discharge regulations across the Great Lakes Seaway System is to have strong federally mandated standards managed by unified federal agency coordination between Canada and the U.S. in partnership and consultation with the States and Provinces. These partnerships will help minimize the creation of a patchwork of inconsistent regulations, which would have a negative impact of vessel compliance and operation. Even worse, inconsistent regulations would effectively deter vessels from transiting or completing loading/unloading operations in some state waters. The current high effectiveness of ballast water exchange coupled with the BWWG's aggressive enforcement of current regulations and the high industry compliance rate should be seen as minimizing the urgency for state involvement in ballast water regulation.

The St. Lawrence Seaway is uniquely situated to prevent the further introduction of invasive species. With a central inspection point, situated outside of the Lakes, the ballast water tanks of all inbound vessels are inspected by both Canada and the United States. Joint vessel inspections by Transport Canada, the U.S. Coast Guard, and the U.S. and Canadian Seaway Corporations have been regularly conducted in Montreal. This inspection process, in place since 1997, has been successful in enhancing the operational and environmental security of the Great Lakes St. Lawrence Seaway System. Improvements are continually being made to the inspection programs to incorporate updated procedures and technology. All four agencies work cooperatively in a binational manner to address issues as they arise. The Seaway regulation harmonizes the ballast water requirements for vessels transiting the U.S. waters of the Seaway with those currently required by Transport Canada for transit in waters under Canadian jurisdiction of the Seaway. This regulation is intended to be an interim solution while the U.S. Coast Guard completes its ballast water discharge rulemaking, anticipated to be issued in the near future. The BWWG will continue its work to deter the introduction of aquatic invasive species in the Great Lakes using regulatory, technological, and management-based protocols. The agencies take the threat of invasive species very seriously and are dedicated to finding new answers to combat the problem.

Chapter 6 – Contributions

Members of the Ballast Water Working Group

U.S. Coast Guard, Ninth District would like to thank the following members of the Great Lakes Ballast Water Working Group and all the inspectors who contributed to the 2009 Joint Ballast Water Management Exam Program and to this final report.

Saint Lawrence Seaway Development Corporation
Lori Curran
Carol Fenton
Thomas Rausch
Matt Trego
Chris Ehrman
Marvourneen Dolor

St. Lawrence Seaway Management Corporation
Peter Burgess
Robert Elliott
Jack Meloche
Stephen Kwok
Jean Aubry-Morin

Transport Canada Marine Safety
Andre Desrochers
Laurent Jean
Chris Wiley
Julie Guay

U.S. Coast Guard
CDR Gary Croot
CDR Tim Cummins
CDR Patrick Nelson
LCDR Carl Kepper
LT Ann Henkelman

For further information on the Great Lakes Ballast Water Program, please visit the following:

The Seaway website: http://www.greatlakes-seaway.com/en/environment/ballast-water/index.html

The NBIC website: http://www.hrw.com/science/si-science/biology/animals/marineinvasions/ballast.html

The USCG website: http://cgweb.comdt.uscg.mil/g-ms/g-mso/estandards.htm

Transport Canada's website: http://www.tc.gc.ca/en/menu.htm

Appendix

A Historical Review:

1989:

In response to calls from the International Joint Commission and the Great Lakes Fishery Commission over the discovery of the Ruffe in Lake Superior, Canada established guidelines requesting all vessels entering the freshwaters of the St Lawrence River and the Great Lakes to exchange their ballast. The use of ballast water exchange was based on the effectiveness of Canadian studies undertaken by Environment Canada to protect the aquaculture facilities in the Magdalen Islands.

Early 1990's to 1997:

The U.S. Coast Guard established regulations based on the Canadian Guideline in 1993 under the authority of the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 (NANPCA). Ballast Water on Board (BOB) vessels, are vessels that declare they have ballast tanks that contain ballast water. The U.S. Coast Guard started testing BOB vessels on a voluntary basis in 1991 and on a mandatory basis in 1993. The inspection process included boarding vessels between the two U.S. locks in Massena (Eisenhower and Snell) and testing the salinity of the ballast water to ensure salinity was at least 30 ppt. Ballast with a salinity of at least 30 ppt is considered evidence that the tanks have been adequately exchanged with seawater, providing a reasonably harsh environment for any remaining freshwater organisms.

1997 to Present:

The U.S. Coast Guard, Transport Canada and the Seaway Corporations developed a joint inspection program called the "Enhanced Seaway Inspection" (ESI) for foreign flag vessels, which covered applicable safety and environmental equipment onboard vessels and is conducted prior to the vessel's initial transit of the Seaway Great Lakes System.

During the vessel's ESI, a ballast tank inspection is conducted by one or more of the BWWG member agencies to ensure compliance with U.S., Canadian, and Seaway ballast regulations. The vessel's ballast tanks are sampled to verify compliance with all BWWG members' regulations.

<u>2002 St. Lawrence Seaway Requirement:</u>

The U.S. and Canadian Seaways instituted a requirement that all foreign flag vessels entering the Seaway Great Lakes System comply with the Best Management Practices of the Shipping Federation of Canada.

In addition, vessels that do not operate beyond the EEZ but do operate within the Great Lakes and Seaway (i.e., lakers) 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, dated January 26, 2001. These voluntary management practices require vessels to agree to regular inspections of ballast tanks and regular removal of sediment.

2004 U.S. Coast Guard National Mandatory Ballast Management Requirements

This final rule changed the national voluntary BWM program to a mandatory one, requiring all vessels equipped with ballast water tanks and bound for ports or places of the United States to conduct a mid-ocean BWE, retain their ballast water onboard, or use an alternative environmentally sound BWM method approved by the Coast Guard. Penalties were established for failure to comply with the reporting requirements located in 33 CFR part 151 and the applicability of the reporting and recordkeeping requirements were broadened to include a majority of vessels bound for ports or places of the United States.

2005 U.S. Coast Guard NOBOB Best Management Practices:

As a result of the National Oceanic and Atmospheric Administration (NOAA) and Great Lakes Environmental Research Laboratory (NOAA/GLERL) study published in April 2005 and the risks identified therein, the U.S. Coast Guard and Transport Canada Marine Safety inspectors began examining NOBOB vessels in conjunction with the ESI in May of 2005. In August 2005, the U.S. Coast Guard issued its “NOBOB Best Management Practices”. This policy recommends vessels conduct mid-ocean ballast water exchange whenever possible and if not possible, conduct mid-ocean salt water flushing. The goal of these practices is to raise the salinity level of residual, unpumpable ballast above 30 ppt. The increase in salinity reduces the likelihood of introducing aquatic nuisance species to the Great Lakes when the tanks are ballasted with Great Lakes fresh water at one port and deballasted in another Great Lakes port.

2006 Canadian Regulations:

Canada promulgated the Ballast Water Control and Management Regulations under the Canada Shipping Act in June of 2006. The regulations enact the IMO D1 requirements for ballast water exchange for any vessel entering waters under Canadian jurisdiction from outside Canada’s EEZ and include both trans oceanic and coastal voyages (BOB and NOBOB).

Additionally vessels coming from outside waters under Canadian jurisdiction, declaring no ballast on board, must ensure that the residual ballast water in tanks has been exposed to salinity conditions equivalent to ballast water exchange by complying with one of the following options:

- The residual ballast water came from ballast water that was properly exchanged at sea;
- The residual ballast water meets the international standard for treated ballast water;

- The vessel complies with sections 1, 2, 6 and 7 of the Code of Best Practices for Ballast Water Management of the Shipping Federation of Canada dated September 28, 2000, or;
- The vessel conducted a saltwater flushing at least 200 nm from shore.

Coastal Navigation information for either BOB or NOBOB: Ballast water that has been taken on board the vessel, outside of waters of Canadian jurisdiction, on Coastal or Non-Transoceanic Navigation shall be exchanged to meet the prescriptions of Canadian BWCMR section 7-which means that a Mandatory Deviation if required to meet minimum depth of 500 meters – In winter months Section 6. (3) may apply under exceptional circumstances.

2006 Ballast Water Working Group (BWWG):

The Great Lakes BWWG was formed in January 2006.

The mission of the BWWG is to harmonize ballast water management efforts between the U.S. Coast Guard, Transport Canada-Marine Safety, St. Lawrence Seaway Development Corporation and the St. Lawrence Seaway Management Corporation. The BWWG coordinates enforcement and compliance efforts for reducing aquatic nuisance species invasions via ballast water and residuals in the Seaway and Great Lakes.

2008 St. Lawrence Seaway NOBOB Requirement:

The U.S. and Canadian St. Lawrence Seaway agencies enacted new requirements effective at the start of the 2008 Navigation Season that requires vessels to conduct saltwater flushing of their ballast tanks that contain residual amounts of ballast water and/or sediment in an area 200 nm from any shore before entering waters of the Seaway. Vessels must also maintain the ability to measure salinity levels in each tank onboard so that final salinities of at least 30 ppt can be ensured.

All four agencies committed resources to accomplishing the additional work required to carry out the increased tank inspection program. The overall goal of the 2008 inspection program was to inspect each vessel entering the system from outside the EEZ on every transit and increase the number of both BOB and NOBOB tanks tested.

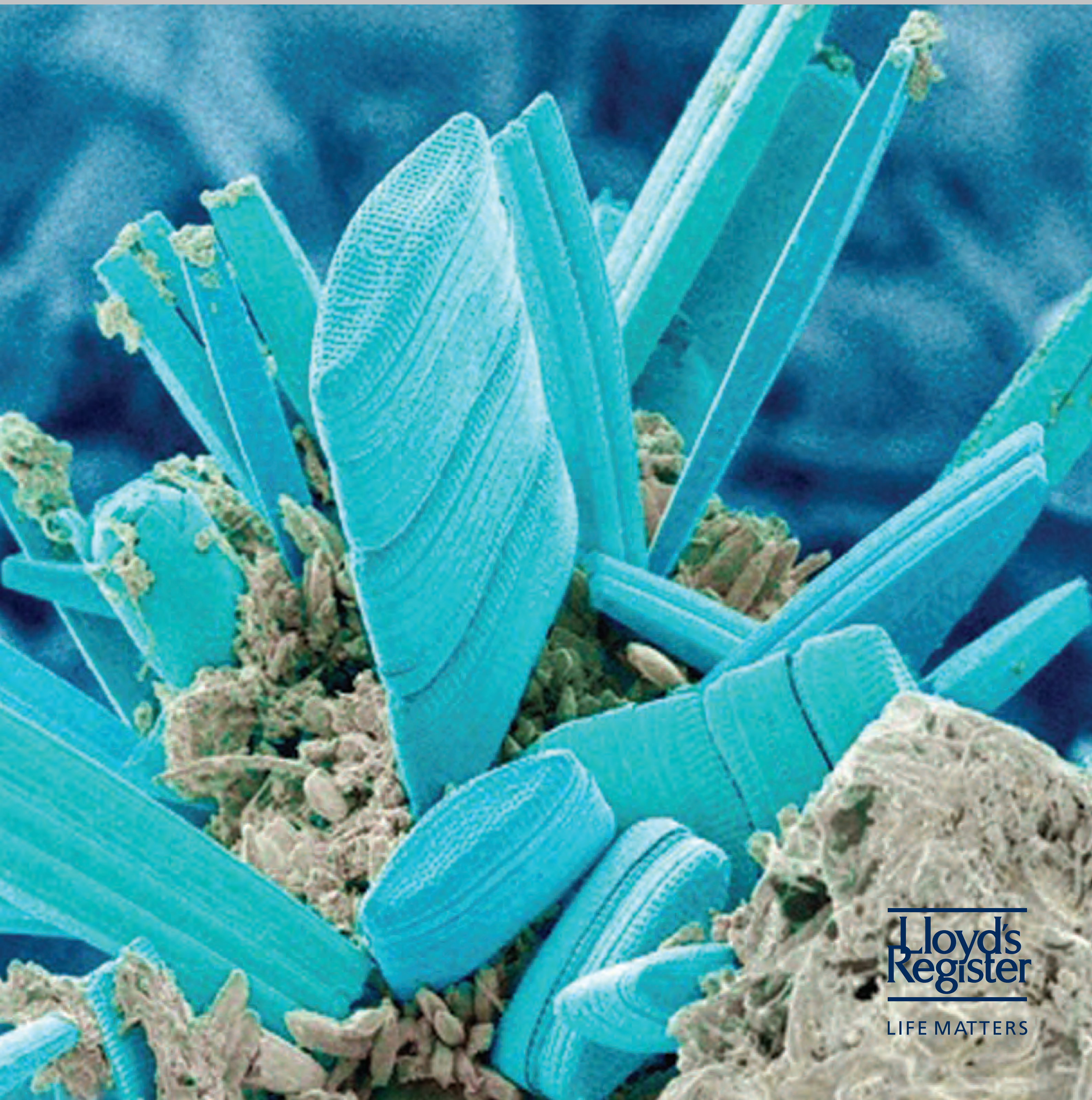
2009 Coast Guard Proposed Ballast Water Discharge Standard Rulemaking:

The Coast Guard is proposing a two-phase standard for the allowable concentration of living organisms in vessels' ballast water discharged in U.S. waters. The Coast Guard is currently drafting responses to public comments and is preparing the final rulemaking for publication.

Ballast water treatment technology

Current status

February 2010



Lloyd's Register

LIFE MATTERS

Cover image: Coloured scanning electron micrograph (SEM) of marine diatoms (blue).

Contents

Ballast Water Treatment Technology

1. Introduction

Ballast water contains a variety of organisms including bacteria and viruses and the adult and larval stages of the many marine and coastal plants and animals. While the vast majority of such organisms will not survive to the point when the ballast is discharged, some may survive and thrive in their new environment. These 'non-native species', if they become established, can have a serious ecological, economic and public health impact on the receiving environment.

The International Maritime Organization (IMO) has developed international legislation, the International Convention for the Control and Management of Ships' Ballast Water and Sediments, to regulate discharges of ballast water and reduce the risk of introducing non-native species from ships' ballast water.

The requirement for ballast water treatment has arisen from the requirements of regulation D-2 of the Convention. In response to this, a number of technologies have been developed and commercialised by different vendors. Many have their basis in land-based applications for municipal and industrial water and effluent treatment, and have been adapted to meet the requirements of the Ballast Water Management Convention and shipboard operation. These systems must be tested and approved in accordance with the relevant IMO Guidelines.

This revision of the guide provides updated information on suppliers and the solutions that they provide, and indicates the status of systems in relation to the approval process. An outline description of water treatment processes and an appraisal of commercially available and developing technologies for ballast water treatment are also provided.

A summary both of the governing regulation that ultimately makes ballast water treatment mandatory forms Section 2 and water treatment technology as it relates to ballast water management, Section 3. These sections then provide the background knowledge and context for an assessment of the commercial technologies either currently commercially available or projected to be market-ready by 2010/2011 with reference to their efficacy, technical and economic viability and testing and approval status (Section 4). Full data, referenced against individual suppliers, are provided in the Annex.

This is the third edition of the Ballast Water Treatment Technology guide and revisions have been undertaken by the Institute for the Environment at Brunel University. The continued assistance of the technology suppliers who contributed much of the information published herein is gratefully acknowledged.

2. Regulation

Ballast water quality and standards

Regulation D-2 of the Ballast Water Convention sets the standard that the ballast water treatment systems must meet (Table 1). Treatment systems must be tested and approved in accordance with the relevant IMO Guidelines.

Ships will be required to treat ballast water in accordance with the timetable shown in Table 2. According to this table, the first key milestone was in 2009, when ships under construction during or after that date having less than 5000 m^3 ballast water capacity were required to have ballast water treatment installed to meet the D2 Standard in the Convention. However, as the Convention is not yet in force internationally, these dates cannot be enforced at present.

Organism category	Regulation
Plankton, >50 µm in minimum dimension	< 10 cells / m^3
Plankton, 10-50 µm	< 10 cells / ml
Toxicogenic Vibrio cholera (O1 and O139)	< 1 cfu* / 100 ml
Escherichia coli	< 250 cfu* / 100 ml
Intestinal Enterococci	< 100 cfu* / 100 ml

Table 1 IMO 'D2' standards for discharged ballast water

* colony forming unit

Ballast capacity	Year of ship construction*			
	Before 2009	2009+	2009-2011	2012+
< 1500 m^3	Ballast water exchange or treatment until 2016 Ballast water treatment only from 2016	Ballast water treatment only		
1500 – 5000 m^3	Ballast water exchange or treatment until 2014 Ballast water treatment only from 2014	Ballast water treatment only		
> 5000 m^3	Ballast water exchange or treatment until 2016 Ballast water treatment only from 2016		Ballast water exchange or treatment until 2016 Ballast water treatment only from 2016	Ballast water treatment only

Table 2 Timetable for installation of ballast water treatment systems

* *Ship Construction* refers to a stage of construction where:
- The keel is laid or construction identifiable with the specific ship begins; or
- Assembly of the ship has commenced comprising at least 50 tonnes or 1% of the estimated mass of all structural material, whichever is less; or
- The ship undergoes a major conversion.

Major conversion means a conversion of a ship:
- which changes its ballast water carrying capacity by 15 percent or greater or which changes the ship type, or
- which, in the opinion of the Administration, is projected to prolong its life by ten years or more, or
- which results in modifications to its ballast water system other than component replacement-in-kind.

Conversion of a ship to meet the provisions in the Convention relating to ballast water exchange ('regulation D- 1') does not constitute a major conversion in relation to the above requirements.

The approval processes

Technologies developed for ballast water treatment are subject to approval through specific IMO processes and testing guidelines designed to ensure that such technologies meet the relevant IMO standards (Table 1), are sufficiently robust, have minimal adverse environmental impact and are suitable for use in the specific shipboard environment.

A company offering a treatment process must have the process approved by a Flag Administration. In general the manufacturer will use the country in which it is based to achieve this approval, although this is not a specific requirement and some companies may choose to use the Flag State where the testing facility is based or the Flag State of a partner company. In general the Flag State will probably choose to use a recognised organisation - such as a classification society - to verify and quality assure the tests and resulting data.

The testing procedure is outlined in the IMO's Guidelines for Approval of Ballast Water Management Systems1 (frequently referred to as the 'G8 guidelines'). The approval consists of both shore based testing of a production model to confirm that the D2 discharge standards are met and ship board testing to confirm that the system works in service. These stages of the approval are likely to take between six weeks and six months for the shore based testing and six months for the ship based testing.

Further requirements apply if the process uses an 'active substance' (AS). An AS is defined by the IMO as 'a substance or organism, including a virus or a fungus that has a general or specific action on or against harmful aquatic organisms and pathogens'. For processes employing an AS, basic approval from the GESAMP2 Ballast Water Working Group (BWWG), a working committee operating under the auspices of IMO, is required before shipboard testing proceeds. This is to safeguard the environment by ensuring that the use of the AS poses no harm to the environment. It also prevents companies investing heavily in developing systems which use an active substance which is subsequently found to be harmful to the environment and is not approved. At the MEPC 59 meeting, in July 2009, it was decided that treatment systems using UV light on its own as a treatment technology did not require active substance approval according to the G9 guidelines

The GESAMP BWWG assessment is based largely on data provided by the vendor in accordance with the IMO approved Procedure for Approval of Ballast Water Management Systems that make use of Active Substances[3] (frequently referred to as the 'G9 Guidelines').

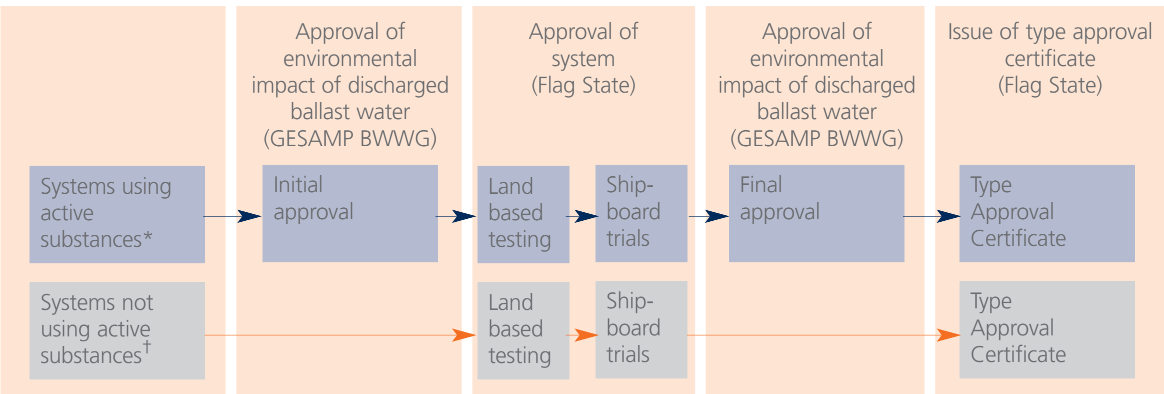


Fig 1. Summary of approval pathway for ballast water treatment systems

* Includes chemical disinfectants, e.g. chlorine, ClO_2, ozone
† Includes techniques not employing chemicals, e.g. deoxygenation, ultrasound

---

[1] Guidelines for approval of ballast water management systems (G8) IMO resolution MEPC.174(58) of 10/10/2008 which revokes MEPC.125(53).
[2] Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection. An advisory body established in 1969 which advises the UN system on the scientific aspects of marine environmental protection.
[3] Procedure for approval of ballast water management systems that make use of active substances (G9) IMO resolution MEPC.169(57) of 04/04/2008 which revokes MEPC.126(53).

Basic Approval is the first step in the approval process when using an active substance. In most cases Basic Approval has been granted with caveats and the request for further information for the purposes of Final Approval. Basic Approval is thus an 'in principle' approval of the environmental impact of an active substance, which may then expedite inward strategic investment or marketing within the supplier's organisation and allow testing of a system at sea. After Basic Approval for active substances, treatment systems can be tested both on land and onboard ship according to the IMO Guidelines for Approval of Ballast Water Management Systems ('G8 guidelines'). Final Approval by the GESAMP BWWG will take place when all testing is completed. Once final approval is granted by GESAMP the Flag Administration will issue a Type Approval certificate in accordance with the aforementioned guidelines. If the process uses no active substances the Flag Administration will issue a Type Approval certificate without the need for approval from the GESAMP BWWG.

Whilst there is a considerable amount of published information concerning the efficacy of the commercially available or developing ballast water treatment technologies, these data have not all been generated under the same conditions of operation, scale and feedwater quality. This makes appraisal of the technologies difficult. The IMO 'G8' Guidelines for Approval of Ballast Water Management Systems are therefore designed to create a level playing field for assessment of technological efficacy. The stipulated testing regime and protocols are prescriptive in nature and costly to undertake. The sea-based test alone requires six months of testing based on a triplicated trial, with biological analysis to be completed within six hours of sampling. The land-based testing is based on specific organisms which therefore have to be either indigenous in the water or cultured specifically for the test. The land based and shipboard testing is overseen by the Flag Administration or a recognised organisation (generally a classification society).

It can take up to two years from first submitting an application for Basic Approval for an active substance to completion of testing and acheiving approval under the G8 guidelines. By February 2010, eight systems had received type approval certificates, five of which have been required to go through the full 'G9' active substance approval procedure. It is almost certain that more approvals will occur during 2010, with up to four systems likely to obtain basic approval and three others final approval at MEPC 60 in March.

3. Treatment Process

Background

The technologies used for treating ballast water are generally derived from municipal and other industrial applications; however their use is constrained by key factors such as space, cost and efficacy (with respect to the IMO discharged ballast water standards).

There are two generic types of process technology used in ballast water treatment: solid-liquid separation and disinfection (Fig. 2).

Solid-liquid separation is simply the separation of suspended solid material, including the larger suspended micro-organisms, from the ballast water, either by sedimentation (allowing the solids to settle out by virtue of their own weight), or by surface filtration (removal by straining; i.e. by virtue of the pores in the filtering material being smaller than the size of the particle or organism).

Disinfection removes and/or inactivates micro-organisms using one or more of the following methods:

- chemical inactivation of the microorganism
- physicochemical inactivation by irradiation with ultraviolet light, which denatures the DNA of the micro-organism and therefore prevents it from reproducing. Ultrasound or cavitation (termed 'micro-agitation' for the purposes of this publication) are also physico-chemical disinfection methods
- deoxygenation is achieved by reducing the partial pressure of oxygen in the space above the water with an inert gas injection or by means of a vacuum which asphyxiates the micro-organisms.

All of the above disinfection methods have been applied to ballast water treatment, with different products employing different unit processes. Most commercial systems comprise two stages of treatment with a solid-liquid separation stage being followed by disinfection (Fig. 2), though some disinfection technologies are used in isolation. One ballast water treatment technology also employs chemical enhancement (ie coagulation/ flocculation) upstream of solid-liquid separation; another uses titanium dioxide (TiO_2) to intensify ultraviolet irradiation.

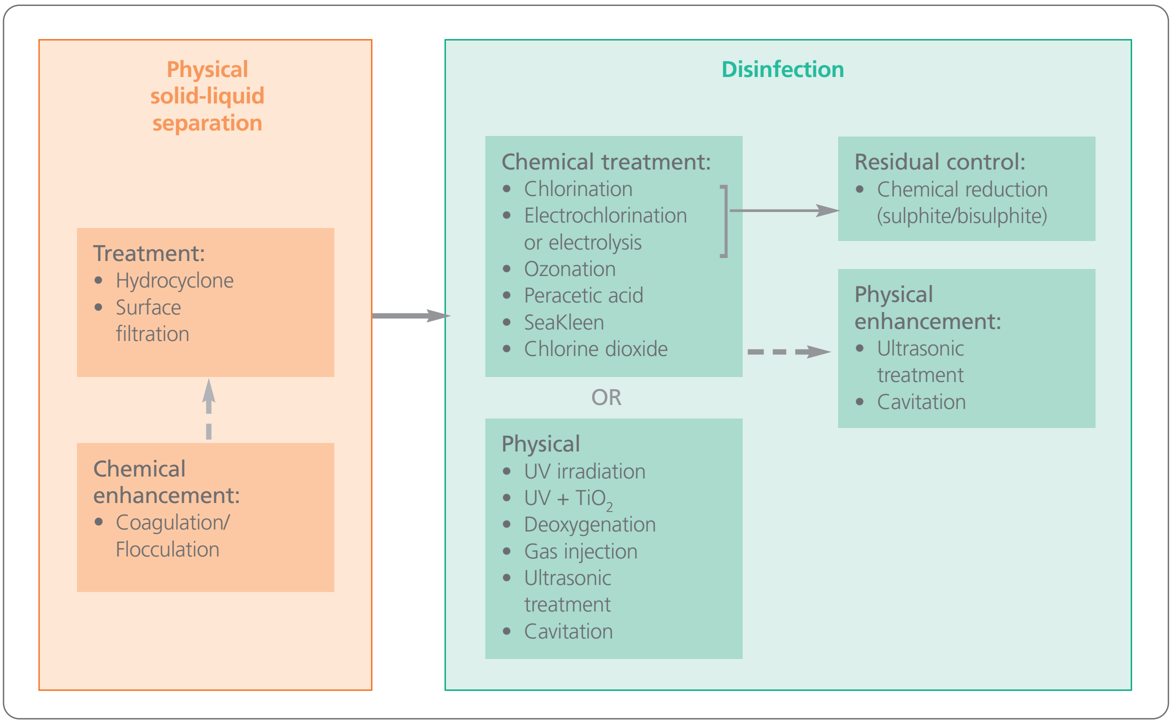


Fig. 2 Generic ballast water treatment technology process options

Separation processes

As previously stated, the chemical or physicochemical unit processes used for disinfection are usually preceded by physical solid-liquid separation, by either filtration or hydrocyclone technology.

The filtration processes used in ballast water treatment systems are generally of the automatic backwashing type using either discs (Fig 3a) or fixed screens. Since the standards relating to treated ballast water are size-based, technologies capable of removing materials above a specific size are most appropriate.

Removal of larger organisms such as plankton (Table 1) by filtration requires a filter of equivalent mesh size between 10 and 50µm. Such filters are the most widely used solid-liquid separation process employed in ballast water treatment, and their effective operation relates mainly to the flow capacity attained at a given operating pressure. Maintaining the flow normally requires that the filter is regularly cleaned, and it is the balance between flow, operating pressure and cleaning frequency that determines the efficacy of the filtration process. In principle, surface filtration can remove sub micron (i.e. less than 1µm in size) micro-organisms. However, such processes are not viable for ballast water treatment due to the relatively low permeability of the membrane material.

Hydrocyclone technology is also used as an alternative to filtration, providing enhanced sedimentation by injecting the water at high velocity to impart a rotational motion which creates a centrifugal force (Fig. 3b) which increases the velocity of the particle relative to the water. The effectiveness of the separation depends upon the difference in density of the particle and the surrounding water, the particle size, the speed of rotation and residence time.

Since both hydrocylcones and filters are more effective for larger particles, pre-treatment with coagulants to aggregate (or 'flocculate') the particles may be used upstream of these processes to increase their efficacy. However, because flocculation is time dependent, the required residence time for the process to be effective demands a relatively large tank. The processes can be advanced, however, by dosing with an ancillary powder of high density (such magnetite or sand) along with the coagulant to generate flocs which settle more rapidly. This is sometimes referred to as 'ballasted flocculation', and is used in some municipal water treatment installations where space is at a premium and has been used in one of the systems included in this publication.

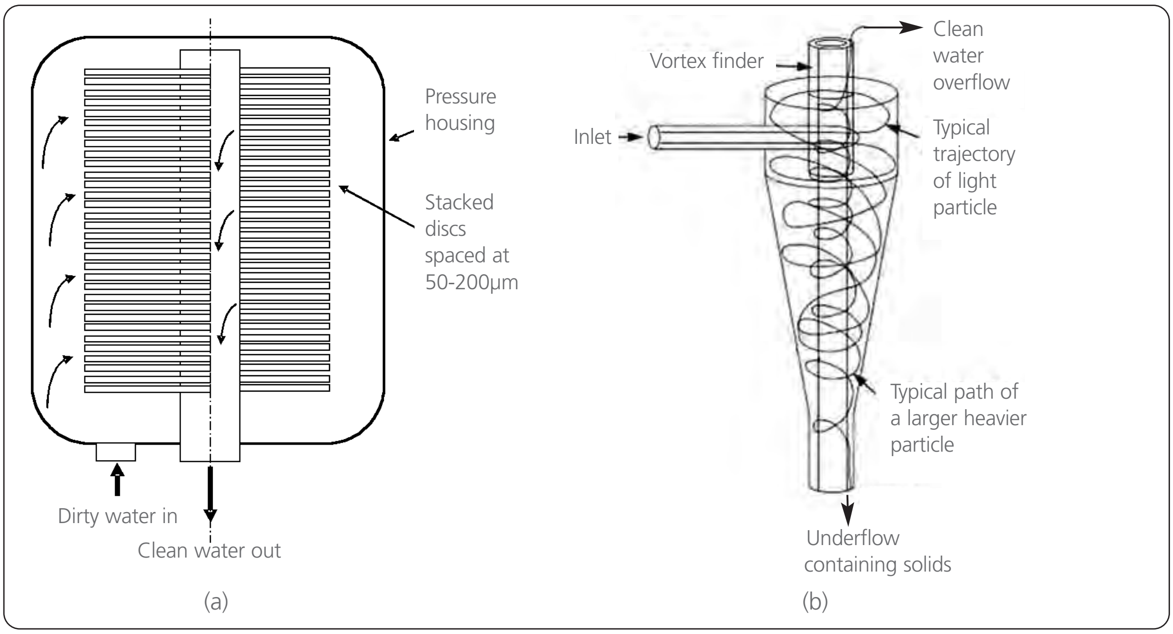


Fig. 3 (a) Filtration, and (b) Hydrocyclone processes

Disinfection

Chemical disinfection

A number of different chemicals or chemical processes have been employed in the ballast water treatment systems reviewed including:

- Chlorination
- Electrochlorination
- Ozonation
- Chlorine dioxide
- Peracetic acid
- Hydrogen peroxide
- Menadione/Vitamin K

The efficacy of these processes varies according to the conditions of the water such as pH, temperature and, most significantly, the type of organism. Chlorine, whilst relatively inexpensive is virtually ineffective against cysts unless concentrations of at least 2 mg/l are used. Chlorine also leads to undesirable chlorinated byproducts, particularly chlorinated hydrocarbons and trihalomethanes. Ozone yields far fewer harmful byproducts, the most prominent being bromate, but requires relatively complex equipment to both produce and dissolve it into the water. Chlorine dioxide is normally produced in situ, although this presents a hazard since the reagents used are themselves chemically hazardous.

Peracetic acid and hydrogen peroxide (provided as a blend of the two chemicals in the form of the proprietary product Peraclean) are infinitely soluble in water, produce few harmful byproducts and are relatively stable as Peraclean. However this reagent is relatively expensive, is dosed at quite high levels and requires considerable storage facilities.

For all these chemicals pre-treatment of the water with upstream solid-liquid separation is desirable to reduce the 'demand' on the chemical, because the chemical can also react with organic and other materials in the ballast water.

Post-treatment to remove any residual chemical disinfectant, specifically chlorine, prior to discharge using a chemical reducing agent (sodium sulphite or bisulphite) may be appropriate if high concentrations of the disinfectant persist. In potable water treatment this technique is routinely employed. When used in ballast water treatment, dosing to around 2 mg/l of chlorine can take place, leaving a chlorine residual in the ballast water tanks to achieve disinfection. The chlorine level is then reduced to zero ('quenching' the chlorine completely) prior to discharge. This technique is used in at least two of the ballast water treatment systems currently reviewed.

Menadione, or Vitamin K, is unusual in that it is a natural product (although produced synthetically for bulk commercial use) and is relatively safe to handle. It is marketed for use in ballast water treatment under the proprietary name *Seakleen*® by Vitamar, LLC. As with other disinfectant chemicals, it is not without a history of application elsewhere and has been used in catfish farming where it is liberally spread into water. Over three tonnes of menadione are used annually for this application alone.

Physical disinfection

Of the physical disinfection options ultraviolet irradiation (UV) is the most well established and is used extensively in municipal and industrial water treatment applications. The process employs amalgam lamps surrounded by a quartz sleeve (Fig.3) which can provide UV light at different wavelengths and intensities, depending on the particular application. It is well known to be effective against a wide range of microroganisms, including viruses and cysts, but relies on good UV transmission through the water and hence needs clear water and unfouled clean quartz sleeves to be effective.

The removal of water turbidity (i.e. cloudiness) is therefore essential for effective operation of the system. UV can be enhanced by combining with another reagent, such as ozone, hydrogen peroxide or titanium dioxide which will provide greater oxidative power than either UV or the supplementary chemical reagent alone.

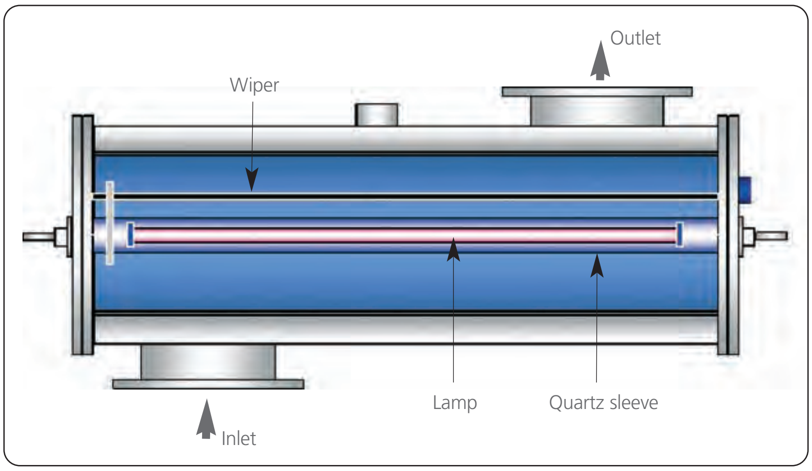


Fig. 4 UV tube and system

The remaining physical disinfection processes do not inherently require use of pre-treatment. However, the efficacy of both processes is subject to limitations. Deoxygenation takes a number of days to come into effect due to the length of time it takes the organisms to be asphyxiated. However, most voyages will exceed this time period so this should not be a significant constraint.

Cavitation or ultrasonic treatment processes both act at the surface of the micro-organism and disrupt the cell wall through the collapse of microbubbles. Although not used extensively in conventional water / wastewater treatment processes, systems which use these technologies have been awarded Type Approval certificates as of February 2010.

Ballast water treatment unit processes
The range of unit processes employed for ballast water treatment is shown in Table 3. The commercial systems differ mainly in the choice of disinfection technology and the overall system configuration (i.e. the coupling of the disinfection part with solid liquid separation, where the latter is used). Almost all have their basis in land-based systems employed for municipal and industrial water and wastewater and thus can be expected to be effective for the duty of ballast water, albeit subject to constraints in the precise design arising from space and cost limitations.

Table 3 Commercial technologies by generic unit operation type

	Solid-liquid sepn				Chemical disinfection and dechlorination					Physical disinfection			Micro-agitation		AO
	HC	Filt	None	Coag	O_3	Cl	EL/EC	Chem/ Biol	Res	UV	Deox	Heat	Cav	US	
1. Alfa Laval Tumba AB		X								X					TiO_2
2. atg UV Technology		X								X					
3. Atlas-Danmark		X					X								
4. Auramarine Ltd.		X								X					
5. Brillyant Marine															
6. Coldharbour			X								X		X		
7. DESMI Ocean Guard A/S		X			X					X					
8. Ecochlor Inc			X			X (as ClO_2)									
9. Electrichlor Inc															
10. Environmental Technologies Inc		X			X									X	
11. Erma First SA	X						X								
12. Hamann AG	X	X						X							
13. Hamworthy Greenship	X						X								
14. Hitachi		X		X											
15. Hi Tech Marine Pty Ltd			X									X			
16. Hyde Marine Inc		X								X					
17. Hyundai Heavy Industries - EcoBallast		X								X					
Hyundai Heavy Industries - HiBallast							X		X						
18. JFE Engineering Corporation		X				X (as Cl_2)			X						
19. Mahle NFV GmbH		X								X					
20. Marenco Technology Group Inc		X								X					
21. Mexel Industries								X							
22. MH Systems Inc			X								X				
23. Mitsui Engineering & Shipbuilding			X		X								X		
24. NEI Treatment Systems LLC			X								X		X		
25. NK Co., Ltd.			X		X										
26. Nutech 03			X		X										
27. Oceansaver AS		X					X				X		X		OH•
28. Optimarin AS		X								X					
29. Panasia Co., Ltd.		X								X					
30. Pinnacle Ozone Solutions		X			X		X			X					
31. Qingdao Headway Technology Co Ltd		X					X							X	OH•
32. Qwater		X												X	
33. Resource Ballast Technology / Unitor BWTS		X			X		X						X		
34. RWO		X					X								OH•
35. Sea Knight Corporation			X					X			X				
36. Severn Trent De Nora		X					X		X						
37. Siemens		X					X								
38. Techcross			X				X								
39. TG Corporation		X				X (as Cl_2)			X						
40. Vitamar, LLC-*Seakleen* TM			X					X							
41. Aalborg Industrie / Aquawrox[1]		X								X					
42. China Ocean Shipping Company (COSCO)[1]															
43. EcologiQ[1]		X								X					
44. Kwang San Co., Ltd[1]															
45. Maritime Solutions Inc[1]															
46. SunRui Corrosion & Fouling Control Co.[1]															
47. 21st Century Shipbuilding Co., Ltd.[1]		X								X					plasma

[1]Data incomplete - did not return completed survey forms
HC Hydrocyclone Filt Filtration Coag Coagulant (with magnetic particles) UV Ultraviolet irradiation Deox Deoxygenation O_3 Ozonation
Cav Cavitation Cl Chlorination EL/EC Electrolysis/electrochlorination ClO_2 Chlorine dioxide Res Residual Cl neutralisation US Ultrasound
AO Advanced oxidation OH• Hydroxyl radical

4. Treatment technologies and suppliers

Suppliers

This publication considers only suppliers of complete systems for ship based ballast water treatment rather than suppliers of unit operations, although individual proprietary unit operations (e.g. filters, electrochlorination devices, disinfectant chemicals and UV sterilisers) may be included as part of the systems reviewed.

Basic technical information is available from 47 companies, and 40 of these took part in the survey, to produce this February 2010 edition, compared to 28 respondents in September 2008. This is a 42% increase in the 18 months since the guide was last updated. Information from each of the 40 companies which responded in detail to the survey (Table 3) is presented in the Annex. Where available on web sites, or from other sources, information on the other 7 companies listed in Table 3 has been incorporated into the guide. Of the suppliers, around one third are part of a multi-billion dollar turnover international group of companies with significant activity in marine and/or engineering areas. The remainder appear to be SMEs (small to medium enterprises, generally defined as having less than 250 employees) all of which have been set up within the past 15 years. Fourteen different countries are represented by these 40 companies, with the predominant nation being the US (Fig. 5).

It is apparent from Fig. 5 that since September 2008, the number of suppliers of ballast water treatment systems and the number of countries in which they are based has increased significantly.

Technologies

The combination of treatment technologies utilised by the various suppliers are summarised in Table 3; since one supplier Hyundai offers two systems, there are 41 systems in total. All of the products for which information is available, other than those based on gas injection, are either modular or can be made so.

All of the systems reviewed have undergone preliminary pilot trials. The published data from these trials has shown the systems to be generally effective with reference to the IMO treated water standards applicable to discharged ballast water shown in Table 1.

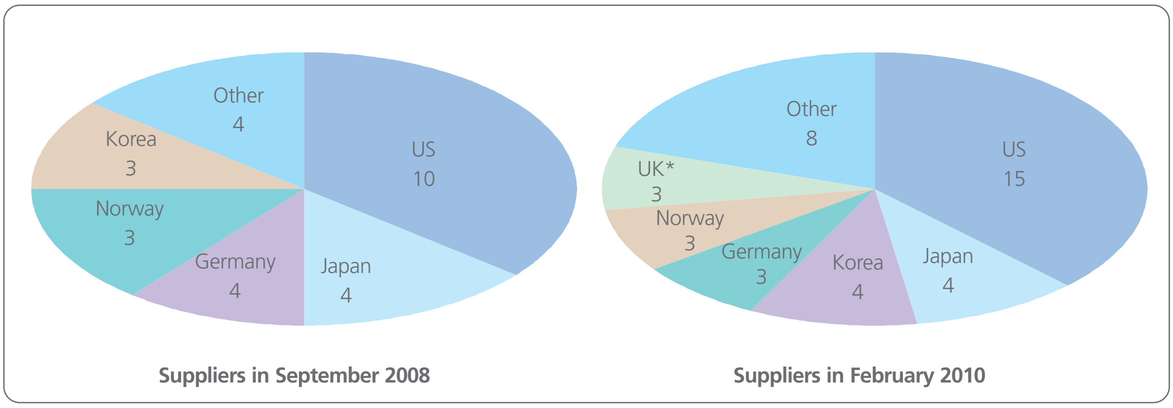


Fig 5. Technology suppliers have increased from 28 in 2008 to 41 in 2010. `Other' comprise Australia, China, Denmark (2), Finland, France, Greece and South Africa.

*one UK supplier also based in the Netherlands.

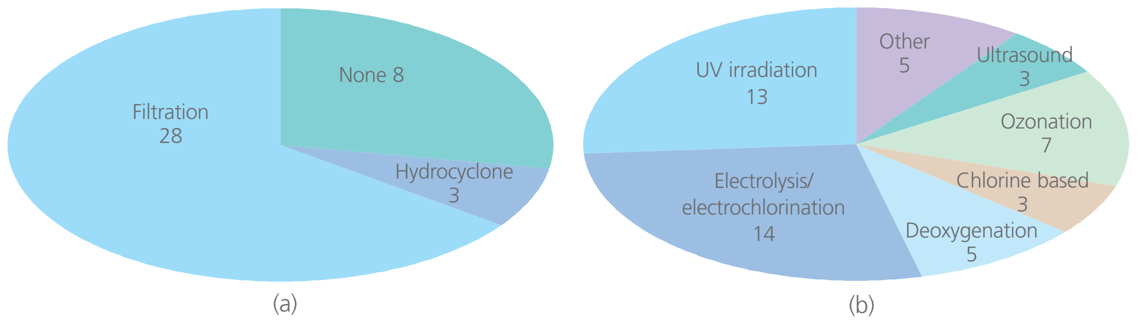


Fig. 6 Summary of treatment technologies used for (a) physical pre-treatment, and (b) disinfection. Note one or more disinfection options may be used. `Other' treatments include the use of coagulant before filtration (1), heat treatment (1) and non-chlorine chemical disinfection (3).

Of the systems considered the majority employ upstream filtration for solid-liquid separation (Fig. 6a), with the filter pore size primarily in 30-50 μm range. Only one system (Hitachi) employs pre-coagulation upstream of the filter. This particular system employs magnetic particles to accelerate the clarification process ('enhanced flocculation'). A magnetic separator is then used prior to filtration to remove particles. One supplier uses cartridge filters which are not backwashable. Three suppliers employ hydrocyclones.

All solid-liquid separation processes produce a waste stream containing the suspended solids. This waste stream comprises the backwash water from filtering operations or the underflow from the hydrocyclone separation. These waste streams require appropriate management. During ballasting they can be safely discharged at the point where they were taken up. On deballasting, the solid-liquid separation operation is generally by-passed.

Whilst there are a range of disinfection processes used for ballast water treatment, the majority of the systems are based on either electrolytic treatment (electrolysis or electrochlorination) or UV irradiation (Fig. 6b). In one case (Alfa Laval system), the UV irradiation is supplemented with titanium dioxide (TiO_2) to intensify the oxidative power of the UV light.

The electrolytic treatment products have different design features but all essentially employed a direct current to electrolyse the water. Electrolytic technologies provided for ballast water treatment may be designed to generate either chlorine, as in the classic electrochlorination process, or other oxidative products. Those designed for chlorine generation rely on the salinity of the feedwater for effective chlorine generation; supplementary brine is necessary when the abstracted ballast water is fresh. This is not an issue for chlorination, of which there are three examples, using either chlorine gas or hypochlorite. There are only single examples of the use of chemicals such as SeaKleen, vitamin K and non-oxidising biocides. One supplier, Sea Knight, uses bio-remediation following deoxygenation.

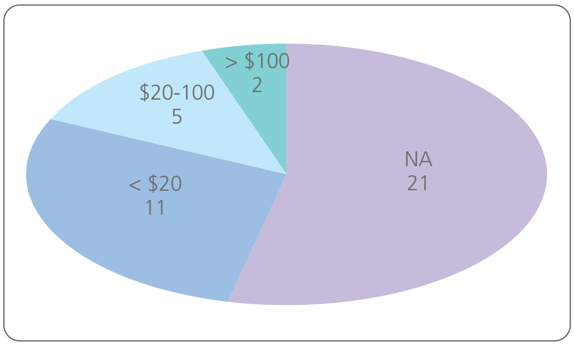


Fig. 7 Estimated plant operating cost per 1000m^3 of treated water; information not available or not provided for 21 systems.

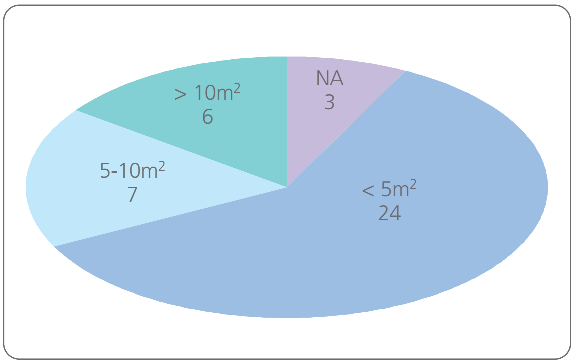


Fig. 8 Estimated footprint of a 200m^3/h plant; information not available or not provided for three systems. One supplier stated that footprint was vessel dependent.

Almost half of the systems reviewed treat the ballast water both during ballasting and discharge (Table 5). If filtration is used with backwashable filters then the filters are by-passed during discharge to avoid discharging non native organisms and other material into the receiving water. The majority of the other technologies treat only during ballasting. Of the remainder, two treat during discharge and others during ballasting and during the voyage.

Cost and footprint

The key technical features of the system with respect to ballast water treatment are the flow capacity, footprint, overall size of the system and costs, the latter comprising capital expenditure (capex) and operating expenditure (opex). Most of the technologies have been developed for a flow rate of about 250m^3/hr, considered to be the flow rate required for the first phase of ships required to be equipped with ballast water treatment technology. Since the systems are largely modular in design (other than the gas injection type), there is no technical limit to the upper flow rate other than that imposed by size and/or cost. In some cases there are examples of systems already installed for flows above 5000 m^3/hr.

The mean key data for costs and footprint for all the technologies are summarised in Table 4 and Figures 7 and 8. Full data are provided in Table 5. The mean quoted estimated or projected operating cost of the systems, on the basis of the 19 sets of data provided is $39 per 1000m^3, within a broad range of values from no cost (when waste heat is used) to $200 per 1000m^3 treated water. Eleven of the 19 suppliers who provided operational expenditure information quoted costs below $20 per 1000m^3, and variation may be due to methods of calculating opex. Some suppliers indicated that extra water head on ballast pumps may be required. There is a tendency, where data is available, for larger units to be more efficient in terms of power requirements, which for the 33 systems for which data was available ranged from 0 to 220 kW per 1000m^3 of treated ballast water. In most cases (except for the few technologies that use stored chemicals and the gas injection units that use fossil fuel) the majority of the opex relates to the power required to operate the process (UV irradiation, electrolysis or ozonation).

	Footprint, m^2 for unit capacity of:		Height m	Capex, $'000		Opex	Power
	200 m^3/h	2000 m^3/h		200 m^3/h	2000 m^3/h	$/1000 m^3/h	kw/1000m^3
Mean	7	21	3	281	863	39	68
Data points	37	30	37	20	21	19	33
Min	0.3	1	1	20	50	0	0
Max	30	145	20	600	2000	200	220

Table 4 Summary of plant footprint, height and capital and operating expenditure

*System flow rate

Manufacturer	Treatment protocol	Capacity* 1000's m^3/h	Estimated Footprint		Estimated Capex $'000 (installed cost)		Estimated Opex $/1000 m^3
			200 m^3/h	2000 m^3/h	200 m^3/h	2000 m^3/h	
Alfa Laval Tumba AB	A+B+D	5	3	12			
atg UV Technology	A+B+D	>10	25				
Atlas-Danmark	A+C+D	>10	1.6+0.7	1.6+10.5	180	850	
Auramarine Ltd	A+B+D	>10	3	20			40
Brillyant Marine	A	20+	1.2	12	300	2000	
Coldharbour	C	Unlimited					
DESMI Ocean Guard A/S	A+D	3	4-6	12-30			
Ecochlor Inc	A	10	6.8	9.5	500	800	80
Electrichlor Inc	A+B+D	>10	3	-	350		19
Environmental Technologies Inc	B	>10		15		500	cost of power
Erma First SA	A	>10	2.0	14.0			
Hamann AG	A	2	4.3	on request			200
Hamworthy Greenship	A	1	2.1				
Hitachi	A	>10	20	100		400	
Hi Tech Marine Pty Ltd	A+B+C	0.6	7.3	145	150	1600	nil***
Hyde Marine Inc	A+B+D	1.5	3.5	25	230	1200	<$20
Hyundai Heavy Industries - EcoBallast	A+B+D	5	4				
Hyundai Heavy Industries - HiBallast	A	>10	7	10			
JFE Engineering Corporation	A+B+D	3.5	5	8			53
Mahle NFV GmbH	A+B+D	2.5	4	18			
Marenco Technology Group Inc	B	1	1.2		145	175	0.6-1.0
Mexel Industries	A+C	>10	1	2	20	50	
MH Systems Inc	A+C	Unlimited	5	9	500	1500	60
Mitsui Engineering & Shipbuilding	A	0.3	30				
NEI Treatment Systems LLC	A	>10	3	6	249	670	130
NK Co., Ltd	A	>10	20	40	250	1000	7
Nutech 03	A	>10	22	40	250	450	7
Oceansaver AS	A+B	5			288	1600	
Optimarin AS	A+B+D	>20	2.91	8.54	290	1280	
Panasia Co., Ltd.	A+B+D	6	2.96	11.11			
Pinnacle Ozone Solutions	A+B+D	10	6	11	200	500	13
Qingdao Headway Technology Co Ltd	A+B+D	>10	0.6	3			1.8
Qwater	A+B+D		15	30			
Resource Ballast Technology / Unitor BWTS	A	4	2	4	275	700	
RWO	A+B+D	>10					
Sea Knight Corporation	B+C	VD	VD	VD	165	275	<15
Severn Trent De Nora	A	>10	8	12	630	975	20
Siemens	A	>10	9	23	500	1000	8.5 - 10
Techcross	A	>10	4.5	11	200	600	3
TG Corporation	A+B+D	3.5	5	8			53
Vitamar, LLC	A	>10	0.25	1			

Table 5 System key data: capacity, footprint and costs

A ballasting, B discharging, C during voyage, D bypass filter on deballasting, VD Determined by vessel size.
*Maximum treatment flow currently available (>10m^3/h indicates no stated maximum)
**includes pipework
***Assumes waste heat utilised

Capital cost information is more widely available in 2010 compared to 2008, however, just over half of the suppliers regard this information as confidential. From the 19 sets of data provided, the capital cost of a 200 m^3/h plant ranges from $20,000 (by Mexel Industries) to $600,000, with a mean value of around $281,000, which is $100,000 less than in September 2008. For a 2000 m^3/h plant, the equivalent values are $50,000 (again Mexel) to $2,000,000 with a mean of $863,000, also lower than 2008. As with the opex, from the limited information provided there appears to be no correlation between the quoted capex and the configuration of the process, and variations in price arise from differences in assumptions made by the various suppliers regarding inclusion or exclusion of specific components. Prices quoted must be regarded as tentative since some of these products are still under development and the price is to some extent determined by the marketplace.

The footprint of the systems reviewed varies between 0.25 and 30 m^2 for a 200 m^3/h unit, with a mean value of 7 m^2, according to the data provided by suppliers in relation to 37 systems. For a unit of ten times this flow capacity, there is less information, since some suppliers do not provide units of this size, and the minimum, maximum and mean values are 1, 145 and 21 m^2 respectively. One supplier (Atlas) gave data for both the control panel / electrolysis system and the pre-filter. Optimarin stated that their system may be suspended under the deck, giving a zero footprint. Thus, whilst the units may be predominantly modular, this does not imply that the footprint increases proportionately with flow capacity.

Other system characteristics

Other technical features of the products are not necessarily common to all of them and are specific to generic types of process technology. These process-specific facets can be summarised as follows:

- Deoxygenation is the only technology specifically developed for ballast water treatment and is effective because the de-aerated water is stored in sealed ballast tanks. However the process takes between one and four days to take effect, and thus represents the only type of technology where voyage length is a factor in process efficacy. This type of technology is also the only one where, technically, a decrease in corrosion propensity would be expected (and, according to one supplier, has been recorded as being suppressed by 50-85%), since oxygen is a key component in the corrosion process. The water is re-aerated on discharge.

- Systems in which chemicals are added normally need to be neutralised prior to discharge to avoid environmental damage in the area of discharge. Most ozone and chlorine systems are neutralised but some are not. Chlorine dioxide has a half life in the region of 6-12 hours, according to the supplier, but at the concentrations at which it is employed it can be safely discharged after a maximum of 24 hours.

- Essentially most UV systems operate using the same type of medium pressure amalgam lamps. A critical aspect of UV effectiveness is the applied UV dose/power of the lamp. This information has not been given by all suppliers. Another aspect of UV effectiveness is the clarity of the water. In waters with a high turbidity or colloidal content, UV would not be expected to be as effective.

- Most chlorination systems are applying a dose in the region of 2 mg/l residual chlorine which has proven to be effective.

- Most ozonation suppliers are using an ozone dose of 1-2 mg/l which has proven to be effective.

- Deoxygenation plants are relatively simple devices if an inert gas generator is already installed on the ship and in the latter case would take up little additional space.

- The biggest operating cost for most systems is power and for large power consumers (electrolytic and advanced oxidation processes) availability of shipboard power will be a factor.

- For chemical dosing systems, power is very low and chemical costs are the major factor. For these reasons chemical addition may be better suited to small ballast capacities.

ID Manufacturer	Active substance approval[1]		System testing		Test site	Type Approval Certificate	Commercially available[2]	Units installed[3]	Projected Production units / y
	Basic	Final	Shipboard	Landbased					
Aalborg Industries / Aquawrox	07/2009				NIOZ		2011		No limit
Alfa Laval Tumba AB	07/2007	07/2007	04/2008	04/2008	NIVA	06/2008	2006	5	No limit
atg UV Technology	NR	NR					Yes	1	
Atlas-Danmark		2011*	2011*	2011*		2012*	2010	0	No limit
Auramarine Ltd	NR	NR	06/2010	01/2010	NIVA	12/2010*	2010	0	No limit
Brillyant Marine	10/2010*	04/2011*	03/2011*	10/2010*	Maryland	08/2011*	2011	0	No limit
China Ocean Shipping Company (COSCO)	07/2009								
Coldharbour	NR	NR	09/2010*	05/2010*	NIOZ		2010		
DESMI Ocean Guard A/S	03/2010+				DHI		2010		No limit
Ecochlor Inc	10/2008		ONGOING	06/2008	NIOZ		2006	2	100
Electrichlor Inc							2006	3	240
Environmental Technologies Inc									
Erma First SA	10/2010*	06/2011*	10/2010*	06/2010*		06/2011*	2010		>100*
Hamann AG	03/2006	04/2008	06/2007	06/2007	NIOZ	06/2008	2006	2	65
Hamworthy Greenship	10/2008	07/2009	06/2008	10/2007	Harlingen		2006	4	No limit
Hitachi	04/2008	07/2009	07/2008	06/2008			2009	0	50
Hi Tech Marine Pty Ltd	NR	NR	Original tests 1997	02/2003	Sydney	Pending	Yes	0	As required
Hyde Marine Inc	NR	NR	04/2009	04/2009	NIOZ	04/2009	2000	7	600
Hyundai Heavy Industries - EcoBallast	07/2009	03/2010+	2009	2008	HHI	2010*	2011	0	98
Hyundai Heavy Industries - HiBallast	03/2010+	2011*	2011*	2009	HHI	2012*	2012	0	165
JFE Engineering Corporation	10/2008	03/2010+	09/2009	03/2009	NIVA	Spring, 2010	Spring, 2010	1	300
Kwang San Co,. Ltd	03/2010+								
Mahle NFV GmbH	NR	NR	2010*	2009	NIOZ		2010	1	No limit
Marenco Technology Group Inc	NR	NR	2007	2007	MLML		2008	3	240-360
Mexel Industries							2010	2	No limit
MH Systems Inc	NR	NR	09/2010*	07/2010*	SIO		2010	0[4]	300
Mitsui Engineering & Shipbuilding	10/2006	10/2010*	07/2009	02/2008	JAMS		2009	1	40-100
NEI Treatment Systems LLC	NR	NR	[5]	[5]	NOAA	10/2007	2006	6	200
NK Co., Ltd	07/2007	07/2009	2008	2008	KOMERI	11/2009	2008	4	400-700
Nutech 03							2008	4	400-700
Oceansaver AS	04/2008	10/2008	09/2008	11/2007	NIVA	04/2009	2008	6	>200
Optimarin AS	NR	NR	01/2009	05/2008	NIVA	11/2009	Yes	11	1000
Panasia Co., Ltd.	04/2008	03/2010+	10/2009	12/2008	KORDI	12/2009	2009	2	1400
Pinnacle Ozone Solutions	NR	NR		10/2011	GSI		2011		
Qingdao Headway Technology Co Ltd	03/2010+	10/2010*		10/2009	NIVA	12/2010*	2009	1	2000
Qwater	NR	NR					04/2009	0	
Resource Ballast Technology / Unitor BWTS	04/2008	03/2010+	2010*	2010*	Cape Town		2009	4	2000+
RWO	10/2006	07/2009	01/2010	09/2007 11/2008	Bremen NIVA	03/2010*	2008	16	No limit
Sea Knight Corporation	10/2010*	06/2011*	-	-	Virginia	06/2011*	2011	0	No limit
Severn Trent De Nora	03/2010+	10/2010*	12/2010*	07/2009	NIOZ	03/2011*	2010	2	1500
Siemens	03/2010+	06/2011*	02/2011*	04/2010*	GSI+MERC	2011*	2010		
Sunrui Corrosion and Fouling Control Company	03/2010+								
Techcross	03/2006	10/2008	08/2007	08/2007	KORDI	12/2008	2007	31	1200
TG Corporation	10/2008	03/2010+	09/2009	03/2009	NIVA	Spring 2010*	Spring 2010*	1	300
Vitamar, LLC	2010*	2011*	2011*	2011*	NIOZ+MERC	2012*	2012/13*	0	1000
21st Century Shipbuilding Co., Ltd.	03/2010+								

Table 6 System status: commercial development and approval

+ expected to be granted at MEPC 60
* dates projected by manufacturer
1 Guidelines for approval of ballast water management systems that make use of active substances (G9) IMO resolution MEPC.126(53) and subsequently MEPC.169(57)
2 year commercialised or anticipated for commercialisation for ballast water treatment;
3 refers to existing installations;
4 system design for R/V Melville, (Scripps' vessel) completed
5 tests comparable to IMO 'G8' ballast water management systems testing protocol stated to have been completed prior to introduction of 'G8' protocol
6 five land based systems have been installed
ex explosion proof type approval certificate
NR not required

- Although the systems operate at generally low pressure and thus do not require additional ballast water pumping pressure, those employing venturi devices (for exerting shear) incur pressure losses of up to 2 bar.

- For most systems it is recommended that installation takes place in the engine/machine room near the existing ballast water pumps, although installation on deck may also be possible if appropriate precautions are taken. If the location is in an explosion zone, then the installation will need explosion proofing and one supplier, Techcross, has Type approval for an explosion proof system. The generation of hydrogen by the electrolytic technologies is not considered an issue, since the gas is vented and diluted with air to safe levels.

- Whilst disinfection by-products are an issue, and central to the approval of ballast water management systems that make use of active substances, suppliers are confident that the levels generated are unlikely to be problematic. There is a large amount of scientific and technical information on disinfection by-products formation that is likely to support this.

Commercial availability

By February 2010, 27 suppliers stated that they had systems installed on ships. A total of 119 ballast water treatment systems had been installed by these suppliers as of February 2010, an increase of 50 systems over the 18 months since the last update to this guide. UV based systems, from Hyde Marine and Optimarin account for around 25% of installations, and electrochemical systems, from RWO Marine and Techcross accounting for a further 35%.

Approval status

The regulatory framework requires that a key distinction is to be made between those systems employing active substances (primarily disinfectant chemicals) and those which do not. Non-AS systems would appear to have less regulatory hurdles to overcome as they do not require GESAMP G9 approval. However, a number of manufacturers have successfully demonstrated that it is possible to obtain full type approval certification ahead of systems which do not require GESAMP approval, as five of the nine systems with type approval certificates have been through the G9 approval process.

According to information provided by the suppliers, an increasing number of the technologies reviewed are progressing towards approval, though the scheduling of the testing differs between the different suppliers and thus the projected date for final approval. To date 18 of the active substance systems have received basic approval from the MEPC, however, a further eight are expecting basic approval at MEPC 60. As of February 2010, ten of these 18 have obtained final approval, with a further 3 expected to gain this at MEPC 60. Further approvals are likely at subsequent MEPC meetings, with manufacturers projecting approvals in both 2010 and 2011. It is clear, however, that many systems are undergoing 'G8' ballast water management systems approval without having received basic approval for the active substances. Indications are that up to twelve companies are or will be undertaking testing of ballast water management systems at test facilities during 2010 and 2011.

By February 2010, nine systems had received type approval certificates, one of which (Techcross) also has type approval for an explosion proof system. Suppliers of three systems state that they expect type approval in early 2010 and a further nine project dates between late 2010 and 2012.

5. Concluding remarks

The previous edition of this ballast water treatment technology guide predicted that the number of systems with type approval would "significantly increase over the next 12 - 18 months". In fact, since September 2008, the number of such systems has almost trebled, from three to nine.

The systems that have obtained type approval demonstrate that a wide range of technologies, with or without the use of active substances, are suitable for the treatment of ballast water to the standards required by the G8 guidelines. The use of active substances and the need to undergo the approval process specified in the G9 guidelines do not present a significant barrier to obtaining type approval.

It is now apparent that technologies to treat ballast water to meet the D2 standard within the International Convention for the Control and Management of Ship's Ballast Water and Sediments are available and established, with over one hundred such systems installed worldwide.

Annex – Listing by supplier

Supplier **Alfa Laval Tumba AB**
Process *Pureballast*: Filtration + Ultraviolet/TiO_2
System used Ballasting + discharging (filter bypassed on discharging)
Partner(s) Wallenius
Country Norway
Web site www.alfalaval.com

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commercially available	Units installed	Projected production Units/y
07/2007*	07/2007*	04/2008	04/2008	NIVA	06/2008	2006	5	**
Capacity 1000 m³/h	**Footprint, m² for unit capacity of: 200 m³/h**	**2000 m³/h**	**Maximum height m**	**Capex, $k 200 m³/h**	**2000 m³/h**	**Opex $per 1000 m³/h**	**Company formed**	**No. employees**
5	3	12	3	NA	NA	NA	1883	9500
Power requirement kW / 1000 m³/ h		**Additional services**		Comments	*Basic and final approval granted MEPC 56 **According to an evaluation of potential growth to 2016, manufacturing not seen as a limiting factor			
NA		Air, water (rinsing)						

Supplier **atg UV Technology**
Process Filtration + ultraviolet
System used Ballasting + discharging (filter bypassed on discharging)
Country United Kingdom
Web site www.atguv.com

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commercially available	Units installed	Projected production Units/y
-	-	-	-	-	-	Yes	1	NA
Capacity 1000 m³/h	**Footprint, m² for unit capacity of: 200 m³/h**	**2000 m³/h**	**Maximum height m**	**Capex, $k 200 m³/h**	**2000 m³/h**	**Opex $per 1000 m³/h**	**Company formed**	**No. employees**
>10	25	NA	2.2	NA	NA	NA	1985	20
Power requirement kW / 1000 m³/ h		**Additional services**						
125		none						

Supplier **Atlas-Danmark**
Process Filtration and electrolysis
System used Ballasting + during voyage (filter bypassed on dischargiing)
Country Denmark
Web site www.atlas-danmark.com

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commercially available	Units installed	Projected production Units/y
-*	2011**	2010/11**	2011**	ND	2012**	2010	0	3
Capacity 1000 m³/h	**Footprint, m² for unit capacity of: 200 m3/h**	**2000 m³/h**	**Maximum height m**	**Capex, $k 200 m³/h**	**2000 m³/h**	**Opex $per 1000 m³/h**	**Company formed**	**No. employees**
No limit	1.6 + 0.7***	1.6 + 10.5***	1.6 + 1.8*	180	850		N/A	5
Power requirement kW / 1000 m³/ h		**Additional services**		Comments	* Basic approval applied for but not expected to be granted at MEPC 60 **Projected by manufacturer. *** First value is for the panel and electrolysis system; the second is for the pre-filter.			
20 (max)		8.5 kg salt + 3.4m³ desalinated water per 1000m³						

Supplier **Auramarine**
Process Filtration + UV-C radiation
System used Ballasting + discharging (filter bypassed on discharging)
Country Finland
Web site www.auramarine.com

Active substance approval (if applicable)		System approval		Test site	Type approval certificate	Commer-cially available	Units installed	Projected production Units/y
Basic	Final	Shipboard	Landbased					
NR	NR	06/2010	01/2010	NIVA	12/2010*	2010	0	No limit
Capacity 1000 m3/h	**Footprint, m^2 for unit capacity of: 200 m^3/h**	**2000 m^3/h**	**Maximum height m**	**Capex, $k 200 m^3/h**	**2000 m^3/h**	**Opex $per 1000 m^3/h**	**Company formed**	**No. employees**
>10	3	20	3	NA	NA	15-40**	1974	180

Power requirement kW / 1000 m^3/ h	Additional services
110***	air

Comments * Date projected by manufacturer
** Operation without maintenance 15-20. Upper value includes maintenance
*** Power depends on water quality

Supplier **Brillyant Marine LLC**
Process Electric Pulse
System used Ballasting
Country USA
Web site www.brillyantwater.com

Active substance approval (if applicable)		System approval		Test site	Type approval certificate	Commer-cially available	Units installed	Projected production Units/y
Basic	Final	Shipboard	Landbased					
10/2010*	04/2011**	03/2011	10/2010	Maryland	08/2011***	2011	0	No limit
Capacity 1000 m3/h	**Footprint, m^2 for unit capacity of: 200 m^3/h**	**2000 m^3/h**	**Maximum height m**	**Capex, $k 200 m^3/h**	**2000 m^3/h**	**Opex $per 1000 m^3/h**	**Company formed**	**No. employees**
20+	1.2	12	1.8	300	2000	NA	2007	12

Power requirement kW / 1000 m^3/ h	Additional services
20	None

Comments *Basic approval expected 10/2010
**Final approval expected 04/2011
***Date projected by manufacturer

Supplier **Coldharbour Marine**
Process Deoxygenation & Cavitation
System used During voyage
Country UK
Web site www.coldharbourmarine.com

Active substance approval (if applicable)		System approval		Test site	Type approval certificate	Commer-cially available	Units installed	Projected production Units/y
Basic	Final	Shipboard	Landbased					
NR	NR	09/2010*	05/2010*	NIOZ		2010		
Capacity 1000 m3/h	**Footprint, m^2 for unit capacity of: 200 m^3/h**	**2000 m^3/h**	**Maximum height m**	**Capex, $k 200 m^3/h**	**2000 m^3/h**	**Opex $per 1000 m^3/h**	**Company formed**	**No. employees**
Unlimited							2000	9

Power requirement kW / 1000 m^3/ h	Additional services
	Cooling water

Comments *Dates projected by manufaturer

Supplier **DESMI Ocean Guard A/S**
Process Filtration + UV and Ozone
System used Ballasting (filter bypassed on discharging)
Country Denmark
Web site www.desmioceanguard.com

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commercially available	Units installed	Projected production Units/y
03/2010*				DHI		2010		
Capacity 1000 m3/h	**Footprint, m² for unit capacity of: 200 m³/h**	**2000 m³/h**	**Maximum height m**	**Capex, $k 200 m³/h**	**2000 m³/h**	**Opex $per 1000 m³/h**	**Company formed**	**No. employees**
0.3 - 3	4 - 6**	12 - 30**					25/06/2009	2
Power requirement kW / 1000 m³/ h		**Additional services**		**Comments:**				
50 - 90**				*Basic approval expected at MEPC 60 **Power and foot print requirement depends upon ballast water quality				

Supplier **Ecochlor Inc.**
Process ClO_2
System used Ballasting
Partners Rolls-Royce Marine; Proflow Inc., Eka Chemicals
Country US
Web site www.ecochlor.com

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commercially available	Units installed	Projected production Units/y
10/2008*	-**	Ongoing	06/2008	NIOZ		2006	2	100
Capacity 1000 m3/h	**Footprint, m² for unit capacity of: 200 m³/h**	**2000 m³/h**	**Maximum height m**	**Capex, $k 200 m³/h**	**2000 m³/h**	**Opex $per 1000 m³/h**	**Company formed**	**No. employees**
0.25-10	6.75	9.5	2.5	500	800	80	2001	6
Power requirement kW / 1000 m³/ h		**Additional services**		**Comments:**				
NA		Water		*Basic approval at MEPC 58 ** Final approval applied for but not expected to be granted at MEPC 60				

Supplier **Electrichlor Hypochlorite Generators Inc.**
Process Filtration + electrolysis/electrochlorination
System used Ballasting + discharging (filter bypassed on discharging)
Partners Garnett Inc., Vitamar, LLC
Country US
Web site www.electrichlor.com

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commercially available	Units installed	Projected production Units/y
-	-	-	-	ND		2006	3	240
Capacity 1000 m3/h	**Footprint, m² for unit capacity of: 200 m³/h**	**2000 m³/h**	**Maximum height m**	**Capex, $k 200 m³/h**	**2000 m³/h**	**Opex $per 1000 m³/h**	**Company formed**	**No. employees**
>10	3	NA	2	350	NA	19	2000	19
Power requirement kW / 1000 m³/ h		**Additional services**						
>10		NA						

Supplier **Environmental Technologies Inc.**
Process Filtration + ozone + ultrasound
System used Discharging
Country US
Web site www.timcos.com

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commer-cially available	Units installed	Projected production Units/y
		-	-	NA		NA	0	NA
Capacity 1000 m³/h	**Footprint, m² for unit capacity of: 200 m³/h**	**2000 m³/h**	**Maximum height m**	**Capex, $k 200 m³/h**	**2000 m³/h**	**Opex $per 1000 m³/h**	**Company formed**	**No. employees**
>10*	NA	15	2.4	NA	500	**	1994	3
Power requirement kW / 1000 m³/ h		**Additional services**		Comments	*Capacity: The E.T.I. BWTS is a modular system that can treat 227 to 1360 m³ of ballast water/h per module. **Opex would be the cost of the power required to run the system.			
100		Water (cooling)						

Supplier **ERMA FIRST SA**
Process Multi Hydrocyclone separation+ Electrolysis/ Electrochlorination
System used Ballasting (Hydrocyclones bypassed on discharging)
Country Greece
Web site www.ermafirst.com

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commer-cially available	Units installed	Projected production Units/y
10/2010*	06/2011*	10/2010*	06/2010*	NA	06/2011*	2010	-	>100
Capacity 1000 m³/h	**Footprint, m² for unit capacity of: 200 m³/h**	**2000 m³/h**	**Maximum height m**	**Capex, $k 200 m³/h**	**2000 m³/h**	**Opex $per 1000 m³/h**	**Company formed**	**No. employees**
>10	2.0	14	1.6	NA	NA	NA	2009	5
Power requirement kW / 1000 m³/ h		**Additional services**		Comments	*Dates projected by manufacturer			
50		NA						

Supplier **Hamann AG[1]**
Process 2 step filtration and peracetic acid (Peraclean®Ocean)
System used Ballasting
Partner(s) EVONIC Industries
Country Germany
Web site www.hamannag.com

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commer-cially available	Units installed	Projected production Units/y
03/2006*	04/2008*	06/2007	06/2007	NIOZ	06/2008	Since 2006	2	65
Capacity 1000 m³/h	**Footprint, m² for unit capacity of: 200 m³/h**	**2000 m³/h**	**Maximum height m**	**Capex, $k 200 m³/h**	**2000 m³/h**	**Opex $per 1000 m³/h**	**Company formed**	**No. employees**
0.05-2	4.3	on request	2.2-2.9	NA	NA	200	1970	84
Power requirement kW / 1000 m³/ h		**Additional services**		Comments	*Basic approval at MEPC 54; final approval at MEPC 57			
25		Air and water						

1 Temporarily withdrawn from the market as of 31/01/2010

Supplier **Hamworthy Greenship**
Process Hydrocyclone and Electrolysis/electrochlrorination
System used Ballasting only

Country UK/Netherlands
Web site www.hamworthy.com

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commercially available	Units installed	Projected production Units/y
10/2008*	07/2009*	06/2008	10/2007	Harlingen	**	2006	2	no limit
Capacity 1000 m^3/h	**Footprint, m^2 for unit capacity of: 200 m^3/h**	**2000 m^3/h**	**Maximum height m**	**Capex, $k 200 m^3/h**	**2000 m^3/h**	**Opex $per 1000 m^3/h**	**Company formed**	**No. employees**
1	2.1	NA	2.0	NA	NA	NA	1911	1200
Power requirement kW / 1000 m^3/ h		**Additional services**		Comments	* Basic approval at MEPC 58; final approval at MEPC 59 ** Target date of spring 2010			
30		None						

Supplier **Hitachi**
Process Filtration + pre-coagulant (enhanced flocculation)
System used Ballasting

Partners Mitsubishi HI
Country Japan
Web site www.hitachi.com

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commercially available	Units installed	Projected production Units/y
04/2008*	07/2009*	07/2008	06/2008			2009	0	50
Capacity 1000 m^3/h	**Footprint, m^2 for unit capacity of: 200 m^3/h**	**2000 m^3/h**	**Maximum height m**	**Capex, $k 200 m^3/h**	**2000 m^3/h**	**Opex $per 1000 m^3/h**	**Company formed**	**No. employees**
>10	20	100	NA	NA	400	NA	1929**	9,256,000
Power requirement kW / 1000 m^3/ h		**Additional services**		Comments	* Basic approval at MEPC 57; final approval at MEPC 59. ** as Hitachi Plant Technologies; original company formed in 1910			
NA		NA						

Supplier **Hi Tech Marine Pty Ltd**
Process Heat
System used Ballasting / discharging or during voyage

Country Australia
Web site www.htmarine.co.au

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commercially available	Units installed	Projected production Units/y
NR	NR		02/2003	Sydney		Yes	0	As required
Capacity 1000 m^3/h	**Footprint, m^2 for unit capacity of: 200 m^3/h**	**2000 m^3/h**	**Maximum height m**	**Capex, $k 200 m^3/h**	**2000 m^3/h**	**Opex $per 1000 m3/h**	**Company formed**	**No. employees**
0.6	7.3	145	3	150	1600	nil*		
Power requirement kW / 1000 m^3/ h		**Additional services**		Comments	* Assumes waste heat utilised. Pumping requires 13.27kW for 200 m^3/h system			
nil*								

Supplier **Hyde Marine**
Process Filtration + ultraviolet
System used Ballasting + discharging (filter bypassed on discharging)
Country US
Web site www.hydemarine.com

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commer-cially available	Units installed	Projected production Units/y
NR	NR	04/2009	04/2009	NIOZ	04/2009	2000	15	500
Capacity 1000 m^3/h	**Footprint, m^2 for unit capacity of: 200 m^3/h**	**2000 m^3/h**	**Maximum height m**	**Capex, $k 200 m^3/h**	**2000 m^3/h**	**Opex $per 1000 m^3/h**	**Company formed**	**No. employees**
1.5*	3.5	25	2	230	1200	15-20	1969	20
Power requirement kW / 1000 m^3/ h		**Additional services**		Comments: *Approved up to 6000 m^3/h				
89-125		Air (80psi)						

Supplier **Hyundai Heavy Industries - EcoBallast**
Process Filtration + ultraviolet
System used Ballasting + discharging (filter bypassed on discharging)
Country Republic of Korea
Web site http://hhi.co.kr/

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commer-cially available	Units installed	Projected production Units/y
07/2009*	03/2010**	2009	2008	HHI	2010***	2011	1	98
Capacity 1000 m^3/h	**Footprint, m^2 for unit capacity of: 200 m^3/h**	**2000 m^3/h**	**Maximum height m**	**Capex, $k 200 m^3/h**	**2000 m^3/h**	**Opex $per 1000 m^3/h**	**Company formed**	**No. employees**
5	4	NA	3.2	NA	NA	NA	NA	50
Power requirement kW / 1000 m3/ h		**Additional services**		Comments *Basic approval given MEPC 59 **Final approval expected at MEPC 60 ***Target date of 09/2010				
110		none						

Supplier **Hyundai Heavy Industries - HiBallast**
Process Electrolysis/electro-chlorination
System used Ballasting
Partner Elchemtech
Country Republic of Korea
Web site http://hhi.co.kr/

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commer-cially available	Units installed	Projected production Units/y
03/2010*	2011**	2011***	2009	HHI	2012***	2011***	1	165
Capacity 1000 m^3/h	**Footprint, m^2 for unit capacity of: 200 m^3/h**	**2000 m^3/h**	**Maximum height m**	**Capex, $k 200 m^3/h**	**2000 m^3/h**	**Opex $per 1000 m3/h**	**Company formed**	**No. employees**
>10	7	10	2.7	NA	NA	NA		50
Power requirement kW / 1000 m^3/ h		**Additional services**		Comments *Basic approval expected at MEPC 60 **Final approval projected for MEPC 62 ***Date projected by manufacturer				
200		none						

Supplier **JFE Engineering Corporation**
Process Filtration + chlorination + mixing / agitation + residual control
System used Ballasting + discharging (filter bypassed on discharging)
Partners TG Corporation
Country Japan
Web site www.jfe-eng.co.jp

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commercially available	Units installed	Projected production Units/y
10/2008*	03/2010*	09/2009	03/2009	NIVA	Spring 2010**	Spring 2010**	1	300

Capacity 1000 m^3/h	Footprint, m^2 for unit capacity of: 200 m^3/h	2000 m^3/h	Maximum height m	Capex, $k 200 m^3/h	2000 m^3/h	Opex $per 1000 m^3/h	Company formed	No. employees
3.5	5	8	2.6	NA	NA	53	2003 (1912)***	7400

Power requirement kW / 1000 m3/ h	Additional services	Comments
3	Water	* Basic approval at MEPC 58; final approval expected at MEPC 60 ** Date projected by manufacturer *** Established in 1912 and reformed in 2003

Supplier **Mahle NFV GmbH**
Process Filtration + ultraviolet
System used Ballasting + discharging (filter bypassed on discharging)
Country Germany
Web site www.nfv-gmbh.de

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commercially available	Units installed	Projected production Units/y
NR	NR	2010*	2009	NIOZ		2010	1	50**

Capacity 1000 m^3/h	Footprint, m^2 for unit capacity of: 200 m^3/h	2000 m^3/h	Maximum height m	Capex, $k 200 m^3/h	2000 m^3/h	Opex $per 1000 m3/h	Company formed	No. employees
2.5	4	18	2.5	NA	NA	NA	1965	45

Power requirement kW / 1000 m^3/ h	Additional services	Comments
60	Control air and water	* Shipboard testing is in progress ** No limit

Supplier **Marenco Technology Group, Inc.**
Process Filtration + ultraviolet
System used Discharging
Country US
Web site www.marencogroup.com

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commercially available	Units installed	Projected production Units/y
NR	NR	2007*	2007*	MLML		2008	1	240-360

Capacity 1000 m^3/h	Footprint, m^2 for unit capacity of: 200 m^3/h	2000 m^3/h	Maximum height m	Capex, $k 200 m^3/h	2000 m^3/h	Opex $per 1000 m^3/h	Company formed	No. employees
**	1.165	NA	1.38	145	175	0.6-1.0	1999	NA

Power requirement kW / 1000 m^3/ h	Additional services	Comments
60	none	*testing may not be strictly to IMO standards **modular system able to service most ranges of ballast water flow

Supplier **Mexel Industries**
Process Ballasting and during voyage
System used Non oxidizing biocide

Country France
Web site www.mexel.fr

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commercially available	Units installed	Projected production Units/y
						2010	2	No limit
Capacity 1000 m^3/h	**Footprint, m^2 for unit capacity of: 200 m^3/h**	**2000 m^3/h**	**Maximum height m**	**Capex, $k 200 m^3/h**	**2000 m^3/h**	**Opex $per 1000 m^3/h**	**Company formed**	**No. employees**
>10	1	2	0.5	20	50	NA	1995	20

Power requirement kW / 1000 m^3/ h	Additional services
0.5	

Comments Utilises a biodegradable and non-oxidizing biocide

Supplier **M H Systems Inc.**
Process Deoxygenation with inert gas and CO_2
System used Ballasting and during voyage

Country US
Web site www.mhsystemscorp.com

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commercially available	Units installed	Projected production Units/y
NR	NR	09/2010*	07/2010*	SIO		2010	0	200
Capacity 1000 m^3/h	**Footprint, m^2 for unit capacity of: 200 m^3/h**	**2000 m^3/h**	**Maximum height m**	**Capex, $k 200 m^3/h**	**2000 m^3/h**	**Opex $per 1000 m^3/h**	**Company formed**	**No. employees**
Unlimited**	5	9	3	500	1500	60	1989	8

Power requirement kW / 1000 m^3/ h	Additional services
10-18	NA

Comments * Dates projected by manufacturer
** An "in-tank" or batch process system unaffected by ballasting flow rate.

Supplier **Mitsui Engineering and Shipbuilding Co. Ltd.**
Process Hydrodynamic shear, cavitation and ozonation
System used Ballasting

Partner(s) JAMS; Marine Technology Institute; Laboratory of Aquatic, Science Consultant Co; Shinko Ind; M.O. Marine Consulting; Mitsui O.S.K. Lines.
Country Japan
Web site www.mes.co.jp

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commercially available	Units installed	Projected production Units/y
10/2006*	10/2010**	07/2009	02/2008	JAMS		2010	1	40-100
Capacity 1000 m^3/h	**Footprint, m^2 for unit capacity of: 200 m^3/h**	**2000 m^3/h**	**Maximum height m**	**Capex, $k 200 m^3/h**	**2000 m^3/h**	**Opex $per 1000 m^3/h**	**Company formed**	**No. employees**
0.3***	30	NA	2.8	NA	NA	NA	1917	3,700

Power requirement kW / 1000 m^3/ h	Additional services
70	Air and cool water

Comments *Basic approval MEPC 55
**Final approval projected for MEPC 61
***larger capacity may be possible

Supplier **NEI Treatment Systems LLC**
Process Deoxygenation + cavitation
System used Ballasting

Partner(s) Mitsubishi Kakoki Kaishi Ltd (Japan)
Samgong Co. (Korea)
Country US
Web site www.nei-marine.com

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commercially available	Units installed	Projected production Units/y
-	-	-	-	NOAA	10/2007	2006	6	200
Capacity 1000 m^3/h	**Footprint, m^2 for unit capacity of: 200 m^3/h**	**2000 m^3/h**	**Maximum height m**	**Capex, $k 200 m^3/h**	**2000 m^3/h**	**Opex $per 1000 m^3/h**	**Company formed**	**No. employees**
>10	3	6	2.6	249	670	130	1997	9
Power requirement kW / 1000 m^3/ h		**Additional services**						
30		Air and water						

Supplier **NK Co. Ltd.**
Process Ozonation
System used Ballasting

Partner(s) Nutech O_3[1]
Country Republic of Korea
Web site www.nkcf.com

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commercially available	Units installed	Projected production Units/y
07/2007*	07/2009*	2008	2008	KOMERI	11/2009	2008	4	400-700
Capacity 1000 m^3/h	**Footprint, m^2 for unit capacity of: 200 m^3/h**	**2000 m^3/h**	**Maximum height m**	**Capex, $k 200 m^3/h**	**2000 m^3/h**	**Opex $per 1000 m^3/h**	**Company formed**	**No. employees**
>10	20	40	2.5	250	1000	7	1980	500
Power requirement kW / 1000 m^3/ h		**Additional services**		Comments	* Basic approval MEPC 56; final approval MEPC 59 ** power consumption reduced 40-50% if service air already available			
>70 **		Air						

[1] Nutech O_3 and NK Co. Ltd. are independent companies, although their technologies are similar and share patents. Nutech O_3 will remain an independent company registered in USA after acquisition by NK Co. Ltd. and Nutech O_3 may apply to utilise IMO approval awarded to NK Co. Ltd.

Supplier **Nutech O_3**
Process Ozonation
System used Ballasting

Partner(s) NK Co., Ltd.[1]
Country US
Web site www.nutech-o3.com

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commercially available	Units installed	Projected production Units/y
						Late 2008	4	168
Capacity 1000 m^3/h	**Footprint, m^2 for unit capacity of: 200 m^3/h**	**2000 m^3/h**	**Maximum height m**	**Capex, $k 200 m^3/h**	**2000 m^3/h**	**Opex $per 1000 m^3/h**	**Company formed**	**No. employees**
>10	22	40	2	250	450	*	1997	4
Power requirement kW / 1000 m^3/ h		**Additional services**		Comments	* Manufacturer states "$0.007 per treatment"			
10		Air and water						

[1] Nutech O_3 and NK Co. Ltd. are independent companies, although their technologies are similar and share patents. Nutech O_3 will remain an independent company registered in USA after acquisition by NK Co. Ltd. and Nutech O_3 may apply to utilise IMO approval awarded to NK Co. Ltd.

Supplier **Oceansaver AS**
Process Filtration + deoxygenation + cavitation
System used Ballasting + discharging (filter and cavitation only)
Country Norway
Web site www.oceansaver.com

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commer-cially available	Units installed	Projected production Units/y
04/2008*	10/2008*	09/2008	11/2007	NIVA	04/2009	2008	6	>200
Capacity 1000 m³/h	**Footprint, m² for unit capacity of: 200 m³/h**	**2000 m³/h**	**Maximum height m**	**Capex, $k 200 m³/h**	**2000 m³/h**	**Opex $per 1000 m³/h**	**Company formed**	**No. employees**
0.5-5	**	**	**	288	1600	NA	2003	18

Power requirement kW / 1000 m³/ h	Additional services	Comments
NA	Cooling water	* Basic approval MEPC 57; final approval at MEPC 58 ** System footprint difficult to estimate, since several sub-components and the largest of these can be located anywhere

Supplier **Optimarin**
Process Filtration + ultraviolet
System used Ballasting + discharging (filter bypassed on discharging)
Country Norway
Web site www.optimarin.com

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commer-cially available	Units installed	Projected production Units/y
NR	NR	01/2009	05/2008	NIVA	11/2009	Yes	11	1000
Capacity 1000 m³/h	**Footprint, m² for unit capacity of: 200 m³/h**	**2000 m³/h**	**Maximum height m**	**Capex, $k 200 m³/h**	**2000 m³/h**	**Opex $per 1000 m³/h**	**Company formed**	**No. employees**
>20	2.91*	8.54*	1.94**/4.62**	290	1280	-	1995	10

Power requirement kW / 1000 m³/ h	Additional services	Comments
220	Air	* Installation may be suspended under deck for reduced footprint ** Service area for filter included

Supplier **Panasia Co Ltd Korea**
Process Filter and UV
System used Ballasting + discharging (filter bypassed on discharging)
Country Republic of Korea
Web site www.pan-asia.co.kr
www.GloEn-Patrol.com

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commer-cially available	Units installed	Projected production Units/y
04/2008*	03/2010**	10/2009	12/2008	KORDI	12/2009	2009	2	1400
Capacity 1000 m³/h	**Footprint, m² for unit capacity of: 200 m³/h**	**2000 m³/h**	**Maximum height m**	**Capex, $k 200 m³/h**	**2000 m³/h**	**Opex $per 1000 m³/h**	**Company formed**	**No. employees**
2	2.96	11.11	1.8	NA	NA	NA	1989	120

Power requirement kW / 1000 m³/ h	Additional services	Comments
120	Air	* Basic approval at MEPC 57 ** Final approval expected at MEPC 60

Supplier **Pinnacle Ozone Solutions**
Process Filtration + Ozonation
System used Ballasting + discharging (filter bypassed on discharging)
Country USA
Web site www.pinnacleozonesolutions.com

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commer-cially available	Units installed	Projected production Units/y
NR	NR	10/2011*	10/2011*	GSI		2011*		
Capacity 1000 m³/h	**Footprint, m² for unit capacity of: 200 m³/h**	**2000 m³/h**	**Maximum height m**	**Capex, $k 200 m³/h**	**2000 m³/h**	**Opex $per 1000 m³/h**	**Company formed**	**No. employees**
0.25 - 10	6	11		200	500	13		
Power requirement kW / 1000 m³/ h		**Additional services**		**Comments**	* Date projected by manufacturer			

Supplier **Qingdao Headway Technology Co Ltd.**
Process Filtration + electrocatalysis & ultrasound
System used Ballasting + discharging (filter bypassed on discharging)
Country China
Web site www.headwaytech.com

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commer-cially available	Units installed	Projected production Units/y
03/2010*	10/2010**	NA	10/2009*	NIVA	***	2009	1	2000
Capacity 1000 m³/h	**Footprint, m² for unit capacity of: 200 m³/h**	**2000 m³/h**	**Maximum height m**	**Capex, $k 200 m³/h**	**2000 m³/h**	**Opex $per 1000 m³/h**	**Company formed**	**No. employees**
>10	0.6	3	2.4	NA	NA	1.8	2005	150
Power requirement kW / 1000 m³/ h		**Additional services**		**Comments**	* Basic approval expected at MEPC 60 ** Final approval projected for MEPC 61 *** Target date of 12/2010.			
12		none						

Supplier **Qwater**
Process Filtration + ultrasound
System used Ballasting + discharging (filter bypassed on discharging)
Country US
Web site www.qwatercorp.com

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commer-cially available	Units installed	Projected production Units/y
NR	NR	NA	NA	NA		04/2009	0	NA
Capacity 1000 m³/h	**Footprint, m² for unit capacity of: 200 m³/h**	**2000 m³/h**	**Maximum height m**	**Capex, $k 200 m³/h**	**2000 m³/h**	**Opex $per 1000 m³/h**	**Company formed**	**No. employees**
NA	15	30	2.4	NA	NA	NA	2002	NA
Power requirement kW / 1000 m³/ h		**Additional services**						
NA		NA						

Supplier **Resource Ballast Technology / Unitor BWTS**
Process Cavitation, ozone, electrolysis and filtration
System used Ballasting
Parter(s) Wilhelmsen Ships Equipment AS (Norway)
Country South Africa
Web site www.resource-technology.com

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commercially available	Units installed	Projected production Units/y
04/2008*	03/2010**	2010	2010	Cape Town		2010	4	2000+
Capacity 1000 m³/h	**Footprint, m² for unit capacity of: 200 m³/h**	**2000 m³/h**	**Maximum height m**	**Capex, $k 200 m³/h**	**2000 m³/h**	**Opex $per 1000 m³/h**	**Company formed**	**No. employees**
0.2-4	2	4	2	275	700	NA	2001	6
Power requirement kW / 1000 m³/ h	**Additional services**	Comments	* Basic approval at MEPC 57 ** Final approval expected at MEPC 60					
13	NA							

Supplier **RWO GmbH, Veolia Water Solutions & Technologies (VWS)**
Process Filtration + EctoSys® (electrolysis / electrochlorination + AOP) (+ neutralisation in seawater)
System used Ballasting + discharging (filter bypassed on discharging)
Country Germany
Web site www.rwo.de

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commercially available	Units installed	Projected production Units/y
10/2006*	07/2009*	01/2010	09/2007 11/2008	Bremen 2007 NIVA 2008	03/2010**	2008	16	no limit
Capacity 1000 m³/h	**Footprint, m² for unit capacity of: 200 m³/h**	**2000 m³/h**	**Maximum height m**	**Capex, $k 200 m³/h**	**2000 m³/h**	**Opex $per 1000 m³/h**	**Company formed**	**No. employees**
0.1 >10	NA	NA	2.0	NA	NA	NA	NA	65
Power requirement kW / 1000 m³/ h	**Additional services**	Comments	*Basic approval given at MEPC 57; final at MEPC 59 ** Projected by manufacturer					
8 - 110	NA							

Supplier **Sea Knight Corporation**
Process Vacuum De-Oxygenation with Bio-Remediation
System used During Voyage and at discharge
Country US
Web site www.seaknight.net

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commercially available	Units installed	Projected production Units/y
10/2010*	06/2011*	-	-	Virginia	06/2011*	06/2011	0	No Limit
Capacity 1000 m³/h	**Footprint, m² for unit capacity of: 200 m³/h**	**2000 m³/h**	**Maximum height m**	**Capex, $k 200 m³/h**	**2000 m³/h**	**Opex $per 1000 m3/h**	**Company formed**	**No. employees**
**	**	**	1	165	275	NA	2006	13
Power requirement kW / 1000 m³/ h	**Additional services**	Comments	* Dates projected by manufacturer. ** Determined by vessel size. All equipment installed above the weather deck					
3								

Supplier **Severn Trent De Nora**
Process Filtration + electrolysis/electrochlorination + residual control
System used Ballasting (filter bypassed on discharging)
Country US
Web site www.severntrentservices.com/denora

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commer-cially available	Units installed	Projected production Units/y
03/2010*	10/2010*	12/2010**	07/2009	NIOZ+MERC	02/2011**	2010	2	700
Capacity 1000 m³/h	**Footprint, m² for unit capacity of: 200 m³/h**	**2000 m³/h**	**Maximum height m**	**Capex, $k 200 m³/h**	**2000 m³/h**	**Opex $per 1000 m³/h**	**Company formed**	**No. employees**
>10	8.7	12.4	3	550/80***	750/225***	20	1923	1500

Power requirement kW / 1000 m³/ h	Additional services	Comments
72	none	* Basic approval expected at MEPC 60 ** Projected by manufacturer *** Cost of BalPure / Cost of filter

Supplier **Siemens**
Process Filtration + electrochlorination
System used Ballasting
Country USA, UK, Germany
Web site www.siemens.com/sicure

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commer-cially available	Units installed	Projected production Units/y
03/2010*	06/2011**	02/2011**	04/2010**	GSI & MERC	2011**	2010		
Capacity 1000 m³/h	**Footprint, m² for unit capacity of: 200 m³/h**	**2000 m³/h**	**Maximum height m**	**Capex, $k 200 m³/h**	**2000 m³/h**	**Opex $per 1000 m³/h**	**Company formed**	**No. employees**
0.2 - >10	9	23	2.2 (3.1)	500	1000	8.5 - 10***	1847	400,000

Power requirement kW / 1000 m³/ h	Additional services	Comments
60-80	Instrument air	* Basic approval expected at MEPC 60 ** projected by manufacturer *** based on HFO (IFO180) price of 480 US$/ton

Supplier **Techcross**
Process Electrolysis
System used Ballasting
Country Republic of Korea
Web site www.techcross.net

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commer-cially available	Units installed	Projected production Units/y
03/2006*	10/2008*	08/2007	08/2007	KORDI	12/2008 09/2009**	2007	13	1200
Capacity 1000 m³/h	**Footprint, m² for unit capacity of: 200 m³/h**	**2000 m³/h**	**Maximum height m**	**Capex, $k 200 m³/h**	**2000 m³/h**	**Opex $per 1000 m³/h**	**Company formed**	**No. employees**
>10	4.5	11	2.0	200	600	3***	2000	60

Power requirement kW / 1000 m³/ h	Additional services	Comments
60 (seawater) 100 (freshwater)	NA	* Basic approval given at MEPC 54; final at MEPC 57 **Explosion proof Type approval certificate *** Fuel costs

Supplier **TG Corporation**
Process Filtration + chlorination + mixing / agitation
System used Ballasting + discharging (filter bypassed on discharging)
Parter(s) JFE Engineering Corporation
Country Japan
Web site www.toagosei.co.jp

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commercially available	Units installed	Projected production Units/y
10/2008*	03/2010**	09/2009	03/2009	NIVA	03/2010***	Spring, 2010	1	300
Capacity 1000 m³/h	**Footprint, m2 for unit capacity of: 200 m³/h**	**2000 m³/h**	**Maximum height m**	**Capex, $k 200 m³/h**	**2000 m³/h**	**Opex $per 1000 m³/h**	**Company formed**	**No. employees**
3.5	5	8	2.6	NA	NA	53****	1975	1500

Power requirement kW / 1000 m³/ h	Additional services
3.0	water

Comments
* Basic approval at MEPC 58
** Final approval expected at MEPC 60
*** Projected by manufacturer
**** Chemical costs ex factory

Supplier **Vitamar, LLC**
Process Menadione / Vitamin K3 (as Seakleen™)
System used Ballasting
Country US
Web site www.seakleen.com

Active substance approval (if applicable) Basic	Final	System approval Shipboard	Landbased	Test site	Type approval certificate	Commercially available	Units installed	Projected production Units/y
2010*	2011*	2011*	2011*	NA	2012*	2012/13	0	NA
Capacity 1000 m³/h	**Footprint, m2 for unit capacity of: 200 m³/h**	**2000 m³/h**	**Maximum height m**	**Capex, $k 200 m³/h**	**2000 m³/h**	**Opex $per 1000 m³/h**	**Company formed**	**No. employees**
>10	0.25	1.0	2	NA	NA	NA	1999	5

Power requirement kW / 1000 m³/ h	Additional services
NA	NA

Comments
* Dates projected by manufacturer

Glossary of terms and abbreviations

Ballast water treatment technology

Technologies

AOP	Advanced oxidation
Cav	Cavitation
Cl	Chlorination
Clarif	Clarification
ClO_2	Chlorine dioxide
Coag	Coagulant (with magnetic particles)
Deox	Deoxygenation
EL/EC	Electrolysis/electrochlorination
Filt	Filtration
HC	Hydrocyclone
O_3	Ozonation
PAA	Peracetic acid (as Peraclean)
Red	(Chemical) Reduction
SK	Seakleen
US	Ultrasonic treatment
UV	Ultraviolet irradiation

Terms

capex	Capital expenditure
opex	Operating expenditure

Organisations, test sites

AISA	Agricultural Institute of South Africa
AWI	Alfred Wegener Institut
FDA	Federal Drug Administration
GSI	Great Ships Initiative
JAMS	Japan Association of Marine Safety
KOMERI	Korea Marine Equipment Research Institute
KORDI	Korean Ocean Research and Development Institute
MERC	Maritime Environmental Resource Centre
MLML	Moss Landing Marine Laboratories
MWB	Motorenwerke Bremerhaven
NIOZ	Royal Netherlands Institute for Sea Research
NIVA	Norwegian Institute for Water Research
SAMSA	South African Department of Transport
SIO	Scripps Institution of Oceanography
USEPA	US Environment Protection Agency
USCG	US Coast Guard
USNOAA	US National Oceanic and Atmospheric Administration
USNRL	US Naval Research Laboratory
NA	Information not available or not made available
ND	Not determined by the supplier

Lloyd's Register EMEA
T +44 (0)20 7709 9166
F +44 (0)20 7423 2057
E emea@lr.org

71 Fenchurch Street
London EC3M 4BS
UK

Lloyd's Register Asia
T +852 2287 9333
F +852 2526 2921
E asia@lr.org

Suite 3501
China Merchants Tower
Shun Tak Centre
168–200 Connaught Road Central
Hong Kong
SAR of PRC

Lloyd's Register Americas, Inc.
T +1 (1)281 675 3100
F +1 (1)281 675 3139
E americas@lr.org

1401 Enclave Parkway
Suite 200
Houston
Texas 77077
USA

www.lr.org

February 2010

LIFE MATTERS

Density Matters:

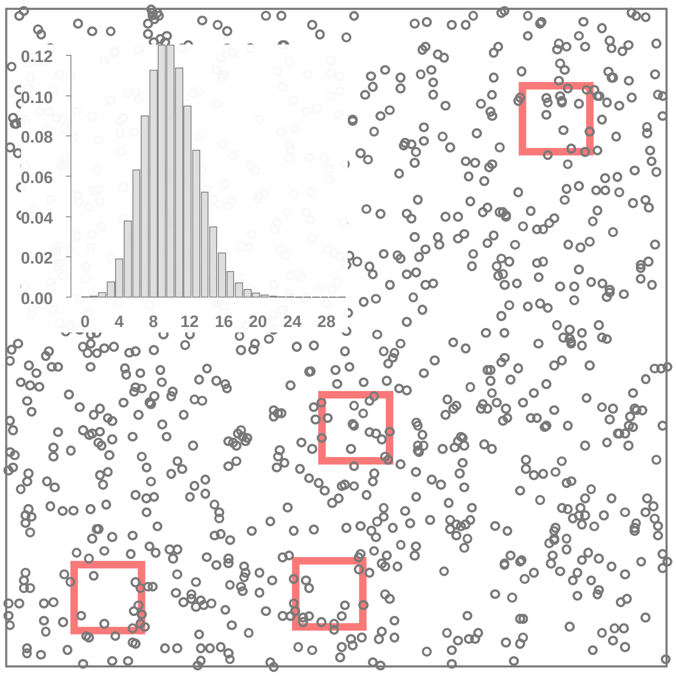
Review of Approaches to Setting Organism-Based Ballast Water Discharge Standards

Henry Lee II[1]

Deborah A. Reusser[2]

Melanie Frazier[1]

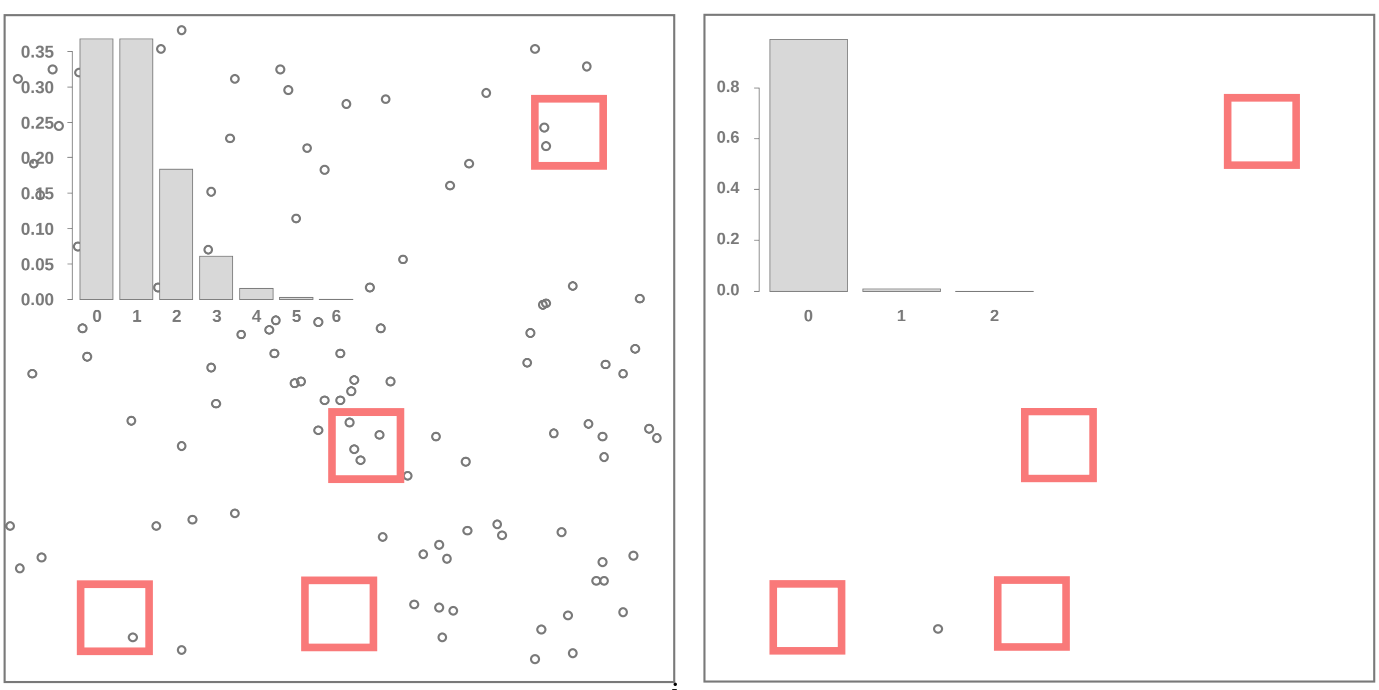
Greg Ruiz[3]



1: Western Ecology Division,
National Health and Environmental Effects Research Laboratory,
Office of Research and Development,
U.S. Environmental Protection Agency,
2111 SE Marine Science Drive,
Newport, OR 97365, U.S.A.

2: U.S. Geological Survey,
Western Fisheries Research Center,
2111 SE Marine Science Drive,
Newport, OR 97365, U.S.A.

3: Marine Invasion Research Laboratory,
Smithsonian Environmental Research Center,
647 Contees Wharf Road, P.O. Box 28,
Edgewater, MD 21037, U.S.A.



Acknowledgements:
The authors wish to thank the following for their contributions to this report: M.S. Minton, P.W. Fofonoff, and A.W. Miller provided data on ballast water discharge and historical invasion rates and insights into their interpretation. Richard Everett, John Lishman, and Ryan Albert provided guidance through the intricacies of IMO, national, and state regulations; Cheryl A. Brown provided advice on mathematical issues; John Van Sickle provided advice on statistical issues. Richard Everett, John Lishman, Ryan Albert, John Van Sickle, Nathan H. Schumaker, Scott Smith, Jody Stecher, Katharine Marko, and Robert J. Ozretich reviewed an earlier version of this document and provided insightful suggestions. Deborah Reusser was partially funded through AMI/GEOSS IAG #DW-14-92231501-0 from the U.S. EPA. Melanie Frazier was funded through AMI/GEOSS EP08D00051.

Preferred Citation: Lee II, H., Reusser, D.A., Frazier, M., and Ruiz, G. 2010. Density Matters: Review of Approaches to Setting Organism-Based Ballast Water Discharge Standards. U.S. EPA, Office of Research and Development, National Health and Environmental Effects Research Laboratory, Western Ecology Division. EPA/600/R-10/031.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

As one of the major vectors by which invasive species invade the coastal waterbodies and the Great Lakes, ballast water discharges from ocean-going ships are a major environmental threat to the Nation's waters. Recognizing the importance of ballast water as a vector for invasive species on a global scale, in February 2004 the text of an international ballast water treaty was negotiated through the International Maritime Organization (IMO). The IMO has proposed organism-based ballast water discharge standards for different size classes of organisms (Table ES-1). While this represents a major accomplishment, there is concern that the IMO standards are not sufficiently protective. Accordingly, the United States Coast Guard (USCG) just released proposed Phase I (equal to the IMO standards) and Phase II (1000 more stringent then the IMO standards) standards for the waters of the United States (Table ES-1). Additionally, California and other states have implemented or have proposed state standards more stringent than those proposed by the IMO (Table ES-1).

Historically, the EPA had excluded discharges incidental to the normal operation of vessels (including ballast water) from the need to obtain an NPDES permit. However, that exclusion from the NPDES permitting program was successfully challenged in court, and as a result, was vacated by the U.S. District Court for the Northern District of California. In light of the court decision, in December 2008 EPA issued a general NPDES permit (known as the "Vessel General Permit" or "VGP") that contains, among other things, standards for ballast water discharges from non-recreational vessels. The Office of Water currently is undertaking development of organism-based discharge standards for ballast water discharges for use in the future reissuance of the VGP. To help ensure it uses a scientifically sound approach in that effort, the Office of Water is seeking an objective and independent scientific opinion on approaches for deriving these standards and has requested that a National Academy of Sciences (NAS) expert panel evaluate the technical merits of approaches to generating the standards.

To assist the NAS technical review, this report evaluates the potential approaches to generating national organism-based discharge standards. Because of data available, we focus on the >50 micron organism class in our review. On the basis of ecological principles we identified six previous approaches to developing standards and developed a new one, the per capita invasion probability approach, which is described here. The approaches are:

1) Reduction in Propagule Supply Based on Expert Opinion/Management Consensus
2) Zero Detectable Living Organisms
3) Natural Invasion Rates
4) Reaction-Diffusion Models
5) Population Viability Analysis (PVA) Models
6) Per Capita Invasion Probability
7) Experimental Studies

Although not an approach to setting standards per se, sampling issues need to be considered when assessing the practicality of verifying that a discharge standard has been met either in test facilities for purposes of regulatory approval of a treatment system or as part of compliance monitoring of vessel discharges. Additionally, the sampling protocol, particularly the volume of

Table ES-1: Existing or proposed international and national ballast water discharge standards applicable to the waters of the United States and examples of state standards. All organism dimensions are for the "minimum dimension". Standards for the >50 micron and >10 - ≤50 micron classes are for "viable" or "living" organisms. Note that Phase II of the Coast Guard standard can be implemented incrementally. The date for the implementation of the final California standard is 2020. The California standards are instantaneous standards while those for Wisconsin are daily averages. NPRM = Notice of proposed rule making. IMO = International Maritime Organization. cfu = "colony forming units"

Organism Class	IMO D-2 Standard	USCG NPRM Phase I	USCG NPRM Phase II	WI State Standard	CA Interim Standards	CA Final Standard
Organisms >50 microns	<10 per m^3	<10 per m^3	<1 per 100 m^3 (< 0.01 per m^3)	<1 per 10 m^3 (<0.1 per m^3)	"No detectable living organisms"	"Zero detectable living organisms"
Organisms >10 - ≤50 microns	<10 per ml	<10 per ml	<1 per 100 ml (<0.01 per ml)	<1 per 10 ml (<0.1 per ml)	≤1 per 100 ml (<0.01 per ml)	"Zero detectable living organisms"
Organisms ≤10 microns	No standard	No standard	<10^3 bacteria/100 ml <10^4 viruses/100 ml	No standard	< 10^3 bacteria/100 ml < 10^4 viruses/100 ml	"Zero detectable living organisms"
Escherichia coli	<250 cfu per 100 ml	<250 cfu per 100 ml	<126 cfu per 100 ml	<126 cfu per 100 ml	<126 cfu per 100 ml	"Zero detectable living organisms"
Intestinal enterococci	<100 cfu per 100 ml	<100 cfu per 100 ml	<33 cfu per 100 ml	<33 cfu per 100 ml	<33 cfu per 100 ml	"Zero detectable living organisms"
Toxicogenic *Vibrio cholerae* (serotypes O1 and O139)	<1 cfu per 100 ml or 1 cfu per g wet wt. zooplankton	<1 cfu per 100 ml	<1 cfu per 100 ml	No standard	<1 cfu per 100 ml or <1 cfu per g wet zoological sample	"Zero detectable living organisms"

water sampled, defines the actual risk level associated with any standard based on "zero detectable living organisms". Accordingly, we address the statistical considerations of the volume of water that needs to be sampled when estimating the concentrations of organisms in ballast water discharges.

The potential utility and limitations of each of the approaches to generating national discharge standards is briefly discussed below and summarized in Table ES-2.

Reduction in Propagule Supply Based on Expert Opinion/Management Consensus: Several of the proposed discharge standards, including the IMO standards, were based on a combination of expert opinion and management consensus. As used here "expert opinion" refers to technical recommendations for ballast water standards from experts in the areas of invasion biology and related life sciences made without the explicit use of a quantitative invasion model. "Management consensus" is used to capture decisions made utilizing this expert opinion in additions to inputs from experts in other disciplines, such as shipping and engineering, risk managers, as well as state, national, non-governmental organization (NGO), and industry representatives. Thus, management consensus decisions in the "real world" incorporate components of risk assessment, risk management, and lobbying.

The major advantage of expert opinion is that it is possible to address complex issues even with limited data and in the absence of quantitative models, which then can be evaluated in a risk management context. Expert opinion/management consensus was successful in generating the IMO organism-based standards despite the uncertainties in the invasion process itself and the politics inherent in any international treaty. This was a "watershed" accomplishment and a critical step toward reducing new invasions via ballast discharges. The question remains, however, as to whether the IMO standards are sufficiently protective. In part, this question arises because the expert opinion/managerial consensus approach does not allow a rigorous evaluation of the process or how the final decisions were reached. In light of these limitations and the continued increase in our scientific understanding, we recommend that future development of standards rely more heavily on quantitative models than qualitative expert opinion. If expert opinion is used as a major input into the development of national standards, we suggest that a formal process be used to reduce the limitations or biases of expert opinion. Additionally, we suggest that experts in a diverse range of biological, shipping, and engineering fields be consulted.

Zero Detectable Living Organisms: California and other states have adopted or proposed standards with the goal of "zero detectable living organisms" in ballast water discharges. California's standards will be adopted in two phases, with an interim standard of "no detectable living organisms" >50 microns in ballast discharged from ships constructed in 2010 to 2012 and a final standard in 2020 of "no detectable discharge" of zooplankton, phytoplankton, protists, bacteria, or viruses in ballast discharges for ships constructed beginning in 2020 (Table ES-1). The stated rationale for the California standard was "The scientific basis for a standard of discharging no exotic organisms is that exotic organisms, unlike conventional chemical pollutants, can reproduce and increase over time, persist indefinitely and spread over large regions. Thus, very large, widespread and long-term impacts could potentially result from the discharge of a small number of individual organisms — in some cases as few as a single mated"

Table ES-2: Comparison of approaches to generate national, organism-based discharge standards for >50 micron organisms in ballast discharges. Assessment is based on current implementation; potential modifications are identified when appropriate. "Reality check" is used to denote that the approach could be used to help evaluate whether predictions from other approaches fall within a realistic range. "Recommend for national standard development" is our assessment of whether the approach should be considered for generating quantitative organism-based discharge standards at the national level.

Approach / Attribute	**Expert Opinion / Management Consensuses**	**Zero Detectable Organisms**	**Natural Invasion Rate**	**Reaction – Diffusion**	**Population Viability Analysis**	**Per Capita Invasion Probabilities**	**Experimental**
Current implementation generates quant. standards	Yes	Yes	Yes (prelim. for CA)	No (volume based)	No (relative comparison)	Yes	No
Apparent range of uncertainty in standard	10,000 fold (range of conc. proposed in IMO negotiations – 0.01 to 100 org m^{-3})	10,000 fold (upper possible conc. w/1L vs. 10 m^3 sample)	100-fold (3 experts) or 10,000-fold (our analysis)	About 200 fold (approx. range in "max. safe release volumes")	<2 fold (w/12 spp. in ballast) to 10,000 fold (multiple voyages – our analysis)	6-fold (among coasts) or 12-fold (w/Great Lakes)	NA
Key data needs for generation of quant. standards	Unknown since decision process not transparent	Development of statistically rigorous sampling protocol	Natural invasion rates in range of ecoregions	Instantaneous population growth rates for a range of taxa	Instantaneous population growth rates & instantaneous variance of the population growth rate for a range of taxa	None	Extensive experimentation w/range of taxa
Assumes linear dose response	Unknown since decision process not transparent	NA (does not assume a dose response)	Yes	No	No	Yes	NA (does not assume a dose response)
Incorporates invasion risk from multiple species in a discharge	Yes?	Yes	Yes	No?	Yes	Yes	No
Incorporates invasion risk from multiple ship discharges	Yes?	Yes	Yes	No	No (modify to incorporate multiple ships?)	Yes	No
Based on historical invasion rates	No	No	Yes	No	No	Yes	No
Based on population dynamics	No	No	No	Yes	Yes	No	Yes

Approach / Attribute	Expert Opinion / Management Consensuses	Zero Detectable Organisms	Natural Invasion Rate	Reaction – Diffusion	Population Viability Analysis	Per Capita Invasion Probabilities	Experimental
Applicable to all taxa and guilds	Yes?	Yes	Yes? (depends on taxa included in analysis)	No (limited to short-lived holoplanktonic species)	Yes? (depends upon which species the pop. data can be obtained)	All	No (limited to taxa adaptable to experiments)
Separates risk assessment from risk management	No	No?	Yes	Yes	Yes	Yes	Yes
Published in peer-reviewed scientific literature	No	No	No	Yes (extensive literature on reaction-diffusion models)	No (extensive literature on PVA models)	No (in process)	Yes (individual experiments)
Recommended for national standard development	No (use as “reality check”)	No	No (possible use as “reality check”)	No (use as “reality check” for holoplanktonic species)	Yes (if sufficient pop. data available for predictions of actual vs. relative risk)	Yes	No (use as “reality check” and test assumptions)

pair, or in the case of asexually-reproducing species, a single individual. From this perspective, the only biologically safe standard is no discharge of exotic organisms.

While it sounds protective, the zero detectable organism standards suffer from several technical limitations. The first is that unless the entire ballast water discharge is sampled, it has to rely on samples of the discharge, and the degree of protection depends directly on the sampling protocol. If a small volume is used to evaluate whether the discharge meets the standard, the sample may contain zero detectable organisms, but the true concentration of organisms may be quite high. For example, even with a relatively high concentration of 100 organisms m^{-3}, only about 10% of 1 L samples will contain one or more organisms. The general point is that more organisms may be released in ballast discharge using a stringent standard paired with a poor sampling protocol than a more lenient standard paired with a stringent sampling protocol.

The second limitation is the feasibility of developing ballast water treatment systems that can remove all organisms while operating within the constraints of a ship. It is beyond the purview of this report to evaluate ballast water treatment systems; however, we did assess California's review of existing treatment systems. They rated a system as having "potential" if no organisms were detected in a laboratory, land-based, or ship-based test if "at least one replicate in compliance with the performance standards". In other words, a system was considered to have "potential" as long as it did not fail the standard in 100% of the replicates. A reanalysis of the data summarized by California showed that with the exception of one system (SeaKleen®), all systems failed a moderate to high percentage of the replicates and/or they were not tested in all three modes (laboratory, land-based, and shipboard testing). While the results for SeaKleen® are promising, the extent of testing does not meet the minimum IMO requirements under their G8 guidelines and it has not been registered by EPA for use in treating ballast water under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). The general point is that approved treatment systems capable of removing all larger (>50 micron) organisms are not likely to be available in the near term, much less systems that can remove all microbes and viruses.

Because of these various issues, we recommend that the zero detectable discharge standard approach not be used at the national level. If, however, zero detectable standards are considered at the national level, it is critical to define the sampling protocols to be used to verify ballast water treatment systems and in compliance monitoring. Without this information, the meaning of the standard is undefined, making it impossible to assess the actual risk or to enforce it in a scientifically defensible fashion.

<u>Natural Invasion Rates:</u> The natural invasion rate approach was proposed by Dr. Andy Cohen in an August 7, 2005, memo to the California Ballast Water Treatment Standards Committee. As noted by the California State Lands Commission, "this approach is based on numerous assumptions that create a high level of uncertainty for its application to performance standards that will have regulatory impacts." Because of these uncertainties, California did not use the natural invasion rate approach to set their state standards. Nonetheless, the natural invasion rate approach is worth examining since it addresses generating ballast water discharge standards in a novel way.

The rationale for the natural invasion rate approach is that marine/estuarine ecosystems are subject to a very small natural rate of invasion from rare events when species drift or raft across oceans and then become established in new locations. A ballast water discharge standard that resulted in an invasion rate approximately equal to the natural rate would be "reasonably close to the natural rate and possibly within the normal range of variation, and thus would be reasonably protective of the environment." To generate a discharge standard from natural invasion rates, four parameters are needed: 1) natural invasion rate; 2) historical invasion rate from ballast discharges; 3) organism concentrations in ballast water; and 4) speciation rate. Of the four parameters, the major limitation is estimating the natural invasion rate with any degree of certainty; indeed, three invasion experts at the California meeting differed by 100-fold in the their estimates of this rate. Our analysis suggests that the full range of uncertainty could be as much as 10,000 fold in the standards depending upon estimates of ballast water organism concentrations, whether additional taxa are included in the analysis, and whether natural invasions from other areas in the North West Pacific region are considered. Additionally, our analysis of the literature indicated a much greater genetic exchange across the Pacific than suggested by the low estimates of natural invasion rates in the Cohen analysis. Because of these uncertainties, we do not believe the natural invasion approach is suitable for the development of national ballast water discharge standards.

Reaction-Diffusion Models: Reaction-diffusion models predict the concentration of a "substance" that is simultaneously influenced by diffusion which dilutes it and by some type of reaction affecting its concentration. The basic assumptions of this family of models in terms of invasions are: 1) they model continuous time and space; 2) there is local random movement of individuals; and 3) population dynamics are deterministic. When applied to ballast water, the two competing processes are the dilution of the ballast water containing the introduced organisms, which rarefies the populations, and the population growth rate of the organisms in the ballast discharge. If the dilution of the species is too fast, the population goes extinct.

The primary use of reaction-diffusion models in invasion biology has been the theoretical analysis of the pattern of invasion spread of terrestrial invaders. The only published example of a reaction-diffusion model applied to ballast water is that of Drake et al. (2005). Using changes in relative population densities, Drake et al. (2005) predicted the maximum safe volume of ballast water that could be exchanged. Because these predictions are volume based, they can not be used to generate organism-based standards. On a more general level, our analysis indicates that violation of the assumption that species are passively distributed is likely to result in a substantial underestimation of the likelihood of establishment of a species. In particular, benthic species whose larval and/or juvenile phases actively settle out of the water column are much more likely to become established than predicted from dilution models. Thus, in aquatic environments, diffusion models are primarily limited to predicting invasions of small, holoplanktonic organisms, such pelagic copepods. Because of this limitation, diffusion models do not appear to be suitable for generating concentration-based discharge standards applicable to the wide range of taxa found in ballast water.

Population Viability Analysis (PVA) Models: Population viability analysis (PVA) models are a family of population growth models commonly used to predict the extinction probability of endangered species. The basic premise of PVA models is that any population undergoing stochastic growth has a certain probability of going extinct even if it is presently showing positive growth. In general, the smaller the population size, the slower the population growth rate, or the larger the variation in population growth rate, the greater the probability of extinction. When used with nonindigenous species, the objective is to predict either the time to extinction or the probability of extinction for an invader, where extinction is the converse of establishment of a new invader.

A PVA model was used in the USCG Draft Programmatic Environmental Impact Statement (DPEIS), which we reviewed in detail because it is part of the technical analysis used by the USCG in setting their proposed rules and because it is the only study that has used a PVA model to address generating ballast water standards. The key parameters that need to be estimated in the form of the PVA model used in the DPEIS are the instantaneous population growth rate, instantaneous variance of the population growth rate, and the critical population density (the threshold at which the population is considered "extinct"). The strategy taken in the DPEIS was to evaluate different discharge standards by predicting the relative increase in the probability of extinction based on the fractional reductions in the number of organisms per cubic meter of ballast discharge among the different standards. This is a relative approach and as such does not generate organism-based discharge standards. The PVA analysis was conducted both for single species and for multiple species in a ballast discharge, though we contend that the latter, which predicts the risk of any invasion occurring from a discharge, is the more ecologically relevant analysis.

A potentially confusing strategy in the DPEIS was to compare relative decreases in organism concentrations resulting from different standards to the full range of organism concentrations found in unmanaged ballast water and ballast water after exchange. In several cases, the use of these extreme ranges obscured the long-term benefits from reducing organism concentrations. Our reanalysis suggests that the relative reduction in risk was greater than indicated by some of the analyses in the DPEIS. Additionally, values for several of the parameters in the DPEIS were not well justified. For these reasons, and because the analysis was based on relative risks among treatment alternatives, we suggest that the DPEIS analysis should not be used to generate new national standards. However, versions of PVA models that predict actual (vs. relative) risk of invasion may be a viable approach to generating organism-based standards. The limitation to developing such models is the lack of instantaneous population growth rates and the instantaneous variances of the growth rates for a range of taxa. While it may be possible to estimate instantaneous population growth rate through various methods, long-term population studies are needed to estimate the instantaneous variance of the population growth rate. To assist in generating these population vital rates, we identify a number of sources summarizing long-term population studies with marine/estuarine organisms. If new PVA are used to generate new national standards, a comprehensive sensitivity analysis should be conducted. In particular, a range of instantaneous growth rates and instantaneous variances in growth rate should be explored, with the ranges based on an extensive review of population dynamics.

Per Capita Invasion Probability: During the process of generating this synthesis, the authors developed a new method of generating ballast water discharge standards that appears to resolve many of the limitations associated with the other approaches. Based on the general consensus that an increase in propagule supply increases the likelihood of invasion, we developed a "per capita invasion probability" (PCIP) approach to estimate the likelihood of invasion based on historical invasion rates and calculated ballast-associated propagule pressure. The PCIP is the per year probability that an individual non-native propagule discharged from ballast water will become established as a new nonindigenous species in a specified waterbody. Using a linear dose response assumption, the PCIP is calculated from the historical number of potential ballast-mediated invasions in a specified waterbody over a defined time period, the average annual total ballast discharged at that location during this time period, and the estimated organism concentration in the discharged ballast water. Once a PCIP is calculated from historical data, it can be used to predict the rate of new ballast-associated invasions in a waterbody with a projected ballast discharge volume and organism concentration. By altering the organism concentration, it is possible to generate risk scenarios predicting the number of new invaders for different discharge standards.

Historical invasion rates were estimated for the period from 1986 to 2005 and ballast discharge rates were obtained from the National Ballast Information Clearinghouse for 2005 to 2007, which represent the most complete records after mandatory ballast water reporting was instituted. A distribution of organism concentrations in unmanaged ballast water was obtained from published estimates and a simulation conducted to predict a range of possible organism concentrations. Using these inputs, an analysis was conducted for the East, Gulf, and Pacific coasts of the coterminous United States as well as for 17 individual coastal estuaries. In addition, a preliminary analysis was carried out for the Great Lakes. Predictions across individual estuaries showed high variation, possibly due to secondary invasions from other estuaries or ports. The three coast-wide estimates, which eliminate the uncertainty with secondary invasions, showed only a 6-fold variation even with the large differences in environments, donor regions for invaders, and intensity of nonindigenous species surveys. Risk diagrams were then constructed that illustrate the relationship of the likelihood of invasion to organism concentrations and ballast water discharge volumes, which allow risk managers to assess the risk with different discharge standards and safety factors.

As with any method, the per capita invasion rate approach makes a number of assumptions. The approach may underestimate the risk of invasion from asexual and parthenogenic species. It also assumes no change in the invasion potential of new invaders or in the invasibility of a specific waterbody over time. These types of uncertainties can be addressed by risk managers by adding a safety factor to the predictions. Because this approach is based on relatively well-known input values and allows risk managers to generate organism-based standards, we recommend that the per capita invasion probability be considered for the development of national standards.

Experimental Studies: Laboratory and field experiments can be used to quantify the likelihood of invasion under controlled environmental conditions and dosing scenarios. Over the last decade both the number and sophistication of such experiments have increased using both freshwater and marine organisms. However, we conclude that it is impractical to derive discharge standards from laboratory or field experiments because of the: 1) impracticality of adequate replication to quantify rare events; 2) limitation in the number and types of species than can be experimentally manipulated; and 3) artificiality and simplification of laboratory experiments and, to a lesser extent, field experiments. The real power of these experiments is to advance the theory of propagule supply and to evaluate and parameterize different types of population models.

Statistical Considerations in Estimating Concentrations of Organisms in Ballast Discharges: The stringent discharge standards that have been proposed will require estimating very small concentrations of organisms in ballast water. At these low densities, very large volumes of water must be sampled to find enough organisms to begin to estimate the actual concentration. To assess the requirements for a statistically rigorous sampling protocol, we assumed a random (Poisson) distribution of organisms in a set of samples. We then calculated the upper possible concentration (UPC) of organisms based on one-tailed 95% confidence intervals when zero organisms are detected in a range of sample volumes. For a 1 L sample with no organisms, the UPC was almost 3000 organisms m^{-3} while for a 10 m^3 sample the UPC was 0.3 organisms m^{-3}. Thus, even if no organisms are detected in a very large sample (10 m^3), the actual concentration could be 30 times greater than the USCG Phase II standard of 0.01 m^{-3}. As large as these volumes are, they likely underestimate the volumes needed if the organisms are aggregated or clumped.

Based on our analysis, it is apparent that instituting standardized sampling protocols is a critical component of implementing ballast discharge standards. One possible strategy is to require the large sample sizes required for high statistical power during the validation of treatment systems, in particular with land-based testing facilities. Practical considerations may limit the role of compliance monitoring to detecting gross violations, though detection of poor performing ships would be improved if there was a global repository of compliance test results for individual ships so as to track compliance over time with multiple samples. It is important to note that these analyses assume that the goal of discharge standards is to directly regulate the concentration of organisms in ballast discharges using "average based sampling". However, if "maximum instantaneous" discharge standards are used, then additional statistical factors must be considered because the results will be very sensitive to the sample number and volume.

I. INTRODUCTION

Henry Lee II

Objectives and Scope of Report:
The U.S. Environmental Protection Agency (EPA) is currently evaluating organism-based ballast water discharge standards (= performance standards or effluent limits), where organism-based standards are based on the concentrations of viable organisms in the discharged ballast water. To support this effort, the objectives of this report are to: 1) summarize approaches that have been used or proposed to establish organism-based ballast water discharge standards that prevent and/or protect aquatic ecosystems from ballast mediated invasions and 2) assess the potential utility and limitations of these methods. While not an original objective, during the process of synthesizing these approaches we developed an approach to the generation of discharge standards that we believe offers a practical alternative (Section VIII: Per Capita Invasion Probabilities). The purpose of our review is to provide the technical background for the U.S. EPA and a National Academy of Sciences (NAS) expert panel to evaluate the technical merits of approaches to generating effluent limits for living organisms in ballast water discharges. The review focuses on organisms $\geq$50 microns, which includes most holoplanktonic organisms (e.g., calanoid copepods), pelagic species such as fishes, and larval stages of benthic organisms. We focus on this size class because most of the theoretical, empirical, and experimental studies have focused on these larger organisms. To the extent possible, we assess whether an approach is potentially applicable to organisms in the 10-50 micron size class, such as phytoplankton and protozoa. The human health endpoints for microbes and viruses are beyond the scope of this document but a brief overview of the approach used to establish microbial ballast water standards is given in Appendix A. We also do not review the efficacy or practicality of various ballast water treatment systems, which have been addressed elsewhere (e.g., Lloyd's Register, 2008; Gregg et al., 2009).

On the basis of ecological principles, we identified seven general approaches to generating organism-based ballast water discharge standards for organisms >50 microns, each of which is evaluated:

1) Reduction in Propagule Supply Based on Expert Opinion/Management Consensus
2) Zero Detectable Living Organisms
3) Natural Invasion Rates
4) Reaction-Diffusion Models
5) Population Viability Analysis (PVA) Models
6) Per Capita Invasion Probability
7) Experimental Studies

Although not an approach to setting standards per se, sampling issues need to be considered when assessing the practicality of verifying that a discharge standard has been met either in test facilities for purposes of regulatory approval of a treatment system or as part of compliance monitoring of vessel discharges. As discussed in Section IV, the sampling protocols define the actual risk levels associated with the "zero detectable living organisms" approach. Accordingly, we address the statistical considerations of the volume of water that needs to be sampled when estimating the concentrations of organisms in ballast water discharges.

Niche or species distribution models that predict the potential distribution of species based on environmental conditions are not considered. While these models can be used to predict current and future distributions of an individual non-native species after it has invaded (e.g., Peterson and Vieglais, 2001; Herborg et al., 2007; Reusser and Lee, 2008), they do not address the likelihood of invasion via ballast water discharges.

Nonindigenous Species Background:
Introductions of nonindigenous species (NIS)[1], also known as aquatic nuisance species (ANS), are recognized as one of the major environmental stressors in freshwater and marine/estuarine ecosystems. Examples of individual invasive species having deleterious impacts on aquatic systems include the zebra mussel (*Dreissena polymorpha*) in the Great Lakes and other freshwater systems (Drake and Bossenbroek, 2004) and the European green crab (*Carcinus maenas*) on both the Atlantic and Pacific coasts (Carlton et al., 2003). Other indicators of the prevalence of nonindigenous species are their dominance in benthic communities in the San Francisco Estuary (Lee et al., 2003) and the large number of invaders found on the East, Gulf, and Pacific coasts of the United States (e.g., Ruiz et al., 2000; Wonham and Carlton, 2005). It is beyond the scope of this document to review the effects of nonindigenous species on aquatic systems, and the reader is referred to previous reviews on the ecological, human health, and economic impacts of invasive species (e.g., McMichal and Bouma, 2000; Pimentel et al., 2005; Lodge et al., 2006). Additionally, implications of invasions of nonindigenous species on the ability of the EPA to achieve its environmental goals and mandates as of 2000 were reviewed by Lee and Chapman (2001).

Nonindigenous species can potentially invade aquatic systems through a variety of mechanisms (Ruiz and Carlton, 2003). Of these potential routes, shipping, including both ballast water discharges and hull fouling, is the primary vector for biological invasions in the Great Lakes (Duggan et al., 2003) and most marine/estuarine ecosystems (Ruiz and Carlton, 2003; Hewitt et al., 2009) with the notable exception of the Mediterranean where Lessepsian invasions through the Suez canal is the major invasion mechanism (Galil and Zenetos, 2002). In the past century, the increase in shipping traffic as well as the reduced time for transoceanic voyages has increased the number and abundance of nonindigenous species arriving in new environments around the world (Ruiz et al., 1997). This increasing propagule supply appears to have increased the rates of invasions in a number of aquatic ecosystems (e.g., Cohen and Carlton, 1998; Holeck et al., 2004; but see Costello and Solow, 2003 and Drake et al., 2005).

Of the sub-vectors associated with shipping, ballast water is a major source of nonindigenous species in both the Great Lakes and most marine/estuarine environments (Carlton and Geller 1993, Carlton 1996; Fofonoff et al. 2003a; Holeck et al., 2004; Hewitt et al., 2009). When ships

---

[1] The terms "nonindigenous species" and "non-native species" are used to denote species that were introduced via anthropogenic vectors into a novel location with no specific connotation of ecological, human health, or economic impacts. "Invasive species" is used to denote a nonindigenous species for which there is evidence of an adverse impact on ecological, human health, or economic endpoints. (Executive Order 13112; http://www.invasivespeciesinfo.gov/laws/execorder.shtml).

take on ballast water to compensate for changes in load, vast assemblages of aquatic organisms are collected and then discharged into subsequent ports. This international transfer of organisms is massive – untreated ballast discharges can contain thousands of organisms per cubic meter (Minton et al., 2005) and the total foreign ballast discharged in the United States in 2004-2005 was over 73 million metric tons (Miller et al., 2007; also see National Ballast Information Clearinghouse (NBIC), http://invasions.si.edu/nbic).

IMO Ballast Water Treaty and Proposed USCG Standards Background:
The first approach to managing this vector was to implement mid-ocean ballast water exchange, where ballast was exchanged either through flow-through of the ballast or empty-and-refill. Ballast water exchange, and similar treatment for vessels declaring "No Ballast on Board" (NOBOBs), have been shown to reduce the number of living organisms in ballast water tanks which are adapted to living in both freshwater and coastal/estuarine environments, thereby reducing the risk of invasion (Gray et al., 2007; Locke et al., 1993; McCollin et al., 2007; Ruiz and Reid, 2007; Cordell et al., 2009; see summary of 4.3 in U.S. EPA, 2008a). Though ballast water exchange and saltwater flushing may reduce the risk of invasion, a number of studies have shown that ballast water exchange was not sufficiently effective or consistent in reducing organism concentrations in ballast water especially in coastal/estuarine environments (e.g., Locke et al., 1991; see summary in Section 4.3.2 of USCG, 2008). Additionally, in many cases, it is not safe for vessels to conduct ballast water exchange, given constraints of design and construction.

In response to this concern, national and international efforts began to evaluate other options for managing ballast water discharges. Ultimately, a key decision was made to base ballast water discharge standards on the concentration of organisms in discharged ballast water, rather than on the percentage of ballast water exchanged during mid-ocean exchanges. Through the Marine Environment Protection Committee (MEPC) of the International Maritime Organization (IMO), an international ballast water treaty ("The International Convention for the Control and Management of Ships' Ballast Water and Sediments, 2004") was initiated to reduce the spread of nonindigenous species through ballast water transport (IMO, 2004a). An overview of the IMO international convention can be found in Gollash et al. (2007). A key section of the IMO treaty (Regulation D-2) sets standards for the maximum concentrations of organisms allowed in discharged ballast water based on different size groups of organisms (Table 1). The treaty has not yet entered into force, and while recognized as a major step forward, the IMO standards are considerably above those proposed by the United States (<0.01 organisms m^{-3}; IMO, 2004b). In response to concerns that the IMO standards were not sufficiently protective, a number of states, such as California and Wisconsin, have initiated or passed more stringent discharge limits for ballast water.

The United States Coast Guard (USCG) responded to this concern by preparing a draft Programmatic Environmental Impact Statement on ballast water discharges (USCG, 2008) and then proposing a two phase implementation of discharge standards (USCG, 2009). The proposed USCG Phase I standards are equivalent to the IMO D-2 standards, while Phase II is 1000-fold more stringent (Table 1). Additionally, California and some other states have proposed alternative standards with the ultimate goal of "no detectable" discharges of organisms in ballast water (Table 1).

Table 1: Existing or proposed international and national ballast water discharge standards applicable to the waters of the United States and examples of state standards. All organism dimensions are for the "minimum dimension". Standards for the >50 micron and >10 - ≤50 micron classes are for "viable" or "living" organisms. Note that Phase II of the Coast Guard standard can be implemented incrementally. The date for the implementation of the final California standard is 2020. The California standards are from the California State Lands Commission (2009). The Wisconsin standards are from the Wisconsin Department of Natural Resources (2010). The California standards are instantaneous standards while those for Wisconsin are daily averages. NPRM = Notice of proposed rule making. IMO = International Maritime Organization. cfu = "colony forming units"

Organism Class	IMO D-2 Standard	USCG NPRM Phase I	USCG NPRM Phase II	WI State Standard	CA Interim Standards	CA Final Standard
Organisms >50 microns	<10 per m^3	<10 per m^3	<1 per 100 m^3 (< 0.01 per m^3)	<1 per 10 m^3 (<0.1 per m^3)	"No detectable living organisms"	"Zero detectable living organisms"
Organisms >10 - ≤50 microns	<10 per ml	<10 per ml	<1 per 100 ml (<0.01 per ml)	<1 per 10 ml (<0.1 per ml)	≤1 per 100 ml (<0.01 per ml)	"Zero detectable living organisms"
Organisms ≤10 microns	No standard	No standard	<10^3 bacteria/100 ml <10^4 viruses/100 ml	No standard	< 10^3 bacteria/100 ml < 10^4 viruses/100 ml	"Zero detectable living organisms"
Escherichia coli	<250 cfu per 100 ml	<250 cfu per 100 ml	<126 cfu per 100 ml	<126 cfu per 100 ml	<126 cfu per 100 ml	"Zero detectable living organisms"
Intestinal enterococci	<100 cfu per 100 ml	<100 cfu per 100 ml	<33 cfu per 100 ml	<33 cfu per 100 ml	<33 cfu per 100 ml	"Zero detectable living organisms"
Toxicogenic *Vibrio cholerae* (serotypes O1 and O139)	<1 cfu per 100 ml or 1 cfu per g wet wt. zooplankton	<1 cfu per 100 ml	<1 cfu per 100 ml	No standard	<1 cfu per 100 ml or <1 cfu per g wet zoological sample	"Zero detectable living organisms"

U.S. EPA Regulatory Background:

Under the Clean Water Act (CWA), the U.S. EPA has the responsibility for managing the National Pollutant Discharge Elimination System (NPDES) Program (see http://cfpub.epa.gov/npdes/home.cfm?program_id=45). Under the NPDES Program, all facilities that discharge pollutants from any point source into waters of the United States generally are required to obtain an NPDES permit (U.S. EPA, no date; U.S. EPA, 1996; see also CWA § 301(a)). Since the early 1970's, EPA regulations (40 C.F.R. 122.3(a)) had excluded discharges incidental to the normal operation of vessels (including ballast water) from the need to obtain an NPDES permit (see http://www.epa.gov/owow/invasive_species/ballast_water.html). However, that exclusion from the NPDES permitting program was successfully challenged in court, and as a result, was vacated (struck down) by the U.S. District Court for the Northern District of California (*Northwest Envtl Advocates et al.* v. *United States EPA*, No. C 03–05760–SI (December 17, 2008) (vacatur of 40 C.F.R. 122.3(a) as of February 6, 2009)). For a further description of the lawsuit, see also, *Northwest Envtl. Advocates v. EPA*, 537 F.3d 1006 (9th Cir. 2008). In light of the court decision, in December 2008, EPA issued a general NPDES permit (known as the "Vessel General Permit" or "VGP") that contains, among other things, effluent limits for ballast water discharges from non-recreational vessels (U.S. EPA, 2008b; http://cfpub.epa.gov/npdes/home.cfm?program_id=350). Specifically, "The 2008 Vessel General Permit (VGP) regulates discharges incidental to the normal operation of vessels operating in a capacity as a means of transportation. The VGP includes general effluent limits applicable to all discharges; general effluent limits applicable to 26 specific discharge streams; narrative water-quality based effluent limits; inspection, monitoring, recordkeeping, and reporting requirements; and additional requirements applicable to certain vessel types. Recreational vessels as defined in section 502(25) of the Clean Water Act are not subject to this permit. In addition, with the exception of ballast water discharges, non-recreational vessels less than 79 feet (24.08 meters) in length, and all commercial fishing vessels, regardless of length, are not subject to this permit." (U.S. EPA, 2008b)

EPA currently is undertaking development of organism-based effluent limits (discharge standards) for ballast water discharges for use in the future reissuance of the VGP. To help ensure it uses a scientifically sound approach in that effort, EPA is seeking an objective and independent scientific opinion on approaches for deriving these standards. As part of the effort to achieve that objective, this document synthesizes potential approaches to generating organism-based discharge standards. This synthesis is a component of the risk assessment process. As pointed out by EPA's Office of the Science Advisor, "The primary purpose of a risk assessment is to inform the risk manager's decision making process. The primary purpose of a risk assessment is not to make or recommend any particular decisions; rather, it gives the risk manager information to consider along with other pertinent information." (U.S. EPA, 2004a). Accordingly, it is not the purpose of this document to propose specific discharge standards, which is a risk management decision that incorporates additional factors potentially including existing laws, social factors, economics, and feasibility.

Challenges in Setting Organism-Based Discharge Standards:
Predicting the rate of invasion into specific water bodies from ballast water and/or other vectors with a high degree of accuracy is one of the most complex problems in applied ecology. The invasion process can be viewed as a series of stages, ranging from the initial entrainment of a potential invader in its native environment to its establishment and spread in a novel location (e.g., Sakai et al., 2001; Ruiz and Carlton, 2003). Each of these stages is confounded with its own suite of complexities and uncertainties, with examples listed in Table 2 (also see Ruiz et al., 2000). The purpose of listing these complexities/uncertainties is not to imply that the problem is insurmountable but rather to help set reasonable expectations about what is possible in the near-term given the nature of the problem and the state of the science. Realistically, development of discharge standards will require a number of simplifying assumptions, and the 1000 fold range in quantitative standards for the >50 micron class (Table 1) reflects, to a large part, differences in the assumptions made. Therefore, one of the objectives of our review is to identify the major stated and implied assumptions of each of the approaches and whether they tend to under- or overestimate the likelihood of invasion via ballast water. Additionally, with this level of complexity we suggest that it is unrealistic to expect development of highly predictive, mechanistic models in the foreseeable future. However, we believe it is possible to generate standards that are protective of the environment under most situations by making "conservative" assumptions, using safety factors similar to those used in ecological risk assessments for pollutants, and/or by setting the standards based on the upper confidence limits of predictions of invasions. The risk management challenge will be to set standards that balance the level of protection afforded versus their technological feasibility and economic viability.

Table 2: Examples of complexities and uncertainties confounding the prediction of invasion rates via ballast water.

Ports, Ship Routes, and Ballast Water

- Over 100 ports in the United States and its territories, ranging from the sub-Arctic to the tropics, both receive foreign ballast water discharges and donate ballast to foreign ports.
- Over 1000 foreign ports across nearly every biogeographic ecoregion that are potential sources of ballast water discharged in the United States.
- Changes in dominant source regions as trade routes are modified in response to changes in the economies at regional, national, and global scales.
- Ship voyages that span multiple foreign and domestic ports and biogeographic regions.
- Mixing of ballast water from multiple waterbodies and/or biogeographic ecoregions within a single voyage.
- Changes in absolute and relative densities of species within ballast tanks during a voyage.
- Different voyage durations and effects on concentrations within ballast water tanks.
- Among-ship variation in organism concentrations and ballast discharge volumes.

Vectors and Propagules

- Stochasticity in the mix of species originally entrained in ballast water in the source waterbody.
- Species that can invade via multiple vectors (polyvectic invaders).
- Uncertainty in the nature of the propagule dose-response relationship for any particular species at any place or time.
- Secondary invasions into a waterbody from other regional waterbodies.

Invasibility of Recipient Waterbody

- Extent of environmental matching between the donor and recipient regions and uncertainty in how to quantify similarity among environments.
- Seasonal changes in invasibility within a waterbody.
- Long-term changes in invasibility within a waterbody due to environmental trends (e.g., increase in nutrient loading).
- Long-term changes in invasibility within a waterbody due to climate change.
- Differences in invasibility among different waterbodies and biogeographic ecoregions.
- Differences in existing pool of NIS among waterbodies (resulting in whether a specific non-native species represents a “new” invader to the waterbody).

Establishment and Spread of New Invader

- Uncertainty regarding population dynamics at low densities
- Competitive interactions with existing flora and fauna.
- Predator/prey interactions with existing flora and fauna in the invaded ecosystem.
- Feedback between existing NIS and establishment of new NIS (biological meltdown).
- Determining whether a NIS is actually established within a waterbody or ecoregion.

Taxonomy and Sampling Biases

- Underestimation of the extent of invasion within a waterbody because of taxonomic difficulties in identification of new invaders.
- Differences in extent of invasion among waterbodies or regions because of different sampling efforts and/or taxonomic expertise.

II. PROPAGULE SUPPLY DOSE-RESPONSE AND ALLEE EFFECTS

Henry Lee II and Deborah A. Reusser

Two major factors driving the likelihood of invasion are the nature of the propagule supply dose-response relationship and Allee effects on population dynamics. We first discuss Allee effects and then propagule dose-response relationships before addressing specific approaches to setting ballast water standards.

Allee Effects:
Allee effects are reductions in the per capita population growth rate in sparse populations. Such depressions in individual growth rates in rarefied populations may occur due to several potentially interacting mechanisms (see Stephens and Sutherland, 1999; Courchamp et al., 1999; Berec et al., 2006; Kramer et al., 2009) including:

1) Mate limitation (i.e., difficulty in finding a mate at low densities).
2) Genetic inbreeding and loss of heterozygosity.
3) Demographic stochasticity of a small population, which may result from random fluctuations in sex ratios and/or birth rates or environmental perturbations.
4) Increased predation due to less effective or lack of predator swamping.
5) Increased predation due to less effective cooperative defense against predators.
6) Absence or reduction of cooperation in social species, including cooperative feeding.
7) Absence or reduction in habitat alteration that increases fitness of recruits.
8) Increased dispersal away from areas of low density.

A distinction is made between “weak” and “strong” Allee effects (Taylor and Hastings, 2005; Kramer et al., 2009) (Figure 1). A weak Allee effect depresses the per capita growth rate at low densities, but the per capita growth rate remains positive. In comparison, a strong Allee effect results in a negative per capita growth rate below a threshold density, referred to as the “critical density”. With deterministic population growth models, the population will go extinct after it falls below its critical density unless there is immigration of new individuals.

Allee effects are predicted to have major impacts on the likelihood that an invader will become established and on its rate of spread (e.g., Lewis and Kareiva, 1993; Drake, 2004; Taylor and Hastings, 2005). Unfortunately, there is limited empirical evidence regarding the role of Allee effects in natural populations, or the densities at which they might occur. In a review of Allee effects with marine organisms, Gascoigne and Lipcius (2004) found little evidence for widespread Allee effects in marine populations, though they did find “suggestive observations” with exploited fish and shellfish populations, as well as with broadcast spawners, a common breeding type among marine/estuarine invaders. In a more complete meta-analysis of natural populations, Kramer et al. (2009) concluded that Allee effects have been documented in a range of taxa, including mollusks, arthropods, and chordates (including three classes of vertebrates). They also concluded that there was evidence that these effects occurred through at least six of the mechanisms listed above.

In assessing the likelihood of Allee effects in populations of non-native species introduced via ballast water discharges, it is important to recognize that the density of any individual species will be very low given the proposed discharge standards (Table 1). This density will be further reduced by dilution of the ballast water in the receiving water. As an upper case example assume: 1) total discharge concentration of zooplankton equal to the IMO standard of 10 organisms m^{-3}; 2) the most abundant species constitutes 50% of the discharged individuals; and 3) a 10-fold dilution of the ballast water when discharged into the receiving water. Under this scenario, the density of the most abundant species is 0.5 organisms m^{-3} in the receiving water. As a lower case scenario, assume: 1) a total zooplankton concentration proposed in Phase II by the USCG of 0.01 organism m^{-3}; 2) the most abundant species constitutes 10% of the discharged individuals; and 3) a 50-fold dilution of the ballast water. With this scenario, the density of the most abundant species is 0.00002 individuals m^{-3}. These two scenarios are for planktonic species, but the low discharge standard concentrations and dilution in the receiving waters would also result in low densities of benthic organisms.

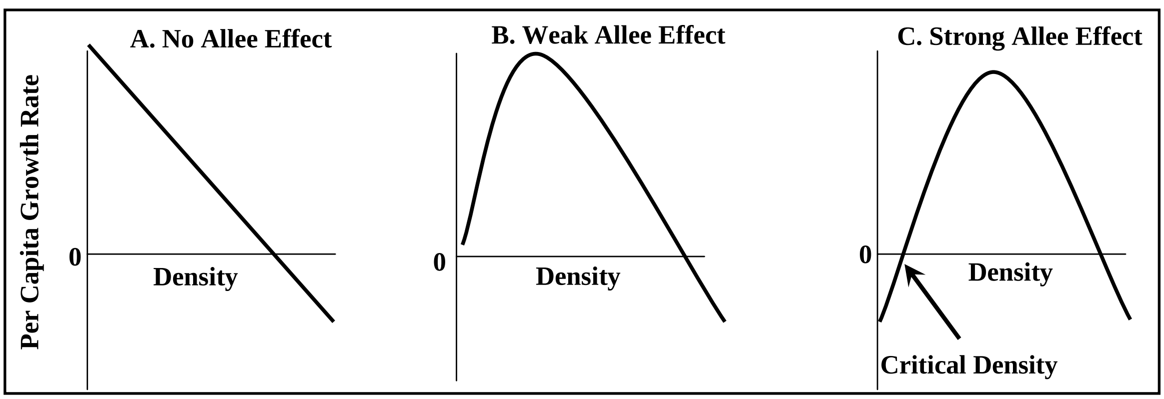


Figure 1: Illustrations of Allee effects on per capita population growth. The per capita rate declines at higher population densities in all three scenarios due to intraspecific interactions such as competition. Scenario A illustrates the case where there is no Allee effect and the per capita rate increases at lower densities. Scenario B illustrates a weak Allee effect where there is a decline in the per capita growth rate at lower population densities but the growth rate does not became negative. Scenario C illustrates a strong Allee effect where the per capita growth rate declines below 0 at population levels below the “critical density”. (Modified from Taylor and Hastings, 2005)

Propagule Supply Dose-Response:

The concept that invasion risk decreases with decreasing propagule supply is the fundamental assumption behind the IMO and USCG ballast water performance standards. This assumption is supported by a wide body of empirical, theoretical, and experimental evidence showing that invasion success increases with an increase in propagule supply, either by a higher concentration of organisms in an inoculation and/or by an increase in the frequency of inoculations (e.g., Simberloff, 1989, 2009; Ruiz et al., 2000; Kolar and Lodge, 2001, Ruiz and Carlton, 2003; Lockwood et al., 2005; Johnston et al., 2008). The difficulty is that the nature of the dose-response relationship (Figure 2) is unknown, and “we cannot predict the corresponding change in invasion success in terms of either the type (general shape) of the response or the specific magnitude (slope) of the response” (Ruiz and Carlton, 2003).

While it is not possible to predict the exact shape of the dose-response, two generalities are possible in context of generating discharge standards. First, there is likely to be a saturation dose beyond which any increase in the number of organisms is unlikely to increase invasion success. In most cases, organism concentrations are likely to be well below this saturation value. The second generality is that the linear dose response is likely to be a reasonably protective first approximation for many, if not most, species and densities. At low concentrations, actual invasion probabilities are likely to be lower than that predicted from a linear dose response because of Allee effects and stochastic events. At higher organism concentrations, response slopes that are steeper than the linear model (e.g., curves a and b in Figure 2) imply some type of positive intraspecific facilitation that increases the likelihood establishment. While there are examples of intraspecific facilitation in freshwater and marine/estuarine species (e.g., Leslie, 2005; Nilsson et al., 2006), they appear to be the exception rather than the rule and do not appear to be sufficiently strong to result in invasion probabilities substantially greater than the linear model.

There are, however, important exceptions to the generalization that establishment is unlikely at very low densities. In experimental studies with freshwater cladocerns, Bailey et al. (2009) found that the probability of establishment of the parthenogenic *Daphnia retrocurva* can be >0.1 with an inoculum density of only 1 individual m^{-3}. Simberloff (2009) cites several cases of mammals and insects where release of just a few individuals resulted in establishment of a non-native species. One sobering example is that all of the Indian mongooses (*Herpestes auropunctatus*) in the West Indies were initially derived from just five females and four males. However, Simberloff goes on to cite the "Noah fallacy" proposed by Jim Carlton - that a single breeding pair suffices for an introduction to take hold and spread. While recognizing the cases where a minute propagule supply was responsible for a successful invasion, Simberloff concludes, "if we think probabilistically (and invasion biology is largely a probabilistic science), the metaphor of Noah's fallacy is correct in spirit, because for most if not all species the probability of such an event is small, even vanishingly small, and larger propagule sizes drastically increase the probability of establishment." In terms of setting ballast water discharge standards, the possibility that a single mated female or parthenogenic individual may result in a successful invasion needs to be acknowledged. However, the only standard that would completely eliminate this possibility is the discharge of sterile water, which not even the "zero detectable organism" standard can provide because of the impracticality of collecting a sufficient ballast water sample to detect a zero concentration with a high confidence (see Sections IV and X). Thus, all practical standards contain some risk of invasion, though to varying extents they can substantially reduce this risk as discussed below.

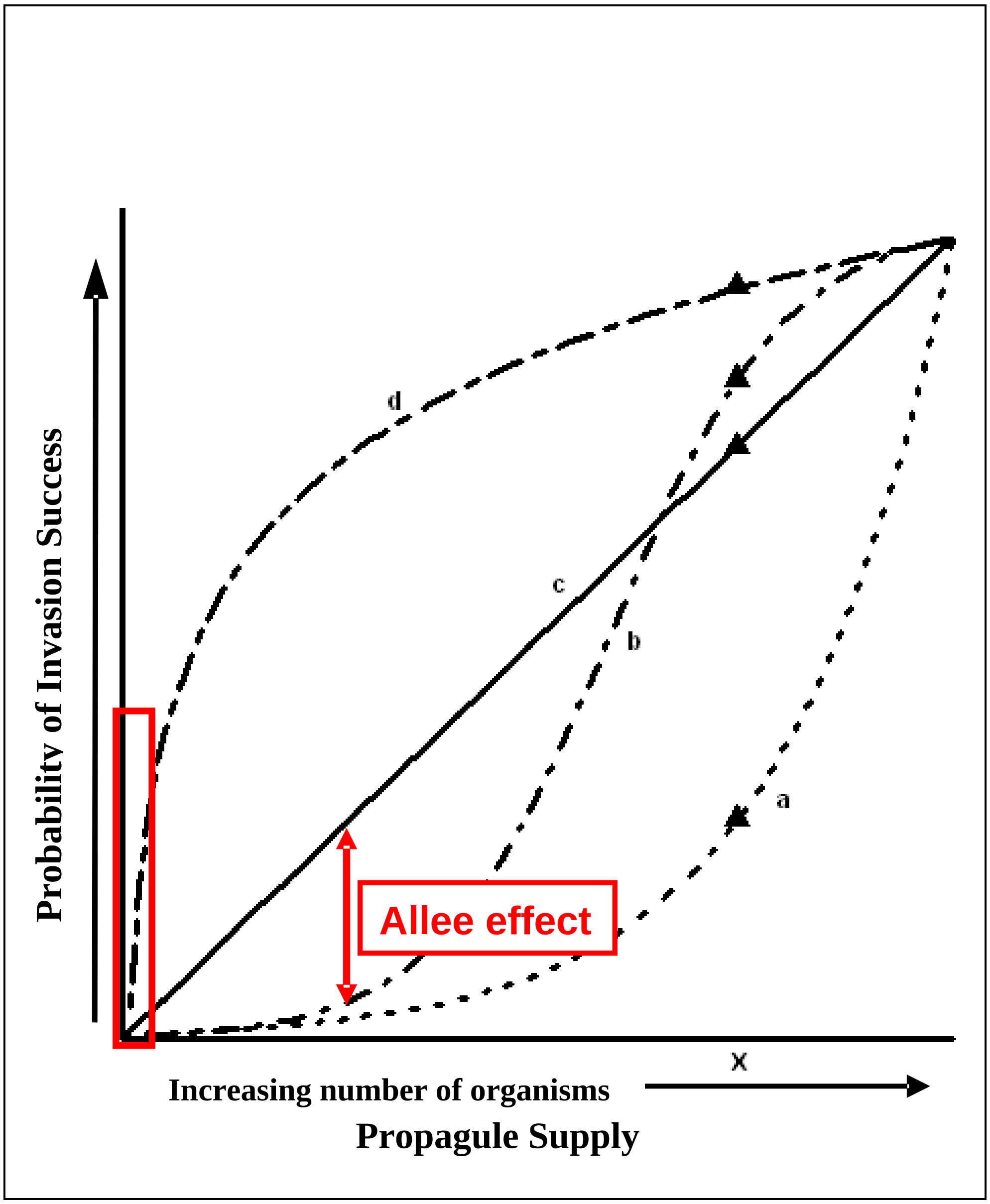


Figure 2: Hypothetical propagule supply dose-response curves. Potential responses include; a) exponential; b) sigmoid; c) linear; and d) logarithmic or hyperbolic. The triangles denote the range in invasion probabilities predicted at a single propagule dose (X) for different response models. The exponential and sigmoid models demonstrate the possible influence of Allee effects on invasion dynamics, and the double-headed arrow shows the reduction in invasion probability, relative to the linear model, due to Allee effects. The box on the left illustrates that the propagule doses associated with the proposed discharge standards (Table 1) are likely to be very low. (Modified from Ruiz and Carlton, 2003).

III. REDUCTION IN PROPAGULE SUPPLY BASED ON EXPERT OPINION/MANAGEMENT CONSENSUS

Henry Lee II

Overview:
Several of the proposed discharge standards were based on a combination of expert opinion and management consensus. As used here "expert opinion" refers to technical recommendations for ballast water standards from experts in the areas of invasion biology and related life sciences made without the explicit use of a quantitative invasion model. "Management consensus" is used to capture decisions made utilizing this expert opinion as well as inputs from experts in other disciplines, such as shipping and engineering, risk managers, as well as state, national, non-governmental organization (NGO), and industry representatives. Thus, management consensus decisions incorporate components of risk assessment, risk management, and lobbying. With homage to G. E. Hutchinson (1965), the consensus process can be characterized as a scientific opera staged by experts in a political theater.

Perhaps the apogee of a consensus driven process was the derivation of the IMO D-2 standards for the >50 micron and 10-50 micron size groups. (IMO standards for microbes and viruses were derived from existing human health criteria and thus had a different origin.) As discussed below, there were several meetings of national and international invasion experts prior to and during the IMO convention evaluating the scientific merits of possible standards. At the treaty convention itself, however, the vast majority of the delegates were not invasion experts and, as is true of any international treaty negotiation, the delegates had a wide range of agendas. Thus, the scientific recommendations from the invasion experts were only one of a suite of factors going into deriving the IMO standards. Additionally, both national and state bills have been drafted (e.g., S. 1578 (110th Congress), "The Ballast Water Management Act of 2007;" see also, accompanying S. Rept. 110-269) with performance standards apparently reflecting an expert opinion/management consensus approach. We suggest that this includes California's "zero detectable discharge" approach as well, though it is discussed separately because of the ambiguity regarding the exact concentrations of the standards.

It is beyond the scope of this document to attempt to decipher the management consensus decision making process at the IMO treaty negotiations or in the derivation of the proposed/existing national bills or state regulations. Rather, we will address the scientific benefits/limitations of an expert opinion approach to generating recommendations for risk managers. We will also summarize the expert opinion process leading up to the IMO convention as an example.

Rationale:
The major advantage of expert opinion is that it is possible to address complex issues even with limited data and in the absence of quantitative models. Additionally, expert opinion can draw upon types of knowledge and experience that is difficult or currently impossible to quantify in a model. Finally, decisions generated using expert opinion inputs provide a focus for guiding future research and management strategies. Because of all the complexities associated with

generating ballast water standards (see Table 2), expert opinion has been a key type of scientific input into the generation of ballast water standards to date.

One of the authors (HL) participated in several technical workshops and IMO meetings where much of the discussion focused on estimating organism concentrations in unexchanged ballast water (see Figure 3 and MEPC, 2003a) and what reduction in these concentrations would be ecologically protective. The basic premise driving the expert decision process was that "less is better" and the greater the reductions in propagule supply, the lower the risk of invasion. No quantitative invasion models were used, though the expert consensus was that the discharge standard needed to be substantially below that normally achieved through ballast water exchange. Additionally, in the U.S.-sponsored workshops, the practicability of achieving the expert-derived concentrations was not explicitly considered. Thus some of the values generated via expert opinion should be viewed as conceptual end-points rather than achievable near-term goals.

To document the expert opinion decision making process, we will briefly summarize the sequence of events that lead up to the IMO standards (Table 1). Some of the first national and international meetings addressing ballast water standards were a pair of workshops held by the U.S. Coast Guard on the East and West coasts in 2001 (USCG, 2002a) and an IMO GloBallast workshop in London also in 2001 (Raaymakers, 2002). Drawing on these workshops, the USCG published the "Advance notice of proposed rulemaking; request for comments" in the Federal Register in March of 2002 (USCG, 2002b). In this notice, they listed four possible standards:

> "S1. Achieve at least 95% removal, kill or inactivation of a representative species from each of six representative taxonomic groups … (GLOBALLAST PROPOSAL ''A''.)
>
> S2. Remove, kill or inactivate all organisms larger than 100 microns in size. (GLOBALLAST PROPOSAL ''B''.)
>
> S3. Remove 99% of all coastal holoplanktonic, meroplanktonic, and demersal zooplankton, inclusive of all life-stages (eggs, larvae, juveniles, and adults). Remove 95% of all photosynthetic organisms … (COAST GUARD WORKSHOP PROPOSAL ''A''.)
>
> S4. Discharge no organisms greater than 50 microns in size, and treat to meet federal criteria for contact recreation … (COAST GUARD WORKSHOP PROPOSAL ''B''.)"

In 2003, an International Workshop on Ballast Water Discharge Standards was hosted by the State Department and the USCG in cooperation with the National Science Foundation (NSF) in Washington, DC. Workshop participants included IMO representatives and technical experts from seven countries (MEPC, 2003a). The synthesis suggestion from this workshop was a standard of <1 organism m^{-3} by 2006 for the >50 micron size group. The workgroup provided two alternative recommendations for >10 – 50 micron organisms by 2015 as either "No detectable viable organisms" or "< 1 org./100 MT" (= 0.01 organisms m^{-3}).

In January of 2004, the United States submitted a recommended discharge standard for zooplankton of <0.01 organisms m^{-3} to the IMO (IMO, 2004b). The rationale for this value was

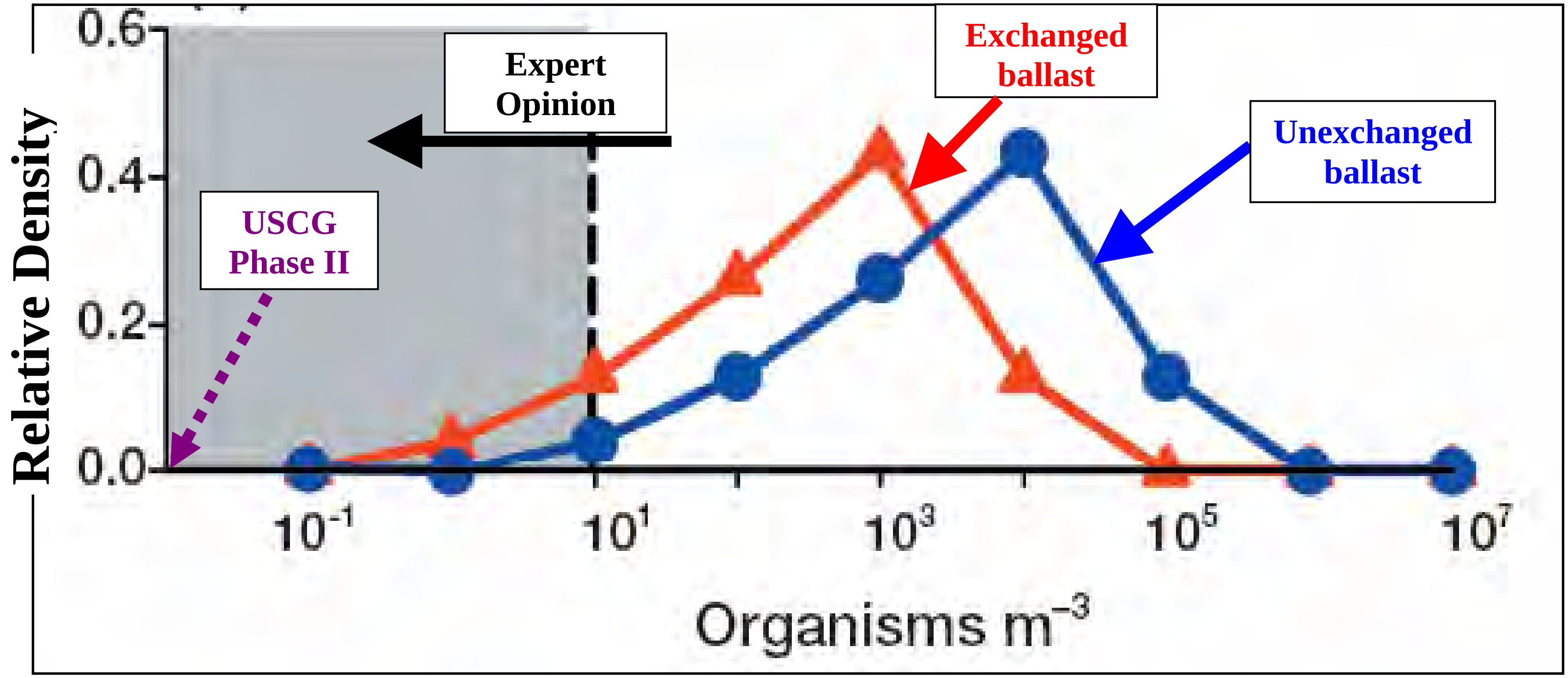


Figure 3: Relative density distributions of zooplankton (>80 micron) in unexchanged ballast water (blue line) and after theoretical ballast water exchange (red line). The dashed line indicates the IMO standard of <10 organisms m^{-3} for >50 micron organisms and the gray area indicates concentrations that meet the IMO standard. The "Expert Opinion" arrow pointing to the left illustrates the basic assumption that lower organism concentrations would reduce invasion risk. The "USCG Phase II" arrow points to the proposed standard of 0.01 organisms m^{-3} for organisms >50 microns. (Modified from Minton et al., 2005).

based on the large number of organisms that would be discharged even at these low concentrations and the additive densities from multiple ship discharges. The example they gave was, "if the ICES figure of an average of 4.6/l [organisms] is used, a vessel with 10,000 m^3 of ballast water would discharge 46,000,000 zooplankton. This vessel would actually be carrying 4,600 zooplankton/m^3, and in the absence of treatment would discharge a total of 46,000,000 zooplankton. Even if treated to reduce the concentration by 4 orders of magnitude [= 0.46 organisms m^{-3}], this single vessel would still potentially discharge 4,600 living organisms into a harbour or estuary. Given that many ports and estuaries receive multiple vessel visits from the same regions over the course of days and weeks, the cumulative number of organisms introduced will be quite a bit larger. For these reasons the United States urges the Conference to adopt less than 0.01/m^3 as the concentration standard for zooplankton."

In February of 2004, the IMO adopted by consensus "The International Convention for the Control and Management of Ships' Ballast Water and Sediments, 2004" (IMO, 2004a) with the specific standards given in Annex D-2 of the Convention as listed in Table 1. There is no discussion in the Convention or the diplomatic conference's Records of Decision of the Plenary as to how these values were settled upon. The reality is that the final IMO standards represent a negotiated compromise between the more stringent standards proposed by the U.S. and some other countries and the less protective standards (100 organisms m^{-3}) proposed by several other countries. Note that the standards in the Convention will enter into force 12 months after ratification by 30 nations, representing 35% of the world shipping tonnage. As of October 2, 2009, 18 countries representing 15.36% of the world's shipping have ratified the treaty. The United States has not yet signed or ratified.

Assumptions and Limitations:
While the IMO standards were developed with input from experts, the numbers ultimately adopted reflect a negotiated outcome among the many countries with differing views that participated in the Diplomatic Conference negotiations. This is not uncommon, as in general, decisions generated through an expert opinion/management consensus approach tend to mix risk assessment, risk management, and politics. This makes it extremely difficult, or impossible, to parse exactly how a decision was made, which in turn, makes it difficult to update the decision based on new information, or even to identify what new scientific information would be required to modify a decision.

A related issue is the lack of documentation on how management consensus decisions are made. One exception is the State of California that provides detailed documentation of their process (http://www.slc.ca.gov/Spec_Pub/MFD/Ballast_Water/Ballast_Water_Default.html).

A general limitation of the expert opinion approach is that it is dependent upon which experts are involved, making it difficult to reproduce the decision making process. A related limitation is that one, or a few, outspoken experts may drive the decision making process at the expense of exploring alternative ideas. This effect can be minimized or eliminated when experts respond via a questionnaire rather than within a workshop setting or with the use of an effective facilitator.

A group of experts restricted to a narrow field of specialization tend to look to at problems through the "lenses" of their particular expertise. Such differences not only reflect differences in the knowledge base of the individuals, but also their values. While such specialization is both appropriate and required, the reality is that additional factors, including economics, feasibility, and timeliness, are likely going to be important considerations when making risk management decisions. Accordingly, we suggest that the best approach would be for experts to provide a range of suggested standards accompanied with details on the ecological risks associated with the different standards. This would allow the risk managers to weight better all the cost-benefits of different standards.

With the exception of certain structured approaches (e.g. Delphi Method), the decision making process is less transparent when it is based on expert opinion in comparison to models. In particular, it is difficult to capture the implicit assumptions that go into an expert's decision, which in turn makes it difficult to assess the validity of the decision or to reproduce the decision making process.

Kuhnert et al. (2009) identified ten "key heuristics, judgments or mental operations that can result in bias when eliciting information from experts" for ecological models. One example was that experts can overestimate the accuracy of their beliefs or underestimate the uncertainty. Another type of bias referred to as "anchoring and adjustment" is the "tendency for groups to anchor around (any) initial estimates and adjust their final estimate from this value irrespective of the initial estimates' accuracy." These authors present several methods to minimize such biases that are summarized below.

Recommendations/Conclusions:

Expert opinion/management consensus was successful in the face of the uncertainties in the invasion process itself and the politics inherent in any international treaty in generating the IMO organism-based discharge standards. This was a "watershed" accomplishment and a critical step toward reducing new invasions via ballast discharges. The question remains, however, as to whether the IMO standards are sufficiently protective. In part, this question arises because the expert opinion/managerial consensus approach does not allow a rigorous evaluation of the process or how the final decisions were reached. In light of these limitations and the continued increase in our scientific understanding, we recommend that future development of standards should rely more heavily on quantitative models. Use of invasion models will not remove the need for expert knowledge (e.g., what models and data to use, etc.) nor will it eliminate the need for risk managers to make difficult decisions weighing environmental risks versus other considerations. However, use of such models will make the process more transparent, more repeatable, and help to generate standards with defined levels of risk and associated uncertainty.

If expert opinion is used as a major input into the development of national standards, we suggest that the recommendations by Kuhnert et al. (2009) be considered to help formalize the process: 1) use multiple experts in a normative setting to avoid overconfidence; 2) pool expert beliefs with a mechanism for separating variability from ignorance; 3) calibrate the expert opinions to ensure that the experts report what they actually mean; 4) incorporate a feedback and comparison process that allows experts to discuss and revise their opinions as well as comparing their assumptions of the methodology with their beliefs; 5) utilize a methodology that allows the experts to respond in a non-threatening manner; and 6) design the elicitation process around the statistical methods that will be used to analyze the data and investigate the impact of this information on the model outcomes. To this, we add that experts in a diverse range of biological, shipping, and engineering fields be consulted.

IV. ZERO DETECTABLE DISCHARGE

Henry Lee II

Overview:
The state of California and other states have adopted or have proposed standards with the goal of "zero detectable living organisms" in ballast water discharges. In this assessment of zero detectable organisms, we will focus on the California standards as they are the best documented of the efforts (see Dobroski et al., 2009a and http://www.slc.ca.gov/Spec_Pub/MFD/Ballast_Water/Ballast_Water_Default.html). California's standards will be adopted in two-phases, with an interim standard of "no detectable living organisms" >50 microns for ships constructed in 2010 to 2012, depending upon vessel size (Table 1). The proposed final standard is "no detectable discharge" of zooplankton, phytoplankton, protists, bacteria, or viruses for ships constructed beginning in 2020 (Table 1). While California considered the natural invasion rate approach (described in Section V), it was not used in establishing the standards and the "no detectable discharge" standard is a special case of the expert opinion/management consensus approach discussed in Section III.

Rationale:
The principal legal authority for California to set these standards is the Coastal Ecosystems Protection Act of 2006. As noted in the Notice of Proposed Regulatory Action (www.slc.ca.gov/Spec_Pub/MFD/.../Art_4-7_2009_NOPR.doc), "Current California law requires that vessels manage ballast water to reduce the discharge of NIS into California waters. The performance standards for the discharge of ballast water prescribed by Article 4.7 are necessary to minimize the transport of NIS into and throughout the waters of the State of California." (Amendments to Article 4.7 entitled "Performance Standards for the Discharge of Ballast Water for Vessels Operating in California Waters"; Updated August 31, 2009).

The environmental rationale for the zero detectable discharge standard given by the "Report and Recommendation of the California Advisory Panel on Ballast Water Performance Standards" (www.slc.ca.gov/Spec_Pub/MFD/Ballast_Water/Documents/Appendix_A.doc) was, "The scientific basis for a standard of discharging no exotic organisms is that exotic organisms, unlike conventional chemical pollutants, can reproduce and increase over time, persist indefinitely and spread over large regions. Thus, very large, widespread and long-term impacts could potentially result from the discharge of a small number of individual organisms—in some cases as few as a single mated pair, or in the case of asexually-reproducing species, a single individual. From this perspective, the only biologically safe standard is no discharge of exotic organisms." This rationale was also discussed by Cohen (2005 in Appendix 3 of the California Panel Report). Note that this rationale implies that no organisms should be discharged (actual zero discharge), which can be substantially different than the "zero detectable discharge" of the California regulation, which is entirely dependent upon the sampling regime used.

Another rationale for setting stringent standards is to "force" technology development. In a letter to California Lt. Governor Bustamante and the California State Lands Commission, The Ocean Conservancy (TOC) stated, "During the [Ballast Water] Committee's work, TOC sought higher

standards because the existence of such standards – combined with a competitive marketplace for ballast water treatment products – would motivate the rapid development of technology appropriate for meeting them."
(http://www.slc.ca.gov/Spec_Pub/MFD/Ballast_Water/Documents/Appendix_C.pdf).

California states that their ballast water standards should be interpreted as instantaneous standards rather than averages over the entire discharge. As a result, if any individual sample from a discharge exceeds any of the standards, this would be grounds for finding non-compliance and it is unnecessary to show non-compliance in multiple samples or in mean values (Dobroski et al., 2009a). California justifies the instantaneous standards based on the 2005 draft MEPC G2 sampling guidelines. However, the final MEPC G2 guidelines were subsequently revised to instead suggest an average method (J. Lishman, pers. comm., November, 2009). It is worth noting that while California cites the earlier G2 guidelines as a justification, any zero based standard is inherently an instantaneous standard since once any sample contains an organism the discharge has failed the standard.

Assumptions and Limitations:
A true zero discharge of all size groups eliminates the risk of invasion via ballast water, assuming perfect compliance and no equipment failures. However, perfect compliance and no failure is practically, if not theoretically, impossible, particularly for microbiological organisms unless ballast water is discharged into a land-based treatment facility or ships are redesigned to eliminate the need to discharge ballast water (see Gregg et al., 2009 for discussion of ballast-free ships). Thus, ignoring all the other issues mentioned below, there will still be some level of risk associated with the proposed California standards resulting from equipment and human failure.

A major limitation with "zero detectable" discharge standards is that they are undefined in the absence of a quantitative sampling protocol, and depending upon the sampling protocol, the actual risk may be considerably higher than that associated with other standards. For example, as discussed in Section X, when zero organisms are detected in a 1 liter sample, the actual ballast water concentration could be as high as 3,000 organisms m^{-3} based on the 95% confidence interval (1-tailed). For a 10 m^3 sample (=2641 gallons) with no detected organisms, the ballast water concentration could be as high as 0.3 organisms m^{-3} (see Table 15). Thus, with a small (1 liter) sample with no organisms, the actual concentration could be as much as 300-fold higher than the IMO standard, while for a 10,000-fold larger sample the actual concentration could be 30-fold higher than the proposed USCG Phase II standard. Without a statistically-robust sampling protocol to quantify the detection limits during both testing of treatment systems and compliance monitoring, it is impossible to conclude that the zero detectable discharge standard is actually any more stringent than the other standards.

These problems with a zero detectable discharge standard for ballast water have been previously identified by various expert panels. For example, the summary of the 2003 "International Workshop on Ballast Water Discharge Standards" (MEPC, 2003a) included the following two points:

> "Experience following passage of the United States Clean Water Act showed that an absolute standard of "zero discharge" was an unrealistic/unworkable concept – detection limits have always been a problem."

> "Setting a specific detection limit means that an actual concentration will be allowed for the testing protocol, therefore it might be better to specify the (acceptable) concentration as determined by the selected test protocols, rather than to use the expression "zero detectable" in the standard. This concept could be specified in the testing protocol guidelines."

Other major challenges are whether the putative low concentration associated with the "zero detectable" standard is economically viable and/or technologically feasible given the constraints of ship operations. These challenges are likely to be especially acute meeting the standards for microbiological organisms. It is beyond the scope of this document to conduct a review of the technical approaches to ballast water treatment methodologies but it is worth noting the scope of the challenges such systems face. Large tankers can carry in excess of 200,000 m^3 of ballast and the rates of ballasting and deballasting can be as high as 20,000 m^3 hr^{-1} (NRC, 1996; Wright, 2007). Treatment systems must fit within the confined spaces available on ships, continue to operate under the demanding conditions of ocean voyages, not be so complex that the crew can not operate them effectively, and pose no risk to the crew or environment. As pointed out by Gregg et al. (2009), "Effectively eliminating the risk of ballast water mediated invasions still remains a monumental technological and economical challenge."

In evaluating the practicality of the "zero detectable" standard, the State of California conducted a review of ballast water treatment systems using available information (Dobroski et al., 2009a, b) in terms of whether they presently meet the California standards or showed the potential of meeting them. They conducted a review for the >50 micron group, 10 - 50 micron size group, *E. coli*, intestinal *Enterococci*, and *Vibrio chlorae*. They initially included viruses, but concluded that there was no widely accepted technique or proxy for enumerating them and dropped them from the evaluation. They noted that their review was hampered by the lack of detailed testing data, inconsistency in the testing methodologies, and differences in the scale and location in which the tests were conducted (e.g., lab based vs. land based vs. shipboard). They also noted that much of the available data have not been subject to a review by an independent scientific organization.

Based on the January 2009 review (Dobroski et al., 2009a), 15 systems were considered to have the potential to meet the California standard of zero detectable discharge for the >50 micron size class (see Table 3). In an October 2009 update to this review (Dobroski et al., 2009b), the MH Systems was also listed as having potential. However, it is critical to note that California listed a system as having the "potential" to meet their standards if it had "at least one replicate in compliance with the performance standards" (Dobroski et al., 2009a). In other words, a system was considered to have "potential" as long as it did not fail the standard in 100% of the replicates, which is the least stringent criterion possible. Failure of these systems could be due to several factors, such as mechanical problems, inherent variability in the efficacy of the system, the system working in one test mode but not another (e.g., working in a land-based testing facility but failing on a ship), or statistical variation in the results based on a inadequate sampling regime. Regardless of the cause for failures, the California criterion for "potential" is much less stringent than the criteria to meet approval through the Marine Environment Protection Committee (MEPC) of the IMO. The G8 MEPC Guidelines for Approval of Ballast Water Management Systems provide that to obtain type-approval, a system needs to satisfy the IMO Regulation D-2 standards in three consecutive valid shipboard test cycles and five consecutive valid land-based cycles (MEPC, 2008a).

To gain a better insight into the performance of these treatment systems, we analyzed their failure rates among replicate trials as presented in Appendix B1 of Dobroski et al. (2009a) (Table 3). It was not possible to conduct this analysis with the more limited data presented in the October update (Dobroski et al., 2009b), so the MH Systems treatment system is not included. With the exception of SeaKleen®, all systems failed a moderate to high percentage of the replicates and/or they were not tested in all three modes (laboratory, land-based, and shipboard testing). While the results for SeaKleen® are promising, they are only based on one laboratory test, two land-based tests, and one ship-based test, which do not meet the minimum G8 requirements mentioned above. Additionally, there are concerns over residual toxicity from SeaKleen®, as well as its effectiveness against bacteria, resistant resting stages, and sediment-dwelling organisms (Gregg et al., 2009). SeaKleen® has not been registered by EPA for use in treating ballast water under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), and thus is not currently approved for such use in the United States. Furthermore, it has not received final type approval under G8 requirements or final approval from IMO for use as an active substance. We identify these issues not criticize SeaKleen® but to point out the gap between identifying a system with "potential" and having an approved system. Finally, our analysis is based only on the percentage failure as reported in Dobroski et al. (2009a); it would take a detailed statistical review of the sampling protocols used in testing these systems to ascertain the statistical confidence of detecting a zero discharge (see Section X) and thus what level of confidence to place in the reported system successes.

Dobroski et al. (2009a) concluded based on their review that "at least two treatment systems have demonstrated the potential to comply with California's performance standards. Many additional systems are close to completing system performance verification testing and will soon have data available for review. Commission staff expects that before 2010 several systems will be ready to meet California standards." Our assessment is not as optimistic, especially since it is now 2010 and no systems meeting the California standards have been approved by IMO. While predictions about technology development are littered with embarrassing prognoses (Ken Olson founder of DEC computers: "*There is no reason anyone would want a computer in their home.*"), our view is that it is unlikely that any practical ballast water treatment system will approach an actual zero discharge of organisms, defined here as concentrations substantially less than the USCG Phase II standards, in the near term, in particular for microbes and viruses. Of course it is possible to achieve a "zero detectable" standard simply by using an inadequate sampling protocol with insufficient statistical power. Again, this emphasizes the need to have quantitative sampling protocols with adequate sample volumes and replication to quantitatively assess these systems.

Recommendations/Conclusions:

As discussed above, "zero detectable" discharge standards are undefined in the absence of a quantitative sampling protocol, and depending on the sampling protocol, the actual risk may be considerable higher than that associated with other standards. Therefore, we recommend that it not be used at the national level as an approach for deriving environmentally protective limits on concentrations of living organisms in ballast water.

If zero detectable discharge standards are considered as a possible approach for national standards, part of the technical analysis should include an assessment of the relative risk associated with the zero detectable discharge standards versus risk associated with the USCG Phase II standards

Table 3: Failure rates of the systems listed as having the "potential" to achieve the California discharge standard for >50 micron organisms (Dobroski et al., 2009a). Failure is defined as detection of organisms in a test sample. The failure rate was calculated as the percent of the replicate tests that failed the criterion using the data in Appendix B1 of Dobroski et al. (2009a). The Hitachi system was listed as achieving the California standard in Table VI-1 of Dobroski et al. (2009a) but no results were given in Appendix B1. The RWO Marine Water Tech. was tested with *Artemia* cysts only. Systems that had a 100% failure rate for the >50 micron organisms may have passed the standard for another size group. The status of the type and active substance approval are from Dobroski et al., 2009a, Dobroski et al., 2009b, and Gregg et al. (2009). The commercial names of the systems are given in parentheses. NT = not tested. NA = approval for active substance not applicable. Note that the number of samples or sample volume used in the validation testing was not reported by Dobroski et al. (2009a, b).

System	Failure Rate for Laboratory Testing (# Tests)	Failure Rate for Land-based Testing (# Tests)	Failure Rate for Shipboard Testing (# Tests)	Type Approval[1]	Active Substance Approval[2]
Alfa Laval (PureBallast)	100% (1)	25% (12)	40% (5)	Yes	Final
Ecochlor (Ecochlor BW Treatment System)	0% (2)	NT	0% (1)	No	Basic
Greenship (Sedinox)	NT	0% (5)	NT	No	Final
Hamann Evonik Degussa (SEDNA)*	0% (2)	16% (19)	20% (5)	Yes (Germany)	Final
Hitachi (Clearballast)	?	?	?	No	Final
Hyde Marine (Hyde Guardian)	100% (1)	50% (4)	100% (4)	Yes	Basic
MARENCO	33% (3)	NT	NT	No	NA
Mitsui Engineering (Special Pipe)	NT	100% (4)	100% (1)	No	Basic
NEI (Venturi Oxygen Stripping (VOS))	NT	80% (5)	75% (4)	Yes (Liberia)	NA
Nutech 03 Inc. (SCX 2000, Mark III)	100% (3)	67% (3)	33% (3)	No	No

System	Failure Rate for Laboratory Testing (# Tests)	Failure Rate for Land-based Testing (# Tests)	Failure Rate for Shipboard Testing (# Tests)	Type Approval	Active Substance Approval
OceanSaver (OceanSaver BWMS)	NT	86% (14)	67% (12)	Yes (Norway)	Final
OptiMarin (OptiMarin Ballast System)	100% (1)	38% (13)	100% (7)	No	NA
RWO Marine Water Tech. (CleanBallast)	0% (1)	NT	NT	No	Final
SeaKleen	0% (1)	0% (2)	0% (1)	No	No
Severn Trent DeNora (BalPure)	NT	40% (5)	NT	No	No
TechCross (Electro-Cleen)	NT	27% (11)	0% (3)	Yes (Korea)	Yes

1) Type Approval: Type approval is granted by Flags states following successful equipment performance during land based and ship board testing in accordance with the IMO G8 Guidelines to verify treatment system efficacy, safety, design, construction, operation, and function (MEPC, 2008a).

2) Active Substance Approval: Active Substance Approval is granted by MEPC, not the Flag state, and is required by Convention Regulation D-3 for those treatment systems that make use of Active Substances (biocides) to comply with the Convention’s Regulation D-2 standards. Active Substance Approval relates to the environmental and safety aspects of the system's use of biocides and is conducted in accordance with the IMO G9 Guidelines (MEPC, 2008b). Approval typically is given in 2 stages, first “basic” approval, and then “final” approval. Systems subject to Active Substance Approval also must undergo type-approval testing by Flag states under the IMO G8 Guidelines.

*****: Harmann Ag ceased work on its ballast water treatment system after it was discovered that the biocide Perclean was more toxic in cold waters and in freshwater than initially assumed (Lloyd’s List, February 9, 2010).

(USCG, 2009) and/or standards derived from the per capita invasion approach (Section VIII). This analysis should include an assessment of the number and impacts of historic invaders in coastal waters and the Great Lakes that the USCG or PCIP standards might not have prevented, in particular asexual and parthenogenic invaders, in comparison to the likelihood that the zero detectable standards would have prevented their introduction, assuming some practical sampling protocol for the zero detectable standards.

If zero detectable standards are considered at the national level, it is critical to define all aspects of the sampling protocols for verification of ballast water treatment systems and for compliance monitoring. (see Section X).

V. NATURAL INVASION RATES

Henry Lee II

Overview:
The natural invasion rate approach was proposed by Dr. Andy Cohen (San Francisco Estuary Institute) in an August 7, 2005, memo to the California Ballast Water Treatment Standards Committee, with a follow-up addendum with corrected values. The memo and addendum are Appendix 5 and 6, respectively, in Appendix A of Falkner et al. (2006). As noted by the California State Lands Commission (Falkner et al., 2006, page 21), "this approach is based on numerous assumptions that create a high level of uncertainty for its application to performance standards that will have regulatory impacts. … The proposed approach had been neither published nor peer reviewed and was thus not known or widely accepted by the scientific community." Because of these uncertainties, they adopted the zero detectable organism approach instead (see Section IV). Even though not adopted by California, the natural invasion rate approach is worth examining since it addresses generating ballast water discharge standards in a novel way.

Rationale:
The rationale for the natural invasion rate approach is that marine/estuarine ecosystems are subject to a very small natural rate of invasion from rare events when species drift or raft across oceans and then become established in new locations. A ballast water discharge standard that resulted in an invasion rate approximately equal to the natural rate would essentially double the natural invasion rate but would be "reasonably close to the natural rate and possibly within the normal range of variation, and thus would be reasonably protective of the environment" (Cohen, 2005 in Falkner et al., 2006). Cohen further assumed that such a standard would be "reasonably protective of the various environmental, recreational and economic beneficial uses of California's waters."

Calculation of Discharge Standard Based on Natural Invasion Rates:
As discussed in Appendices 5 and 6 of Falkner et al. (2006), development of a discharge standard (= concentration standard) resulting in a ballast water invasion rate approximately equal to the natural rate requires that the concentration of organisms in ballast discharges needs to be reduced "by the ratio between the natural invasion rate and the invasion rate due to the discharge of untreated and unexchanged ballast water." This ratio is referred to as the Reduction Factor:

Equation 1: $$\text{Reduction Factor} = \frac{\text{Natural invasion rate}}{\text{Invasion rate due to untreated and unexchanged BW}}$$

Where:
BW = ballast water

Cohen assumes a linear dose-response for propagule pressure (Fig. 2, line c) so that the ballast water standard that would result in an invasion rate approximately equal to the natural rate of invasion is:

Equation 2: $$\text{Discharge Standard} = \frac{\text{Concentration of organisms in}}{\text{untreated \& unexchanged BW}} \text{ X Reduction Factor}$$

Therefore, to calculate the discharge standard, three values are needed: 1) organism concentrations in untreated ballast water; 2) a rate of invasion resulting from discharge of untreated ballast water; and 3) a natural invasion rate. For organism concentrations, Cohen assumes concentrations in untreated ballast water to be on the order of 10^2-10^3 per m^3 for organisms >50 microns, 10-10^2 per mL for organisms between 10 and 50 microns, and 10^8-10^9 per 100 mL for organisms <10 microns.

For the rate of invasion from ballast water, Cohen focused on the San Francisco Estuary for which he has extensive experience (e.g., Cohen and Carlton, 1995; Cohen and Carlton, 1998; Cohen 2005). From 1961 to 1995, which is prior to the California and USCG regulations requiring mid-ocean ballast water exchange, he estimated the rate of invasion as 3.7 species per year, with an increase to 5.2 species per year during 1991 to 1995 (Cohen and Carlton, 1998). The fraction of these invaders assumed to have been introduced via ballast water discharges was 0.7-1.7 species per year for the period 1961 to 1995 and 1.6-3.2 species year for the period 1991 to 1995. Cohen makes the argument that these numbers underestimate the actual rate of invasion because of: 1) new invaders that have not yet been collected; 2) new invaders that have not yet been identified as exotic species (e.g., misidentified as a native species); and 3) species that have been collected but whose invasion status is uncertain (cryptogenic species). Cohen estimates that these factors could increase the invasion rate by 50 to 100%. Cohen is correct in asserting that these factors are likely to result in an underestimation of the true invasion rate (e.g., Ruiz et al., 2000; Carlton, 2009), and while the actual extent of underestimation is not known, increasing the observed invasion rate by 50% to 100% does not seem unreasonable.

These rates only capture invasions into the San Francisco Estuary, and Cohen assumes that including all of California would increase the rate by at least another 50 to 100%. Implicitly this assumes that there are potentially as many unique invaders in the rest of California as have been found in San Francisco. This validity of this assumption was not assessed, though it would be possible to synthesize the existing California invasion records (e.g., http://www.dfg.ca.gov/ospr/about/science/misp.html) to determine how many California invaders are not found in the San Francisco Estuary or were first reported from areas other than San Francisco. Nonetheless, based these assumptions, the invasion rate for all of California from ballast water was estimated by Cohen as 2 to 7 species per year during the 1961 to 1995 period and 4 to 13 species per year during the 1991 to 1995 period.

Estimate of Natural Invasion Rate on Pacific Coast:
The third input value needed is the natural invasion rate, which is the most difficult to estimate. A natural invasion event is defined as a "marine organism that is transported across an ocean by drifting, rafting or some other natural, irregular and rare transport mechanism and becomes established initially as a disjunct, isolated population in waters on the other side" (Falkner et al.,

2006). In assessing the prevalence of natural invasion rates, Cohen excluded several groups of organisms that would “inflate” the natural invasion rate. Pelagic organisms that have “regular, natural genetic exchange between populations on opposite sides of the ocean” were excluded. Such species would include pelagic copepods, many of which have trans-Pacific or trans-Atlantic distributions (see http://copepodes.obs-banyuls.fr/en/index.php). Additionally, species that have continuous ranges on both sides of the ocean (e.g., boreal species that occur from northern Japan across the Aleutians and into British Columbia) were excluded. Another group that was excluded was species that have disjunct, transoceanic populations “that are relics of formerly genetically-continuous populations”. Finally, Cohen excluded species that have teleplanic larvae, which are larvae that have a long residence times as plankton and may be transported across oceans (e.g., Scheltema, 1986; Scheltema and Williams, 1983). There is no discussion of how to identify species that consist of relict populations, what constitutes a continuous range on both sides of the ocean, or the larval duration defining a species as teleplanic. Thus, the taxa that potentially would be included in such an analysis are not well defined.

Cohen’s equation to calculate the one-way invasion rate is:

Equation 3:
$$\text{Natural invasion rate} = \frac{0.5 \times \text{The number of species common to both sides of the ocean that are thought to result from natural invasion}}{\text{The length of time it takes for isolated populations to become morphologically distinct}}$$

The natural invasion rate as defined by this formula is for one side of the ocean and multiplying the number of species common to both sides by 0.5 inherently assumes that there is an equal natural invasion rate in both directions. The logic of dividing by time for isolated populations to evolve into separate species is not discussed but appears to be an attempt to account for species that successfully invaded but are no longer “common to both sides of the ocean” because they evolved into a new species. For example, given 100 species in common and a speciation rate of 0.75 million years, the adjusted natural invasion rate (for one side of the ocean) would be 66.7 invaders per million years versus 50 invaders if no adjustment for speciation had been made. [Note that for speciation rates >1 million years, the time needs to be entered into Equation 3 as years and not million of years otherwise the formula decreases the invasion rate below the observed rate.]. In any case, Cohen assumes that it takes 1 million years for isolated species to become morphologically distinct without giving any documentation.

Then based on a “review of the biogeographical literature and other relevant data”, Cohen estimated that the number of fish and invertebrates common to both sides of the Pacific Ocean resulting from natural invasions is ≤100 species per million years. Two other invasion experts, Dr. Jim Carlton and Dr. Greg Ruiz, estimated ≤10 species per million years and ≤1000 species per million years, respectively (Table 4). While it was stated that a review of the biogeographic literature was conducted, the only reference given was Vermeij’s (1991) estimate that the Northeast Pacific mainland had been invaded by 11 gastropod species from the Line Islands in the Central Pacific over the last 2 million years (a one-way invasion rate). This results in a natural invasion rate of 5.5 species per million years (corrected value from Appendix 6 of Falkner et al., 2006). The assumptions inherent in these estimates are discussed below.

Table 4: Estimates of natural invasion rates, resulting discharge limits, and adjusted discharge limits. Adjustment factors are the extent to which the discharge limit would be increased because of the identified factor. The first three estimates are from invasion experts who participated in the CA Advisory Panel on Ballast Water Performance Standards (Falkner et al., 2006). These estimates are adjusted based on the mean IMO organism concentrations for zooplankton compared to that used by Cohen. The second approach to adjusting the discharge rates is to adjust the natural invasion rate from Vermeij (1991) for gastropods from the Line Islands that invaded the Northeast Pacific. The reduction factors for Vermeij's natural invasion rate are derived from Equation 1 using Cohen's range in the estimate of yearly ballast water invaders in California. The taxonomic adjustment increases Vermeij's rate based on the estimated relative proportion of gastropods to total number of invertebrate and fish species. The two species pool adjustments further increase Vermeij's rate based on the presumed increase in the number of natural invaders when considering the entire Central Polynesia Province or all the ecoregions within the Northwest Pacific and Indo-West Pacific. For reference, the IMO standard for >50 micron size class is organisms is 10 organisms per m^3 while the USCG Phase II is 0.01 organisms per m^3.

Expert / Type of Adjustment	Number of one-way natural invasions per 10^6 years / Extent of adjustment	Reduction Factor	Discharge limits per m^3 for organisms >50 microns	Discharge limits per ml for organisms 10-50 microns	Discharge limits per ml for organisms <10 microns
J. Carlton	≤10	10^{-6}	10^{-4} to 10^{-3}	10^{-5} to 10^{-4}	10^{2} to10^{3}
A. Cohen	≤100	10^{-5}	10^{-3} to 10^{-2}	10^{-4} to 10^{-3}	10^{3} to 10^{4}
G. Ruiz	≤1,000	10^{-4}	10^{-2} to 10^{-1}	10^{-3} to 10^{-2}	10^{4} to 10^{5}
Ballast water conc. adjustment to mean IMO conc.	4.6 to 46 fold increase	NA	4.6 10^{-4} to 4.6 10^{0} (0.00046 - 4.6 org. m^{-3})	NA	NA
Vermeij (1991)	5.5	4.2 - 28 x 10^{-7}	4.2 10^{-5} to 2.8 10^{-4} (0.00004 – 0.0003 org. m^{-3})	NA	NA
Taxonomic adjustment for all inverts & fish	10.6 fold increase	NA	4.45 10^{-4} to 2.97 10^{-3} (0.00045 - 0.003 org. m^{-3})	NA	NA
Species pool within Central Polynesia Province	2 fold increase	NA	8.90 10^{-4} to 5.94 10^{-3} (0.00089 - 0.0059 org. m^{-3})	NA	NA
Species pool within Western Pacific & Indo-West Pacific	10 fold increase	NA	8.9 10^{-3} to 5.94 10^{-2} (0.0089 - 0.059 org. m^{-3}	NA	NA

As mentioned, the only quantitative estimate of a natural invasion rate was for gastropods from the Line Islands to the Eastern Pacific (U.S. Pacific coast). The Line Islands are located 2,500 kilometers south of Hawaii in the central Pacific, and the 5,400 km expanse of deep ocean between the Line Islands and the Clipperton Islands off western Mexico constitute the "East Pacific Barrier" (EPB), the single largest oceanic barrier in the world (e.g., Scheltema, 1988; Collin, 2003). Thus a natural invasion rate derived from the Line Islands presumably represents the "worst case" scenario (i.e., lowest natural invasion rates). No similar analysis was conducted to estimate natural invasion rates from subtropical/tropical Asia and Indo-West Pacific or the Northwest Pacific (northern China, Japan, Korea, or Russia) to the U.S. and Canadian Pacific coasts. Natural invasion rates were not calculated from Europe to the U.S. East Coast.

Discharge Standards Derived from Natural Invasion Rates:
Depending upon the ballast water concentrations and the natural invasion rate used, the discharge standards based on the natural invasion rate for the >50 micron size class reported in Falkner et al. (2006) ranged from 0.1 to 0.0001 organisms per m^3 (Table 4). Natural invasion rates for smaller organisms were not addressed in Falkner et al. (2006) but the reduction factors for the >50 micron invaders were applied to 10-50 micron and <10 micron groups, based on the implicit assumption that there had been a similar number of natural invasions for these smaller taxa. This resulted in ranges of discharge standards of 0.01 to 0.00001 organisms per ml and 100 to 10,000 organisms per ml for the two smaller size classes, respectively (Table 4).

Evaluation of Natural Invasion Rates and Adjustment Factors:
In this section we evaluate several of the assumptions inherent in estimating natural invasion rates and suggest some adjustment factors to these rates. We use these adjustment factors to first modify the range in discharge limits from the expert estimates and second to derive a new discharge limit based on modifying the invasion rate from Vermeij (1991) (Table 4).

<u>Adjustment of Ballast Water Organisms Concentrations to IMO Mean</u>

As stated above, Cohen uses ballast water organism concentrations in untreated ballast water of 10^2-10^3 per m^3 for organisms >50 microns. In comparison, the baseline study submitted to the IMO (MEPC, 2003b) reported a mean zooplankton concentration of 4640 m^{-3}. Because the calculated discharge standards increase linearly with higher organism concentrations (see Equation 2), the estimates of 10^2-10^3 per m^3 used by Cohen could potentially underestimate discharge limits by about 5 to 50 fold. Adjusting the discharge rates from the three experts by IMO organism concentration, results in a range of discharge limits of 0.00046 - 4.6 organisms m^{-3}. The lower value is still more than an order-of-magnitude lower than the USCG Phase II standard while the upper value approaches the IMO standard.

<u>Taxonomically Adjusted Natural Invasion Rate</u>

The number of natural invasions will depend, in part, upon the total number of species available for invasion (i.e., the species pool). The natural invasion rate from Vermeij's (1991) work is based solely on gastropods, and thus substantially underestimates the potential species pool. To adjust this rate to be taxonomically inclusive of all macroscopic taxa in near-coastal ecosystems, we estimated the ratio of total number of gastropods to total number of near-coastal invertebrates and fishes. The invertebrate numbers were taken from the recently revised "*The Light and Smith Manual: Intertidal Invertebrates from Central California to Oregon*" (Carlton, 2007). The preface (page xi) to the *Light and Smith Manual* states that “over 3700 species are keyed or discussed in this fourth edition” and this value was used for the total number of intertidal and near-shore invertebrates. A total of 376 benthic gastropods was determined by counting the number of gastropod descriptions in *Light and Smith Manual* exclusive of the pelagic gastropod families. While we are unaware of a total species inventory for the Line Islands, a total of 281 coastal fishes have been estimated from Kiritimati, one of the Line Islands (Sandin et al., 2008).

Based on these values, gastropods constitute 10.2% of the intertidal and near-coastal invertebrate species in northern California and Oregon. Accordingly, Vermeij’s rate of 5.5 gastropods per million years was multiplied by 9.8 to account for all invertebrate taxa, resulting in an estimated natural invasion rate of 54.1 invertebrates per million years. Adding the number of fishes estimated from Kiritimati to the total species count results in gastropods constituting 9.4% of the total fauna. In turn, this results in an upward adjustment of 10.6 fold, generating a natural invasion rate of 58.5 species per million years. Thus, Vermeij’s rate for gastropods likely underestimates the natural invasion rate by about 10-fold, assuming all taxa have approximately equal probability of natural invasion. These are approximate corrections as ideally the invertebrate ratio would be based on a total species list from the Line Islands, the fish estimate would be based on all the islands within the Line Islands group, and all taxa such as macroalgae would be included. Even with these limitations, we believe that these taxonomic adjustments more closely capture the potential species pool for natural invasion than only using the number of gastropods.

<u>Biogeographic Analysis of Potential Species Pool for Invasion</u>

The size of the potential species pool available for natural invasions depends not only on the taxa included in the analysis but also the geographical area considered to represent potential donor regions. Vermeij’s estimate is based only on the Line Islands, which contain approximately 250 known gastropod species (Vermeij, 1991). While it would take a major effort to conduct a detailed review of the number of potential invaders in the entire Western Pacific, it is possible to use the number of distinct biogeographic regions as a relative indicator of the number of unique species available for invasion.

In the “Marine Ecosystems of the World” (MEOW) hierarchical biogeographic schema, “ecoregions” are the smallest biogeographic breakout which are contained within larger “provinces” (Spalding et al., 2007). The Line Islands are part of the “Line Island Ecoregion” which is contained within the “Central Polynesia Province”. The Central Polynesia Province is composed of two additional ecoregions (Cook Islands and Samoa Islands), which are approximately the same distance from the U.S. Pacific Coast as the Line Islands. The Cook Islands contain 377 extant native gastropod species (search conducted at http://cookislands.bishopmuseum.org/search.asp), while the number of marine gastropods in the Samoa Islands is apparently unknown. Though there is likely some overlap of species among the three ecoregions, the total number of potential gastropod invaders within the entire Central Polynesia Province is greater than from the Line Islands Ecoregion alone, as indicated by the 50% greater number of gastropods in the Cook Islands. Presumably, this increase in the available species pool would also apply to other taxonomic groups as well. In lieu of a detailed biogeographic analysis, we suggest that the total number of potential invaders in the entire Central Polynesia Province is at least 100% greater than the Line Islands alone.

In addition to these tropical island ecoregions, there have likely been natural invasions to the U.S. Pacific Coast from the subtropical/tropical ecoregions of Asia and the Indo-West Pacific as well as the temperate/boreal ecoregions of the Cold Temperate Northwest Pacific Province (northern China, Korea, Japan, and Russia). It is beyond the scope of this document to attempt a biogeographic synthesis of these areas, but it is suffice to say that these regions harbor an extensive number of species. The South China Sea contains more than 3500 fish species (Kwang-Tsao et al., 2008) and more than 20,000 species are listed in an inventory of China's seas (Zongguo, 2001). While the distance of these areas from the U.S. Pacific Coast may have limited the number of natural invasions migrating directly across the Pacific Ocean, it is possible that species "hop scotched". For example, cold adapted species from the six ecoregion making up the Cold Temperate Northwest Pacific Province may have initially colonized the Aleutian Islands before migrating to the Gulf of Alaska and then southward to cold temperate ecoregions of Washington, Oregon, and northern California. The main point is that estimates based on only the Line Islands are likely to substantially underestimate the total number of natural invasions and thus result in artificially low discharge standards. The extent of this underestimate is not known, but given the small size of the Line Island Ecoregion compared to all the potential donor ecoregions, it is possible that it is at least 10-fold.

Evidence for Transoceanic Interchange:
Independent of the adjustments to the natural invasion rates, there are several lines of evidence indicating that transoceanic migrations are not as rare as originally hypothesized. For example, a reasonably high percentage (13%) of the gastropod species from the Line Islands has invaded offshore islands in the Eastern Pacific (Vermeij, 1991). It is possible that these species are not found on the mainland of California and Mexico because of environmental mismatches rather than an absence of dispersal. Additionally, in a review of tropical trans-Pacific shore fishes, Robertson et al. (2004) reported 80 species that likely migrated eastward to the tropical Eastern Pacific and 22 species of shore species that likely migrated westward from the tropical Eastern Pacific.

Another line of evidence for transoceanic transport is the genetic similarity in a number of trans-Pacific species. In a study of 20 reef fish morphospecies found on both sides of the Pacific, Lessios and Robertson (2006) found that 18 of the 20 had high genetic overlap. They concluded that the similarity in these 18 trans-Pacific species was maintained by recurrent gene flow between the populations on the two sides of the Pacific. Additionally, these authors had previously found "massive breaching of the EPB" in two species of sea urchins (Lessios et al. 1998, 2003). Thus Lessios and Robertson (2006) concluded that while the EPB was generally an effective barrier in separating species in the Northwest and Northeast Pacific, it should be considered a "sporadically permeable filter." This conclusion is supported by a study of calyptraeid gastropods (slipper shells) (Collin, 2003). Collin found *Bostrycapulus* species on both sides of the Pacific Ocean, leading her to conclude that the Eastern Pacific Barrier is "somewhat permeable to some calyptraeids". These genetic studies indicate that there is periodic mixing of populations across the Eastern Pacific Barrier, and that such transport is not as "irregular and rare" as assumed in generating the natural invasion rates in Table 4.

A final line of support for the potential for transoceanic dispersal is the increasing appreciation of ocean dispersal as an important factor in determining organism distributions (de Queiroz,

2005) and the importance of rafting as a transport mechanism in particular (e.g., Thiel and Gutow, 2005). As stated by de Queiroz (2005), "If vicariance biogeography was a revolution, we are now in the midst of a counterrevolution, driven primarily by new evidence in favor of oceanic dispersal."

Assumptions and Limitations:
The natural invasion approach has only been described in the memo and addendum to the California Ballast Water Treatment Standards Committee. As such, the assumptions and input values have not been adequately vetted nor have they been peer reviewed. As mentioned, there is no discussion of how to identify species that consist of relict populations, what constitutes a continuous range on both sides of the ocean, the larval duration defining a species as teleplanic, or documentation for assuming a speciation rate of 1 million years.

Our review suggests that the analysis by Cohen underestimated the rate of natural invasions, which then results in an artificially low discharge standard. Specifically, the following would all result in higher natural invasion rates: 1) including taxonomic groups in addition to gastropods; 2) including the additional potential invaders (species pool) from other ecoregions within the Western Pacific; and 3) using higher mean organism concentrations in ballast water. Our conclusion that natural invasion rates were underestimated is consistent with recent genetic studies showing that the East Pacific Barrier is "semi-permeable". Based on these data, we suggest that the estimate of <1000 natural invasions per million years from Falkner et al. (2006) (Table 4) is the most defensible rate for natural invasions, and potentially may still underestimate the rate.

Estimating natural invasion rates is likely to have high uncertainty as indicated by the 100-fold difference among just three invasion experts (Table 4). With the available evidence, it appears that this approach will not generate discharge standards with less uncertainty than those developed using other approaches.

The natural invasion rates used to generate the reduction factors were based on macrofaunal invaders (>50 microns). Application of these reduction factors to the 10-50 and <10 micron groups, which primarily consist of phytoplankton and protozoa, introduces additional uncertainty especially given the differences in rates and vectors for natural dispersal of these smaller taxa especially for the microbes (e.g., Finlay, 2002). A separate analysis would have to be conducted for these groups, perhaps focusing on diatoms because of the availability of fossil records.

The natural invasion rate approach assumes a linear dose-response for propagule pressure. As discussed in Section II, this assumption should be adequate for many species and densities.

The approach assumes that there is an equal invasion rate in both directions across the Pacific (the 0.5 multiplier in Equation 3). This assumption seems unlikely for species transported to/from from the Line Islands. Because of the much greater shoreline, there is a much higher probability that an eastward traveling propagule would encounter the Pacific Coast of the United States compared to the probability that a westward traveling propagule would encounter the Line Islands, or other islands in the central Pacific.

The calculation of the natural invasion rate does not account for species that successfully crossed the oceanic barrier and became established (e.g., survived for 10 generations) but eventually went extinct. A number of nonindigenous species have shown dramatic population crashes (e.g., Simberloff and Gibbons, 2004) so extinction of some fraction of the natural invaders is possible if not likely. Excluding these extinct invaders artificially lowers the natural invasion rate, and thus results in a lower discharge standard.

As with all the approaches that rely on historic invasion rates, the possibility that a nonindigenous species may have invaded via secondary vectors and/or hull fouling or another vector instead of ballast water potentially inflates the ballast-water invasion rate. Incorrectly assigning invaders to ballast water reduces the reduction factor (Equation 1) which in turn reduces the discharge standard.

The geographic scope of the current analysis is the state of California, which is a political entity and is not defined by any specific set of biological or environmental conditions. By the MEOW biogeographic schema, California encompasses two coastal provinces and three ecoregions. Thus the current analysis mixes a number of different areas which likely have different natural invasion rates as well as numbers of ballast-mediated invasions.

Before the Wisconsin glacier, natural invasions into the freshwater bodies of the current Great Lakes region were presumably minimal and less than that for the Pacific Coast. After the retreat of the glaciers, there was relatively rapid population of at least some lakes and ponds (e.g., Daniels and Peteet, 1998), though it is not clear whether this would be considered "natural invasions" or a re-colonization process. Thus, it is not clear that ecologically relevant natural invasion rates could be generated for the Great Lakes or whether the standards resulting from an analysis of coastal regions would be applicable to the Great Lakes.

Recommendations/Conclusions:
We conclude that given the lack of peer review and the high level of uncertainty, the current range of values based on the natural invasion approach should not be used to generate discharge standards. Furthermore, given the inherent uncertainties with the approach, we do not believe that even a revised analysis should be used to generate national discharge standards.

Because the natural invasion rate approach is the only technique that attempts to define an ecologically acceptable invasion rate other than 0, values from a revised analysis could be used as an informal benchmark for comparisons with values generated by other methods. The purpose of such comparisons would be to put results from other methods in context with our current understanding of natural invasion rates. Such a comparison would require that all the techniques use similar assumptions regarding ballast water discharge volumes and organism concentrations.

If the natural invasion rate approach is to be considered either as a formal approach to developing discharge standards or as an informal benchmark for other approaches, it is critical that it be further developed and reviewed not only by invasion biologists but also paleontologists, biogeographers, and geneticists working on connectivity among transoceanic populations. Any future development should address the limitations mentioned above, especially those that are likely to reduce the discharge standards artificially. Such an analysis should develop estimates of uncertainty around the predictions.

Any further development should expand the geographic range considered. Instead of assessing invasion rates across a political entity (California) it would be more ecologically relevant to generate estimates by the biogeographic ecoregions making up the U.S. Pacific Coast. If each ecoregion was evaluated independently, it would then be possible to generate confidence intervals around the suite of estimates. Within the north Pacific, Hawaii provides a "natural experiment" on rates of colonization and speciation, and such an analysis could draw on the efforts to document the biodiversity of the Hawaiian Islands (Eldridge, 2006) as well as their evolutionary history (Price and Clague, 2002). Additionally, natural invasion rates should be evaluated on the East Coast of the United States, especially given the large number of amphi-Atlantic species (e.g., Vermeij, 2005).

VI. REACTION-DIFFUSION MODELS

Henry Lee II and Deborah A. Reusser

Overview:
Reaction-diffusion models predict the concentration of a "substance" that is simultaneously influenced both by diffusion (dilution) and by some type of reaction affecting its concentration (e.g., chemical reaction, population growth). Their applications to biological systems have been reviewed by Okubo and Levin (2002) and Sexton et al. (2009) while their application to invasions is discussed in Kinlan and Hastings (2005). The basic assumptions of this family of models in terms of invasions (Kinlan and Hastings, 2005) are: 1) they model continuous time and space; 2) there is local random movement of individuals; and 3) population dynamics are deterministic. The primary use of reaction-diffusion models in invasion biology has been the theoretical analysis of the pattern of invasion spread of terrestrial invaders, with the models usually predicting a linear rate of spread under the most common assumptions. The only published example of a reaction-diffusion model being applied to determining ballast water standards that we are aware of is that of Drake et al. (2005).

Application to Ballast Water Discharges by Drake et al. (2005):
Drake et al. (2005) developed a reaction-diffusion model with an Allee effect to predict the probability of establishment of species based on the volume of ballast water released. Note that this approach predicts "acceptable volumes" of ballast water and does not directly use or predict concentrations of organisms in the ballast water. Thus, it does not directly generate an organism-based discharge standard.

The form of the model used by Drake et al. (2005) to predict the change in the density of a species released via a ballast water discharge was:

Equation 4: $$\frac{\partial u}{\partial t} = D\nabla^2 u + f(u)$$

Where:
u (relative density) = local population density scaled by carrying capacity (i.e., between 0 and 1)

t = time

D = diffusivity of discharged ballast water (m^2s^{-1})

∇ = Laplace operator defining the spatial gradient over two dimensions

$f(u)$ = model describing local population growth (change in relative density/time)

In Equation 4, the first set of terms is the "diffusion" component of the model which models the dilution of the individuals in the water column over time. The second function captures the simultaneous population growth, which is the "reaction" component. By normalizing population size to carrying capacity, the model does not predict a population concentration but rather changes in relative population size over time due to the combined effects of dilution and population growth (see Lewis and Kareiva, 1993).

Using the cubic population model from Lewis and Kareiva (1993), the local growth of a species subject to an Allee effect was modeled as:

Equation 5: $f(u) = ru(1-u)(u-a)$

Where:
r = intrinsic rate of population increase (day^{-1})

a = Allee "critical density" (unitless).

The form of the relative population growth rate as a function of population size from Equation 5 is illustrated in Figures 4 and 5. In this model, an Allee effect occurs when $0 < a < 1$, where a represents the fraction of the carrying capacity below which the detrimental effects of a low density result in negative population growth (Lewis and Kareiva, 1993). As can be seen in Figure 4, inclusion of a mild Allee effect has a minor effect on population growth over most densities. It is only at very low relative densities (Figure 5) that the Allee effect results in a noticeable decrease in relative population growth. The decline in growth rate above a relative density of about 0.7 is due to negative intraspecific interactions.

Assuming a mild Allee effect and an initial population density substantially above the critical density (a), the necessary and sufficient conditions for the establishment of a population of an introduced species in terms of area occupied is:

Equation 6: $R_{\min} = \dfrac{1}{1/2 - a}\sqrt{\dfrac{D}{2r}}$

Where:
$R_{\min}$ = radius of the initially occupied area from the ballast discharge (m).

To convert this area into a volume, Drake et al. (2005) assumed that the ballast water was dispersed within a 10 m deep zone. Based on this assumption and setting the radius of the cylinder to $R_{\min}$, they calculated $V_{\max}$, the "maximum volume of [ballast] water that may be released to maintain the risk of population establishment at or below a level that would be specified by policy." The risk of population establishment was calculated by utilizing different values of r as described below.

Using the data from Figure 17 of Blueweiss et al. (1978), Drake et al. (2005) generated a regression between body mass and population growth rate (r) (their equation not given). They then estimated the maximum per capita population growth rate, $r_{\max}$, using the upper 0.01, 0.001, and 0.0001 confidence levels of the regression. These upper confidence levels were used as a method to establish a range of "risk tolerances", which represent the probability that a species would become established. Based on Lewis and Kareiva (1993), they then set r_{max} as approximately equal to $4 \times r$ or $r = r_{max}/4$. Substituting r_{max} for r in Equation 6 results in:

Equation 7: $$R_{min} = \frac{2}{1/2 - a}\sqrt{\frac{D}{2r_{max}}}$$

Based on the r_{max} from body size and for given "*a*" (critical density) and *D* (diffusivity), it is possible to calculate R_{min}. Assuming a 10 m depth (*d*), it is then possible to calculate V_{max}, the maximum volume of ballast water that can be discharged at a specified risk level (from the confidence level of the *r*):

Equation 8: $$V_{max} = \pi R_{min}{}^2 d$$ $$V_{max} = \pi R_{min}{}^2 d$$

Where:
V_{max} = maximum volume of ballast water discharge for specified risk level (m^3)

d = depth (m)

Parameter Estimation:
Drake et al. (2005) assumed an Allee effect equal to $a = 0.01$. With this threshold, the population experiences negative growth from an Allee effect at <1% of its carrying capacity (Figure 5). While considered a "mild" Allee effect (i.e., "*a*" is a small fraction of the carrying capacity), it may actually be an important factor at the discharge standards that have been proposed (e.g., 0.01 to 10 organisms > 50 microns per m^3).

As mentioned, a single depth (d) of 10 m was assumed for all ballast water discharges. V_{max} scales linearly with depth so the "exact value is not hugely important". The authors used two horizontal diffusivity values in their calculations, 0.02 $m^2\,s^{-1}$ and 0.3 $m^2\,s^{-1}$, the minimum and maximum values reported from a study of lakes. These values are substantially lower than those found in many estuarine/marine systems, which can have diffusivities over 1000 $m^2\,s^{-1}$ (e.g., Banas et al., 2004; also see Figure 5 of Drake et al., 2005). Because the probability of invasion decreases as diffusivity increases, the use of these lower values is protective of exposed marine/estuarine conditions. However, as noted by the authors, the lake diffusion values may not be protective in enclosed harbors which physically restrict diffusion (see their Figure 5). Note that the diffusivity values in $m^2\,s^{-1}$ need to be multiplied by 86,400 to convert them to $m^2\,day^{-1}$ so that the units are consistent with the intrinsic rate of growth (day^{-1}) when used in Equations 6 and 7.

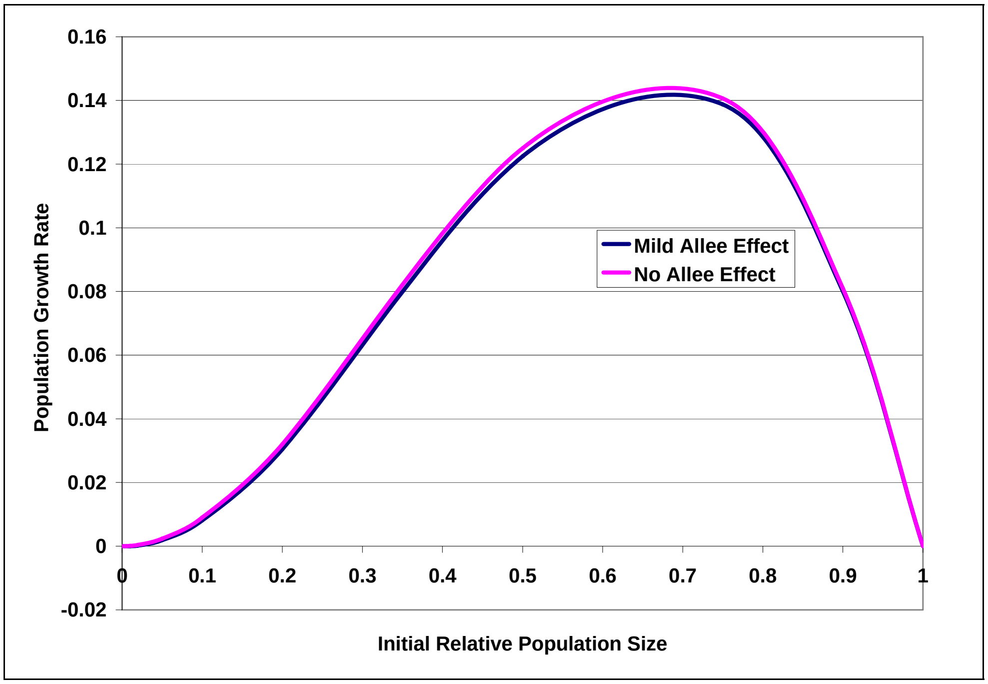


Figure 4: Example of relative population growth rate based on the cubic population model from Lewis and Kareiva (1993) with and without a mild Allee effect (*a* = 0.01). The relative population size is the population of a species at a given time in relation to that species carrying capacity. The decrease in growth rate at high relative population is due to negative intraspecific interactions.

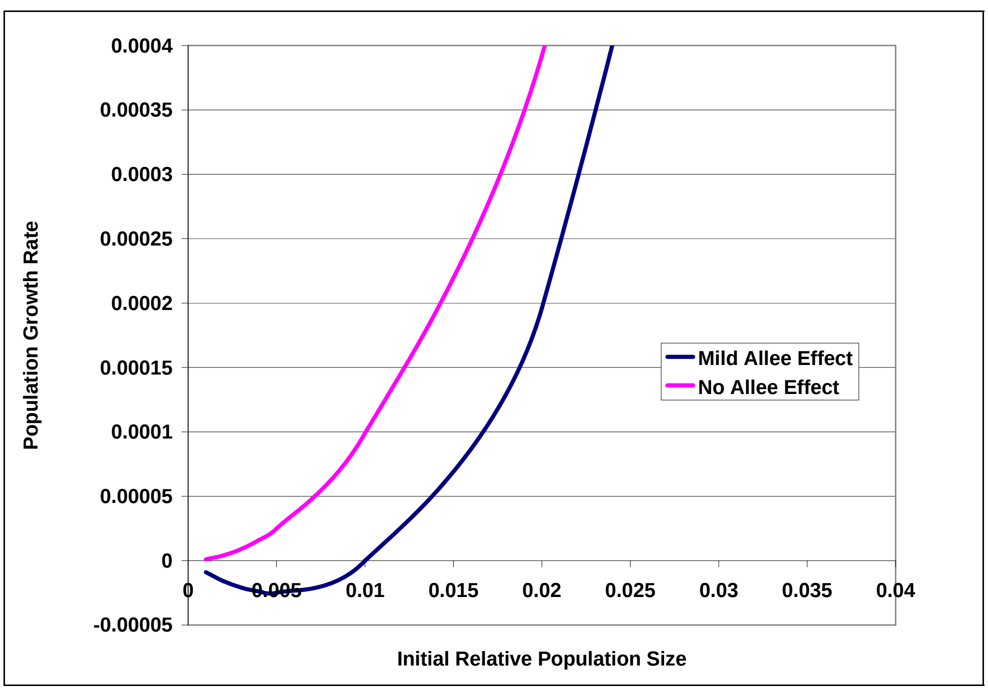


Figure 5: Enlargement of the relative population growth rate based on the cubic population model from Lewis and Kareiva (1993) with and without a mild Allee effect (*a* = 0.01). The population growth becomes negative below a relative density of 0.01 due to the Allee effect.

Drake et al. (2005) use risk tolerance values of p = 0.01, p = 0.001, and p= 0.0001 to represent the "chance of establishment per introduction" to bracket different levels of protection. These risk tolerance values are derived from the upper confidence levels around the allometric relationship between body size and intrinsic rate of population increase (*r*). The validity of the resulting values is discussed below.

Assumptions and Limitations:
The major limitation of the analysis by Drake et al. (2005) for development of discharge standards is that it generates acceptable volumes of ballast water discharges rather than risks associated with the discharge of different organism concentrations. Therefore, it can not be used to generate organism-based discharge standards. We initially attempted to convert their analysis to a concentration basis, but this would require, at the minimum, estimates of carrying capacities for the species in the ballast discharge, which are unknown for nearly all the invertebrates and larval fishes entrained in ballast water. However, as discussed under Recommendations/ Conclusions, it would be possible to use a different form of a reaction-diffusion model or other types of dilution models to predict changes in organism concentrations resulting from dilution.

A general limitation of using reaction-diffusion models to develop ballast water discharge standards is that they only apply to small holoplanktonic species (such as calanoid copepods), that spend their entire adult life span in the water column and that are passively transported by currents. Species with pelagic larvae (e.g., most polychaetes and mollusks) that actively settle out of the water column violate several key model assumptions including: 1) individuals are passively distributed by currents; 2) species complete their life span within the water column; and 3) population dynamics are rapid compared to redistribution through diffusion. Pelagic species such as fish that remain within the water column but which actively swim violate the assumption of passive dispersal and, in nearly all cases, the assumption that population dynamics are rapid compared to diffusion. Because holoplanktonic species make up a relatively small fraction of the total marine/estuarine invaders (see Ruiz et al., 2000; Wonham and Carlton, 2005), this family of models can address only a subset of potential invaders in these systems. Even in the Great Lakes, zooplankton only constitutes 6 of the 37 (16%) fish and invertebrates introduced via "shipping, Ballast Water" (calculated from data at http://www.glerl.noaa.gov/res/Programs/ncrais/docs/great-lakes-list.xls).

Drake et al. (2005) generated a range of "acceptable" ballast water volumes for "invasion risk tolerances" of 0.01, 0.001, and 0.0001. The risk tolerance represents the probability of an invasion of an unknown species; so a risk of 0.0001 means that there is a 1 in 10,000 chance that an invader will become established. These risk tolerances are the probabilities that a single species will become established. However, as discussed in more detail under the PVA model (Section VII), the key environmental question is not whether any particular species will become established but rather whether any of the multitude of species in a ballast discharge will successfully invade. This multi-species risk is calculated as the risk of a single species not invading raised to the power of the number of species in the ballast discharge. Assuming 100 species in a ballast discharge and an individual species' risk tolerance of 0.0001, the probability of a single species not invading is 0.9999; when this is raised to the 100^{th} power, the result (0.99) is the probability of all 100 species not invading. With this multi-species scenario the probability of no species invading is about 1 in a hundred. Thus, even the lowest invasion risk tolerance value used by these authors results in a very high risk of invasion when considering all the species potentially present in a ballast discharge.

It is not possible to use lower risk tolerances in this model because of how they were determined. The risk tolerance levels were generated from the upper confidence limits of "*r*" from the regression of intrinsic rate of growth versus body size. For example, to establish the acceptable volume of ballast discharge at an invasion risk tolerance of 0.0001, they used the intrinsic rate of growth equal to the upper 0.0001 confidence level for the particular size of organism in Equation 7. While an innovative approach, the problem is that the intrinsic growth rates associated with the upper 0.001 and 0.0001 upper confidence levels are unrealistically high. For example, back-calculating from their equations using a risk tolerance of 0.0001, we obtained an intrinsic growth rate (r) greater than 18 day^{-1}. This value is at least an order of magnitude greater than nearly all metazoans, and even for ciliated protozoans the highest value was 6.3 day^{-1} (Taylor and Shuter, 1981). Thus, this approach to setting different protection levels is limited to risk tolerance levels around 0.01, a very high, and presumably unacceptable, invasion risk.

The authors state that the derivation of Equation 6 assumes that the original release density u_0 is "considerably above the Allee threshold a". Given the low proposed discharge standards (0.01 – 10 organisms m^{-3}) it is possible that ballast water concentrations of individual species will not be "considerably" above Allee thresholds. However, it is not clear whether this assumption is actually required for the derivation of the equation or simply that ballast discharge densities below the Allee threshold result in negative growth in Equation 2 and thus result in "relatively little threat of invasion".

The solution in Equation 6 "obtained from Lewis and Kareiva (1993) relies on the assumption that population dynamics are relatively fast compared to organism redistribution through diffusion" (Drake et al., 2005). To evaluate this assumption, the authors conducted numerical simulations to evaluate the potential effects on their results. Based on these simulations, the authors concluded that their model would underestimate the acceptable ballast water volume for larger species (= species with slower population growth rates). From their Figure 3, biased estimates occur for organisms larger than about 0.05 grams, which they list as fish and ctenophores. The lower boundary of adult size for amphipods, decapods, copepods, and ostracods is listed as less than 0.05 grams, and thus have unbiased estimates. They do not state how biomass is measured, but we assume that it is wet weight.

Recommendations/Conclusions:
The work by Drake et al. (2005) can not be used to generate organism-based discharge standards since it is based on "relative densities" to predict acceptable volumes of ballast discharge. However, it should be possible to generate reaction-diffusion models addressing ballast water discharges that utilize actual densities rather than relative densities, though this would require estimates of species specific population vital rates. Alternatively, it may be possible to link population growth models with models simulating dilution of pollutant discharges, such as Visual Plumes or CORMIX2 (see http://www.epa.gov/waterscience/standards/mixingzone/resources.html#models). In this case, the dilution models would be "turned on their head" and the ballast discharge would occur at the surface rather than from depth. These simulation models are "mature" and allow for inclusion of

real world complications not readily captured in analytical models, such as density differences between discharged and receiving waters. Without further analysis, however, it is not clear to what extent the existing dilution models would have to be modified to model ballast discharges.

The more germane question is how much effort should be devoted to diffusion models in general for the generation of organism-based discharge standards. Violation of the assumption that species are passively distributed is likely to result in a substantial underestimation of the likelihood of establishment of a species. In particular, benthic species whose larval and/or juvenile phases actively settle out of the water column are much more likely to become established than predicted from dilution models. Thus, in aquatic environments, diffusion models are primarily limited to predicting invasions of small, holoplanktonic organisms. Because of this limitation, diffusion models do not appear to be suitable for generating concentration-based discharge standards applicable to the wide range of taxa found in ballast water.

While not suitable as a general approach to generating discharge standards, results from diffusion models with holoplanktonic organisms can be used to help elucidate the role of population dilution in initial establishment. Such an analysis may help explain why there are relatively few copepod invaders in marine/estuarine systems even though they make up a substantial portion of the fauna in ballast water (e.g., Lavoie et al., 1999; Levings et al., 2004).

VII. POPULATION VIABILITY ANALYSIS (PVA) MODELS

Henry Lee II

Overview:
Population viability analysis (PVA) models are a family of population growth models commonly used in the conservation field to predict the extinction probability of endangered species (Beissinger and McCullough, 2002; Morris and Doak, 2002). The basic premise of PVA models is that any population undergoing stochastic growth has a certain probability of going extinct even if it is presently showing positive growth. In general, the smaller the population size, the slower the population growth rate, or the larger the variation in population growth rate, the greater the probability of extinction. There are three general types of PVA models: 1) count-based PVA; 2) demographic PVA; and 3) spatially explicit PVA. The count based PVA is the simplest, and utilizes historical census data to estimate population growth rate and variation assuming all individuals are identical. The diffusion approximation of Dennis et al. (1991) is the simplest of the count-based PVA models and is based on two parameters -- the instantaneous population growth rate and instantaneous variation in the population growth rate. The diffusion approximation is most suitable when there is a lack of detailed life history information. Demographic PVA models are based on population projection matrices that incorporate size- or age-specific demographic vital rates, and thus incorporate differences among age/size groups. Spatially explicit PVA models are the most complex and incorporate population migration and colonization into and out of areas.

There is growing recognition that PVA models are a potential tool to predict the establishment and spread of nonindigenous species (Andersen, 2005). When used with nonindigenous species, the objective is to predict either the time to extinction or the probability of extinction for an invader, where extinction is the converse of establishment. Recently, PVA models have also been evaluated in laboratory experiments on population dynamics to gain insights into the invasion process (see Section IX). In this section, we examine the PVA analysis conducted in the USCG Draft Programmatic Environmental Impact Statement (DPEIS; USCG, 2008). We detail this analysis both because it is part of the technical analysis used by the USCG in setting their proposed rules (USCG, 2009) and because it is the only study that we are aware of that used PVA models to directly address ballast water standards. However, as discussed below, the formulation used in the DPEIS is not the only possible PVA methodology to addressing the risks associated with ballast discharges.

PVA Model Used in USCG Risk Assessment for Single Species Scenario:
The DPEIS used the diffusion approximation model (Dennis et al., 1991). The strategy taken in the DPEIS was to evaluate different discharge standards by predicting the relative increase in the probability of extinction based on the fractional reductions in the number of organisms per cubic meter of ballast discharge. This is a relative approach and it was not the objective of the DPEIS analysis to predict the actual probability of invasion associated with any specific organism.

In their analysis, the DPEIS listed five potential treatment alternatives, which for the >50 micron size group were:

Alternative 1: No Action (no ballast water treatment is implemented and ballast water exchange is the preferred option if vessels can conduct it).

Alternative 2: <10 organisms m^{-3} (= IMO standard)

Alternative 3: <1 organisms m^{-3} (= $1/10^{th}$ IMO standard)

Alternative 4: <0.1 organisms m^{-3} (= $1/100^{th}$ IMO standard)

Alternative 5: 0 organisms (= sterilization)

Alternative 1 (No Action) was taken as the baseline against which the other treatments were compared. Ranges in organism concentrations for both unexchanged and exchanged ballast water were used to establish this baseline. Alternative 5 was not formally analyzed because no invasions would occur with sterilization. The DPEIS did not analyze the USCG Phase II standards (= $1/1000^{th}$ IMO standard), but when possible we include such an analysis for the >50 micron organisms.

The remainder of this sub-section will detail the diffusion model and input parameters used in the DPEIS for a single species analysis, which implicitly assumes that all the individuals in a ballast discharge are of single species. The parameters used in the PVA model are given in Table 5, and for all population rates we assume a time unit of a day. The reader is referred to Sections 4 and 5 of Appendix A of the DPEIS for a more detailed derivation of the equations.

The simplest model of population dynamics incorporating stochastic variation is:

Equation 9: $dX(t) = \mu dt + \sigma dW(t)$

In this model, dW(t) is a normal random variable that adds randomness to the population dynamics. The larger the value of dW(t) and/or the larger the instantaneous standard deviation of the population, the larger the swings in population size, and the more likely that the population will drop to the critical population threshold (n_e). Populations with negative growth ($\mu < 0$) will go extinct regardless of initial population size (N(0)) and are not further considered. For populations with positive growth ($\mu > 0$), the probability that a population with an initial size of N(0) will go extinct (i.e., reach the critical population threshold) is:

Equation 10: $p_e = \exp(-2\ \mu\ \text{‘d’} / \sigma) = e^{(-2\ \mu\ \text{‘d’} / \sigma)}$

[Note: Equation 10 is a direct reproduction of Equation 3 in the DPEIS (App. 4, p. A-25); we assume this represents a typographical error and that the authors meant to write:

$p_e = \exp(-2\ \mu\ \text{‘d’} / \sigma^2)$

This equation indeed can be rearranged to Equation 5 in the DPEIS (our Equation 11).]

Table 5: Parameters used in the PVA models in the DPEIS.

$N(0)$ = population size at time 0 (initial population size)

$N(t)$ = population size at time t

$X(t) = \log N(t)$ (log of population size at time t)

μ = instantaneous population growth rate

σ^2 = instantaneous variance of the population growth rate

σ = instantaneous standard deviation of the population growth rate

$dW(t)$ = normal random variable with mean 0 and variance 1 (to add random variation in population dynamics)

n_e = critical population threshold at which the population is considered "extinct" (quasi-extinction). The critical threshold is assumed to be 1 individual in the DPEIS for the single species scenario, which is the smallest possible value.

$x_e = \log n_e$

p_e = probability that a population with initial size N(0) will go extinct

'd' $= X(0) - x_e = \log (N(0)/n_e)$ Log of the ratio of the initial population size to the critical population threshold. (Note that we put quotes around d to differentiate it from "delta" in the rate equations)

$c = 2\,\mu / \sigma^2$ = "biological parameter" (ratio of instantaneous growth rate to instantaneous variance in growth rate; see Equation 85 of Dennis et al., 1991)

exp = exponential function

f = fractional decrease in the initial population size (N(0)) due to a ballast water treatment. f is calculated as the ratio of the total number of organisms discharged under a particular management Alternative to the number discharged under Alternative 1 (No Action option).

$p_e(f)$ = probability of extinction as a function of the fractional decrease in initial population size

f_e = fractional effect on extinction probability (p_e) of reducing initial population size (N(0)) by the factor f. Equal to ratio of probability of extinction with the fractional decrease (f) in initial population size to the probability without the decrease ($= p_e(f) / p_e$).

f_r = the proportion of the mean rate of successful introductions relative to that under Alternative 1 (No Action option)

DE = number of discharge events when calculating joint probabilities of no establishment of a single species from multiple identical discharge events

Assuming positive growth, the corrected version of Equation 10 can be rewritten as:

Equation 11: $p_e = (n_e / N(0))^c$ Where $N(0) \geq n_e$

This equation predicts the probability of extinction (i.e., an invader not becoming established) based on the initial propagule supply (N(0) = organism concentration in ballast * volume of ballast discharged). However, these predictions require quantitative estimates of instantaneous population growth and variance for the specific species. As discussed in the DPEIS, such values are not available for most marine/estuarine or freshwater fishes and invertebrates. Additionally, the specific species composition in foreign ballast discharges is not known. The strategy taken in the DPEIS to circumvent these limitations was to calculate relative changes in the probability of extinction as a function of fractional decreases (f) in the initial population size resulting from different levels of ballast water treatment.

To calculate the relative fractional reductions in initial population size (f) by treatment type, the DPEIS first estimated the range of organism concentrations in unexchanged ballast water and the range that these concentrations would be reduced by ballast water exchange. The range in concentrations in unexchanged ballast water includes concentrations below the IMO limit, thus the range in the percent removal from ballast exchange includes 0 (no reduction). As discussed below, ballast water concentrations below the IMO standard are considered a rare event. From these estimates, they calculated a range of initial population sizes for Alternative 1, which were used to calculate the range in fractional decreases in initial population size in the other treatment alternatives (Table 6).

Because the DPEIS used the lower and upper bounds of organism concentrations in their analyses, there is a wide spread in the fractional decreases for the ballast water treatment alternatives, including 1 (= no reduction). We believe more representative fractional decreases for the >50 micron size group can be calculated from the relative decrease in median propagule doses from ships undergoing ballast water exchange (BWE) versus the doses based on the IMO standards (data from Table 1 of Minton et al., 2005). Under this scenario, the IMO standard resulted in a median fractional decrease slightly more than an order of magnitude (0.094) compared to exchanged ballast water. (A similar comparison to the dose from unexchanged ballast resulted in a fractional decrease of slightly more than 100-fold.) Based on this, we then reduced the fractional decreases in Alternatives 3 and 4 and the USCG Phase II standards each by an order of magnitude, representative of the changes in their ballast water concentrations (Table 6).

Estimates of the biological parameter "c" are needed to translate the fractional decreases in Table 6 to f_e, the factor by which the reduction in initial population size increases the extinction probability. The parameter c ($=2\mu / \sigma^2$) is based on the ratio between instantaneous growth rate and its instantaneous variance and is a critical variable determining the probability of extinction (see Equation 85 of Dennis et al., 1991). As pointed out in the DPEIS, the value of c can vary substantially among taxa and with environmental conditions. They address this uncertainty by using a range of 0.001 to 0.1, though they do not give a detailed justification for these values. A value of 0.1 means that the variance of the instantaneous growth rate is 20 times greater than

Table 6: Ranges in the fractional decreases (f) in initial ballast water population size generated by treatment Alternatives 2 - 4 relative to the range of population sizes in Alternative 1 used by the DPEIS. A value of 0.1 signifies that the initial population size was reduced to 1/10th of the size in Alternative 1 while a value of 1 indicates that there was no decrease relative to Alternative 1. The bolded value for the >50 micron size class for Alternative 2 is a recalculated fractional decrease based on the reduction in median propagule dose associated with the IMO standard versus that associated with exchanged but untreated ballast (concentrations from Minton et al., 2005). The recalculated fractional decreases for the other alternatives based on proportional decreases relative to the IMO standard are also bolded. NC = not calculated in the DPEIS.

Alternative	**Fractional Decrease (f) (10-50 micron taxa)**	**Fractional Decrease (f) (>50 micron taxa)**
Alternative 2 (IMO)	0.1 – 1	0.001 – 1 **(0.1)**
Alternative 3 (1/10th IMO)	0.01 – 1	0.0001 – 0.1 **(0.01)**
Alternative 4 (1/100th IMO)	0.001 – 1	0.00001 – 0.01 **(0.001)**
USCG Phase II (1/1000th IMO)	NC	NC **0.0001**

mean instantaneous growth rate, while a value of 0.001 means that the variance is 2000 times greater. Populations of small invertebrates can be highly variable, but without a quantitative review of their population dynamics it is unclear whether variances on the order of 1000 fold greater than the mean growth rate are representative of many or most species likely to be discharged in ballast water. The significance of these high variances (= low values of c) is that they increase the probability of extinction (Equation 11) because larger population variation increases the likelihood that the population will drop below the critical population threshold (n_e).

Once f and c are estimated, it is then possible to calculate the probability of extinction resulting from the fractional decrease in the initial population size (f):

Equation 12: $p_e(f) = f^{-c}\, p_e \;=\; f^{-c}\, (n_e / N(0))^c$

The effect of reducing the initial population size discharged under each of the treatment alternatives on the probability of extinction can be expressed by f_e, the ratio of the extinction probability with and without the fractional decrease in initial population size resulting from the treatment alternative:

Equation 13: $f_e = f^{-c} = p_e(f)/p_e$

The DPEIS used these formulas to evaluate the sensitivity of extinction probabilities to a range of values of c (their Table 5-2). For small values of c they noted the relative insensitivity of extinction probability to the density of organisms in the ballast. We have recalculated the probabilities (Table 7) and believe that the apparent insensitivity to initial densities needs to be re-examined. In this recalculation we used the assumptions in the DPEIS of a critical population threshold of 1 organism and a ballast discharge volume (used to calculate N(0)) of 10,000 m^3. In Table 7, we report the values with three decimal places (versus two in their Table 5-2) so that it is possible to see that decreasing organism density does in fact increase the likelihood of extinction. Additionally, the apparent insensitivity to organism density is partially due to the high extinction probabilities (>97%) with low values of c, so that there is not "much room" to increase the probability of extinction.

Another key point is that the "small" differences in extinction probabilities become important when considering the joint extinction probabilities of multiple species (discussed below) or with discharges from multiple ships. To explore the risk associated with multiple ship discharges, we calculated the probability that a species would not become established assuming 10 independent, identical ballast water discharges of 10,000 m^3. The probability of extinction resulting from 10 independent discharges of the same species is calculated by raising the probability that the species did not become established in a single event raised to the 10th power.

Table 7: Probability of extinction (p_e) expressed as a function of the initial organism concentrations (>50 microns) in ballast water and the "biological parameter" c for a single species. Extinction probabilities are calculated from Equation 11 based on a single discharge event of 10,000 m^3 with a critical population threshold of 1 organism. The probability that the species becomes established is 1 minus the probability of extinction given in the table, thus the higher the value, the lower the risk of invasion. While the probabilities of extinction are given as actual values, the data are most appropriately analyzed as relative differences among organism concentrations or values of c. Modified from Table 5-2 of the DPEIS, including adding the organism concentration for the USCG Phase II standard.

	Initial Organism Concentration (>50 microns) in Ballast Water (organisms m^{-3})								
c	10^{-2} (USCG Phase II)	10^{-1} (1/100th IMO)	10^{0} (1/10th IMO)	10^{1} (IMO)	10^{2}	10^{3}	10^{4}	10^{6}	10^{8}
0.001	0.995	0.993	0.991	0.989	0.986	0.984	0.982	0.977	0.973
0.01	0.955	0.933	0.912	0.891	0.871	0.851	0.832	0.794	0.759
0.1	0.631	0.501	0.398	0.316	0.251	0.199	0.158	0.100	0.063

The probability of the species becoming established is 1 minus the joint probabilities of extinction across the multiple voyages. This approach is similar to considering the risks from multiple species (discussed below), and the general formula for multiple voyages is:

Equation 14: Probability of a single species becoming established from multiple, identical discharges = $1 - p_e^{DE}$

Where:
DE = number of identical, independent discharge events of the same species.

Results from our analysis of probability of extinction of a single species from 10 identical discharge events are given in Table 8. Considering the risk of multiple discharge events highlights the importance of reducing organism concentrations. For example, at the lowest value of c (0.001), the calculated risk of invasion at the Phase II standard is 0.045 versus 0.1087 for the IMO standard, more than a two-fold reduction in risk with the more stringent standard. A similar two-fold difference in invasion risk was also seen with these standards with a c value of 0.01. The key point from results given in Tables 7 and 8 is that reductions in the organism concentrations in ballast water result in ecologically significant relative decreases in the invasion risk even for species and environments with a naturally low invasion probability (= species/environments with low value of c).

Table 8: Probability of extinction (p_e) as a function of the initial organism concentrations in ballast water and the "biological parameter" c for a single species for 10 identical, independent discharge events. Extinction probabilities are calculated from Equation 11 based on 10 discharge events each of 10,000 m^3 with a critical population threshold of 1 organism. The probability that the species becomes established is 1 minus the probability of extinction given in the table, thus the higher the value, the lower the risk of invasion. While the probabilities of extinction are given as actual values, the data are most appropriately analyzed as relative differences among organism concentrations or values of c.

	Initial Organism Concentration (>50 microns) in Ballast Water (organisms m^{-3})								
c	10^{-2} (USCG Phase II)	10^{-1} (1/100th IMO)	10^{0} (1/10th IMO)	10^{1}	10^{2}	10^{3}	10^{4}	10^{6}	10^{8}
0.001	0.955	0.933	0.912	0.891	0.871	0.851	0.832	0.794	0.759
0.01	0.631	0.501	0.398	0.316	0.251	0.199	0.158	0.100	0.063
0.1	0.010	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000

The DPEIS then goes on to analyze the results as the range in the factor by which the extinction probability would be increased compared to Alternative 1 (versus the absolute values in Table 7). This extinction probability factor (f_e) was calculated from Equation 13 for Alternatives 2-4. Their ranges in f_e for the >50 micron size class are replicated in Table 9 along with our analysis for multiple voyages. For the multiple ship voyages, we calculated f_e from $p_e(f)/p_e$ (see Equation 13). We first calculated p_e for a single voyage based on the assumptions of an organism concentration of 1,000 m^{-3} after ballast water exchange, a discharge volume of 10,000 m^3 per voyage, and a critical population threshold of 1 organism. The $p_e(f)$ were calculated using the same assumptions and the organism concentration associated with each treatment. Then both extinction probabilities for a single voyage were raised to the 10^{th} power and the ratio calculated. The results in Table 9 from a single voyage show that for the lowest c (high variance compared to growth rate), the treatment alternatives do not increase the probability of invasion. As discussed above, this is a consequence, in part, of the high rate of extinction for species with a high population variance. For the species with a lower variance (higher c), the extinction rates can increase two to three fold with the additional reduction of organism concentrations in the ballast.

Table 9: Factor by which the probability of extinction would be increased compared to Alternative 1 (f_e) for >50 micron organisms. The values in Column I represent the f_e for the range in fractional decrease values (f) and in c for a single voyage calculated in the DPEIS. Column II is our calculations of f_e for 10 independent voyages using only the range in c. Modified from Table 5-3 of the DPEIS.

Alternative	**c**	**f**	**I. Single Voyage f_e (range in f & c)**	**II. Multiple Voyages f_e (range of c)**
Alternative 2 (IMO)	0.001 – 0.1	0.001 – 1.0	1.0 – 2.0	1.047 – 100
Alternative 3 (1/10th IMO)	0.001 – 0.1	0.0001 – 1.0	1.0 – 2.51	1.072 – 1000
Alternative 4 (1/100th IMO)	0.001 – 0.1	0.00001 – 1.0	1.0 – 3.16	1.097 – 10,000
Phase II USCG (1/1000th IMO)	0.001 – 0.1	-	-	1.122 – 100,00

With multiple voyages using the median reduction in concentration, there is a relatively small increase in the extinction rate, about 5% to 12%, with the low values of c. However, with the high values of c, the extinction rate increased by orders of magnitude, 100 to 100,000 times, compared to concentrations associated with exchanged ballast water. This result suggests that the importance of decreasing organism concentrations in the ballast becomes increasingly important when there is a likelihood of multiple ships discharging the same organisms within a port. The analysis of the multiple voyages was not part of the DPEIS and we consider these results preliminary. Nonetheless, they suggest that further analysis of the risk of invasion from multiple voyages is warranted.

The final analysis in the DPEIS for single species was to calculate f_r, the mean rate of successful introductions for a treatment relative to Alternative 1. Recalling that the probability of introduction is 1- probability of extinction, f_r is calculated as:

Equation 15: $$f_r = \frac{1 - p_e(f)}{1 - p_e}$$

The numerator in this equation is the probability that invaders will become established with the organism concentration associated with the treatment alternative while the denominator is the extinction probability under Alternative 1. As before, the extinction probabilities were calculated assuming a critical population threshold (n_e) of 1 organism, a ballast discharge of 10,000 m^3, and range of values for c and organism concentrations. The ranges in f_r for the two size fractions from the DPEIS are given in Table 10. We also analyze the ratio of successful invaders using the p_e calculated using a concentration of 1000 m^{-3}, the approximate modal organism concentration after ballast water exchange (from Figure 2 in Minton et al., 2005).

Table 10: Mean rate of successful introductions for treatment alternatives relative to Alternative 1. The ranges in the first two columns are from the DPEIS and were derived from a range of both organism concentrations in unexchanged or exchanged ballast water and a range of c values (Table 5-4 of the DPEIS). To better focus on long-term trends, we compared the treatment alternatives to a single organism concentration of 1000 m^{-3} for ballast water exchange (BWE) and a range of value for c. The smaller the value, the greater the relative reduction in invasion risk compared to Alternative 1 or BWE.

Alternative	Single Voyage: 10 – 50 micron organisms (DPEIS range)	Single Voyage: >50 micron organisms (DPEIS range)	Single Voyage: >50 micron organisms (Comparison to BWE)
Alternative 2 (IMO)	0.92-1.0	0.50-1.0	0.71 – 0.85
Alternative 3 (1/10th IMO)	0.67-1.0	0.50-1.0	0.57 – 0.75
Alternative 4 (1/100th IMO)	0.67-1.0	0.41-1.0	0.43 – 0.62
Phase II USCG (1/1000th IMO)	-	-	0.29 – 0.46

The conclusions in the DPEIS from their values in Table 10 are:

> "The reduction in the mean rate of successful introductions is the complement of the ranges of values presented above. As a result, the reduction in the mean rate of successful introductions, as compared to the No Action Alternative under:
>
> • Alternative 2 is expected to range between no reduction and an 8% reduction, and no reduction and a 50% reduction for smaller and larger organisms, respectively;
>
> • Alternative 3 is expected to range between no reduction and a 33% reduction, and no reduction and a 50% reduction for smaller and larger organisms, respectively;
>
> and
>
> • Alternative 4 is expected to range between no reduction and a 33% reduction, and no reduction and a 59% reduction for smaller and larger organisms, respectively."

As mentioned above, we believe the use of the median reductions in concentrations compared to exchanged ballast water rather than the ranges in the DPEIS give a more representative picture of the long-term improvement due to the treatment alternatives. For Alternatives 2-4, the use of the median organism concentrations indicates a 15% to 57% reduction in the introduction rate of >50 micron organisms. For the USCG Phase II standard, the predicted relative reduction in invasion rate is 54% to 71%.

PVA Model Used in USCG Risk Assessment for Multiple Species Analysis:

The analysis detailed above predicts the relative effects of the alternative treatment options on the invasion probability of a single species discharged in ballast water. The DPEIS also conducted a multiple species scenario, which addressed the probability of invasion by any of the multiple species in a ballast discharge. In other words, this analysis asks "What is the probability that none of the species in a ballast discharge will successfully invade?" Similar to the calculation of the probability of extinction for a single species with multiple voyages (Equation 14), the simplest equation to predict the probability that no species are introduced in a single ballast event is:

Equation 16: probability no species become established = $1 - p_e^n$

Where:
n = number of species introduced in a single ballast water discharge that are not already successfully established in the waterbody.

This equation assumes that all species are independent and that they all have the same extinction probability. The second of these assumptions would nearly always be violated because of different densities of species. The more realistic equation used in the DPEIS is:

Equation 17: $q(m) = 1 - \prod_{j=1}^{n} p_j(m)$

Where:
q(m) = probability that no species become established

$p_j(m)$ = probability that species *j* is not successfully introduced in a single ballast water discharge under treatment option m based on the density of species j

To address the different densities of species, the DPEIS calculated the relative abundances of the n species using a geometric model. Additionally, because many of the species may be rare, and thus close to the critical population threshold, they compared the probability of extinction with $n_e = 1$ and $n_e = 100$. Finally, in this section they also considered different organism population sizes resulting from unexchanged and exchanged ballast.

For brevity sake, we will not detail the steps in this analysis, and the reader is referred to Section 5 of Appendix A of the USCG Draft Programmatic Environmental Impact Statement (USCG, 2008). Rather we will present the final relative treatment efficiencies for Alternatives 2-4 compared to initial organism populations equivalent to unexchanged and exchanged ballast water discharges. From these population sizes and the assumption of 12 different species within the ballast discharge, they calculated the probability (q_m) of at least one successful introduction of a species from the ballast discharge. Probabilities that no species would successfully invade for the treatment alternatives were then determined relative to those with unexchanged ballast water or exchanged ballast water (Table 11).

Table 11: Relative efficiencies of Alternatives 2, 3 and 4 that no species successfully invades from a ballast discharge compared to unexchanged ballast water or after ballast water exchange (BWE). The analysis assumes 12 unique species in the ballast discharge. The critical population threshold (n_e) is equal to 1 or 100 organisms. Modified from Table 5-9 in the DPEIS.

	$n_e = 1$		$n_e = 100$	
Alternative	Unexchanged	BWE	Unexchanged	BWE
2 (IMO)	52%	37%	78%	63%
3 (1/10th IMO)	73%	64%	94%	90%
4 (1/100th IMO)	88%	85%	100%	100%

The conclusion that the DPEIS draws from this analysis is, "The specific reduction depends upon the alternative selected and the size class of the organism considered, but the modeling results for multiple species support the conclusion that more stringent treatment alternatives will substantially reduce the likelihood of new ballast water introductions" (DPEIS, page A-42). This analysis also emphasizes the importance of evaluating the total risk for the multiple species in ballast discharges. Finally, the reduced risk at the higher critical population threshold value illustrates the importance of this value in driving the results from PVA models, at least at the very low population densities that will be associated with the proposed ballast water standards.

Assumptions and Limitations:
Use of PVA models are not without their critics (e.g., Ludwig, 1999; Fieberg and Ellner, 2000; Coulson et al., 2001). Coulson et al. (2001) "doubt the general claim that they can be accurate in their ability to predict the future status of wild populations." More optimistically, in a review of 271 time series representing 46 taxa, Holmes et al. (2005) concluded that diffusion approximations did a reasonably good job at predicting proportional and severe population declines. They were not as good at predicting true extinction. Some of the criticisms of PVA models are blunted when the PVA models are used to evaluate relative differences among treatment alternatives rather than to predict quantitative extinction probabilities, as was noted in the DPEIS (USCG, 2008). However, analyzing relative differences precludes the use of the models to directly develop organism-based discharge standards.

Values for several of the parameters in the DPEIS are not well justified, in particular the values for c and the critical population threshold. These are critical parameters that drive the conclusions, and any future PVA modeling effort needs to justify the input values better.

The multi-species scenario was only run for the >50 micron size class in the DPEIS. As data become available, a similar analysis should be attempted with the 10-50 micron size class. Additionally, the importance of the number of species used in the analysis should be explored, as the assumption of only 12 unique taxa in the DPEIS seems low given the diversity of phytoplankton and zooplankton found in ballast water (e.g., Choi et al., 2005; Cordell et al., 2009).

In several cases, the use of extreme ranges for input parameters in the DPEIS analysis obscured the long-term benefits from reducing organism concentrations. In particular, in the single species analysis, the ranges in organism concentrations of Alternative 1 bracketed the treatment concentrations, resulting in the erroneous conclusion that the treatment alternative would offer no improvement. It is true that some ships may have essentially no organisms in their ballast but this is a rare event (see Minton et al., 2005), and on the average ballast water treatment will substantially reduce organism concentrations, and hence risk. While the DPEIS notes this in their multi-species analysis, it was not apparent in the tables or in the discussion in the single species scenario.

The greatest practical limitation in developing PVA models for marine/estuarine organisms is deriving high quality values for the instantaneous population growth rates and variation from long-term population trends. Diffusion models have primarily been applied to birds and mammals based on 10+ years of population monitoring. Such long-term population data for the marine/estuarine organisms likely to be discharged in ballast water (e.g., phytoplankton, holoplanktonic zooplankton, and benthic species with pelagic larvae) are rare. Even when long-term monitoring data are available, population estimates for marine/estuarine organisms may display a higher sampling variability than found with birds and mammals, which can affect parameter estimation (Holmes et al., 2005; Holmes, 2004).

Recommendations and Conclusions:

Given the current state of the science and data availability, PVA diffusion models are appropriate tools to estimate the relative effectiveness of different ballast water treatment alternatives. While recognizing the substantial insights into relative treatment efficiencies provided by the DPEIS (USCG, 2008), we recommend that any new efforts using PVA models should begin anew rather than building upon the models in this document. We make this suggestion, in part because of the difficulty we had in following some of the specific procedures in the DPEIS and because presenting the results in terms of the total range of ballast water organism concentrations tended to obscure the benefits of the treatment alternatives. Additionally, an independent assessment may suggest a modified approach.

The use of PVA models to generate quantitative predictions of invasion success (versus relative treatment efficiencies) is less clear. The advantage of such models is that they would provide quantitative invasion risks for proposed discharge standards. The greatest limitation is the current lack of quantitative population vital rates. Accordingly, before initiating any quantitative PVA modeling study, we recommend that a dedicated effort be undertaken to extract estimates of population growth rates and variances from long-term studies of marine/estuarine species. One obvious source are the commercial catch statistics, but this would require separating population variability from variability due to fishing related mortality and/or changes in fishing effort. There are, however, other data that would not have these confounding effects. Eckert (2003) synthesized 570 population time series for 170 invertebrate species, with the durations ranging from one to 39 years while Eckert (2009) collected 786 population time series greater than 2 years for 226 species in the Gulf of Alaska. Desmond et al. (2002) report on an eleven year record of fish and invertebrates in Southern California. We are less familiar with zooplankton, but even a cursory scan of the literature suggested that long-term records exist for several estuarine and marine copepod species (Jossi et al., 2003; Pershing et al., 2004). Not all these studies will be suitable for deriving vital rates, but with sufficient effort it should be possible to generate ecologically realistic ranges for population growth and variability for a suite of species across a range of taxa and habitats.

Whether assessing relative treatment efficiencies or quantitative risk probabilities, any future PVA analyses should focus on multiple species scenarios rather than modeling a single species. That is, the analysis should address the question “what is the likelihood of any species from a ballast discharge becoming established?” rather than “what is the likelihood of any particular species becoming established?” The former is the critical ecological and regulatory issue.

A comprehensive sensitivity analyses should be part of any new PVA modeling. In particular, a range of instantaneous growth rates and instantaneous variances in growth rate (the “c” parameter as used in the DPEIS formulation) should be explored, with the ranges based on the review of population vital rates mentioned above. Another important factor that should be evaluated is the critical population density. While a full range of values should be used for all the input parameters, it is critical that the interpretation of the results explicitly consider the likelihood of particular values so as not to obscure the general trends with rare events, such as ships with organism concentrations below the proposed standards.

Any new PVA modeling should evaluate the full range of potential discharge standards including the proposed USCG Phase II standards. Since the USCG may implement more stringent standards in an incremental fashion, we suggest that standards equivalent to 1/10th and 1/100th of the IMO standards (e.g., standards of 1 and 0.1 organisms per m^3 for the >50 micron class) also be evaluated.

VIII. PER CAPITA INVASION PROBABILITIES

Deborah A. Reusser, Henry Lee II, Melanie Frazier, and Greg Ruiz

Overview:
As discussed in Section 2, there is a general consensus that an increase in propagule supply increases the likelihood of invasion. Based on this premise, we developed a "per capita invasion probability" (PCIP) approach to estimating the likelihood of invasion based on historical invasion rates and calculated ballast-associated propagule pressures. The PCIP is the per year probability that an individual non-native propagule discharged from ballast water will become established as a new nonindigenous species in a specified waterbody. Using a linear dose response assumption, the PCIP is calculated from the historical number of potential ballast-mediated invasions in a specified waterbody over a defined time period, the average annual total ballast discharged at that location during this time period, and the estimated organism concentration in the discharged ballast water. We focus on the >50 micron size class because sufficient data are available to calculate the PCIPs for multiple waterbodies and coasts, though the approach can be applied to the 10-50 micron size class if the data are available. We calculate coastal estimates of PCIPs for the East, Gulf, and Pacific coasts of the coterminous United States as well as individual PCIP values for 17 coastal estuaries. Additionally, we include a PCIP value for the Great Lakes as a preliminary assessment of whether standards developed for the marine/estuarine systems would be protective of freshwater systems.

An advantage of this approach is that it can be used to generate quantitative discharge standards because it directly relates the risk of invasion to ballast water organism concentrations. It is important to note, however, that because of the complexities involved with the invasion process (Table 2), our objective was not to find a highly predictive relationship between the calculated propagule supply and site-specific invasion rates. Rather, our objective was to "cut through" the complexities to develop an approach to allow risk managers to generate discharge standards based on defined assumptions and risk levels.

Calculation of Per Capita Invasion Probabilities:
The per capita invasion probability (PCIP) is calculated as:

Equation 18 : $PCIP = N_h / (D_h * C_h)$

Where:
PCIP = per capita invasion probability (new invading species * organism^{-1})
N_h = historical annual invasion rate of potential ballast-associated invaders for a waterbody (new invading species * year^{-1})
D_h = historic annual foreign ballast discharge rate into a waterbody (m^3 year^{-1})
C_h = historic concentration of organisms in ballast water discharged into a waterbody (organisms * m^{-3})

As mentioned, the PCIP is the probability that an individual propagule, or organism, discharged in ballast water will become established as a new nonindigenous species within the waterbody.

For example, if one new nonindigenous species became established within a waterbody in which a total of a million individual organisms were discharged in a year, the per capita invasion probability would be 10^{-6}. Because the PCIP only accounts for new invaders, it does not address the issue of multiple invasions of currently existing nonindigenous species into a waterbody.

This model assumes a linear dose-response, with the number of invaders increasing proportionally with larger ballast water organism concentrations and/or greater volumes of ballast water discharged. Accordingly, after calculating a PCIP from a historical invasion rate, it is possible to predict the number of new, unique invaders per year for a given ballast water organism concentration and ballast water volume:

Equation 19: $N_p = PCIP * D_p * C_p$

Where:
N_p = predicted annual invasion rate of potential ballast-associated invaders for a waterbody (new invading species * $year^{-1}$)
D_p = predicted annual foreign ballast discharge rate into a waterbody (m^3 $year^{-1}$)
C_p = predicted concentration of organisms in ballast water discharged into a waterbody (organisms * m^{-3})

Foreign Ballast Water Discharge Rates for Coastal Waterbodies and the Great Lakes:
Historical average annual foreign ballast discharge rates (D_h in Equation 18) were used to calculate the total propagule supply. Discharge rates for coastal waterbodies were obtained from the Smithsonian Institution ballast water database (see the National Ballast Information Clearinghouse, http://invasions.si.edu/nbic/search.html). Estimates for the contiguous East, Gulf, and Pacific coasts were generated from discharge records from all ships discharging foreign ballast into coastal ports on the respective coasts. Only ballast identified as coming from a foreign source was included. The values in Table 12 are the average of the yearly rates for the period 2005 to 2007, which was chosen because it occurs after the implementation of mandatory ballast water reporting and represents the most complete discharge records available. Average annual foreign discharge rates were also calculated from 2005 to 2007 for 17 coastal ports, representing a cross section of small to large ports. Because the foreign ballast was calculated on a per tank basis, the movement of undischarged foreign ballast among ports can be estimated. That is, by following foreign ballast by tank it is possible to account for foreign ships that initially entered one port but did not discharge their ballast until they visited another port. Foreign discharge values for multiple ports within a waterbody were summed for a total discharge volume for a waterbody, including freshwater ports in larger systems (e.g., Columbia River). For the Great Lakes, the National Biological Invasion Shipping Study (Reid and Carlton, 1997) reported a total annual foreign ballast water discharge into the Great Lakes of 1,395,461 metric tons in 1991. This is before mandatory ballast water exchange, which was initiated in the Great Lakes in 1993.

Estimates of Organism Concentrations in Ballast Water:
Organism concentrations in ballast water discharged in coastal waters (C_h in Equation 18) were estimated from Minton et al. (2005), who reported zooplankton (> 80 microns) concentrations in

Table 12: Historical number of invaders (N_h), foreign ballast discharge volumes (D_h), number of ships discharging foreign ballast, and per capita invasion probabilities (PCIP) for the East, Gulf, and Pacific coasts of the United States, 17 coastal ports, and the Great Lakes. The number of coastal invasions is the number of non-native invertebrates and macroalgae >50 microns first reported from 1981 to 2006 that were possibly introduced via ballast water and considered established. The total number of invaders in the coastal ports includes marine, brackish, and freshwater species, while the total without freshwater excludes the freshwater invaders. The foreign ballast discharges for the coastal waterbodies are the annual averages of 2005 to 2007 and include marine, brackish, and freshwater ports within the waterbody. Per capita invasion probabilities for the coastal waterbodies are given for a range of possible values, including the lower quantile (0.025), median, and upper quantile (0.975), based on the simulation estimates of organism concentrations among the ships discharging into a waterbody. The number of invaders for the Great Lakes is given for both macrofauna and phytoplankton for the period 1960 to 1988, while the ballast water discharge volume is for 1991. The sum of the discharge volumes and number of ships from the 17 ports is less than the coastal averages because all ports were included in the coastal values. FW = freshwater.

Waterbody	Total # Invaders / Total # w/o FW species	Average Annual Foreign Ballast Water Discharge Vol. (m^3 $year^{-1}$)	# Ships with Foreign Ballast Water 2005-2007	PCIP (lower 0.025 quantile)	PCIP (median)	PCIP (upper 0.975 quantile)
East Coast	**40**	**7,407,832**	**12,860**	**4.00E-11**	**4.31E-11**	**4.64E-11**
Charleston	13/12	281,160	563	3.05E-10	3.70E-10	4.46E-10
Chesapeake	17/14	3,011,982	1315	3.85E-11	4.51E-11	5.28E-11
Jacksonville	14/13	130,296	791	7.48E-10	8.58E-10	9.83E-10
Miami	4/4	578,482	2515	5.04E-11	5.51E-11	6.02E-11
Narragansett Bay	13/13	21,030	19	2.38E-09	5.41E-09	1.35E-08
Portsmouth	9/9	6,377	10	3.26E-09	1.54E-08	6.16E-08
Gulf Coast	**18**	**19,605,340**	**11,821**	**6.98E-12**	**7.31E-12**	**7.67E-12**
Corpus Christi	5/5	1,254,845	621	2.65E-11	3.18E-11	3.84E-11
Galveston	4/4	748,136	778	3.53E-11	4.28E-11	5.22E-11
Pensacola	3/3	1,121	8	8.72E-09	2.45E-08	7.88E-08
Tampa Bay	7/1	734,718	923	5.37E-11	6.54E-11	7.88E-11
Pacific Coast	**67**	**14,788,369**	**5998**	**3.41E-11**	**3.61E-11**	**3.83E-11**
Columbia River	22/12	5,533,618	1759	2.89E-11	3.17E-11	3.47E-11
Coos Bay	22/22	583,517	87	2.18E-10	3.04E-10	4.40E-10
Humboldt Bay	29/29	5,539	10	1.42E-08	5.24E-08	1.85E-07

Waterbody	Total # Invaders / Total # w/o FW species	Average Annual Foreign Ballast Water Discharge Vol. (m^3 $year^{-1}$)	# Ships with Foreign Ballast Water 2005-2007	Per Capita Invasion Probability (lower 0.025 quantile)	Per Capita Invasion Probability (median)	Per Capita Invasion Probability (upper 0.975 quantile)
Los Angeles / Long Beach	31/31	2,676,874	1693	8.20E-11	9.23E-11	1.05E-10
Puget Sound	23/21	3,960,438	1167	4.12E-11	4.64E-11	5.23E-11
San Diego Bay	23/21	31,271	112	4.20E-09	5.92E-09	8.52E-09
San Francisco Estuary	53/45	1,548,116	1015	2.33E-10	2.74E-10	3.22E-10
Great Lakes – Macrofauna	17	1,395,461	Unknown	NA	9.10E-11	NA
Great Lakes – Phytoplankton	14	1,395,461	Unknown	NA	NA	NA

unmanaged ballast water in 354 ships of various types (see Figure 3). Similar values were reported in a survey of 429 ships of multiple vessel types that had no ballast water exchange or treatment (MEPC, 2003b). Both of these studies showed that organism concentrations in untreated ballast water can vary by orders of magnitude among ships. For example, about 3.8% of the ships reported by Minton et al. (2005) had organism concentrations less then 10 m^{-3} while about 1.1% of the ships had concentrations greater than 50,000 m^{-3}. Thus, the actual propagule dose a waterbody receives will depend on the distribution of organism concentrations among the ships discharging within the system.

Because the distribution of organism concentrations in ballast water of is highly skewed, the mean concentration may over or underestimate the true propagule pressure depending upon the concentrations in the specific set of ship discharging within the waterbody. Consequently, rather than estimating PCIP values using the mean concentration of organisms we performed a simulation to estimate PCIP values from a range of possible propagule pressures. The simulation was performed by randomly assigning each ship discharging foreign ballast in a waterbody a concentration of organisms, selected from the distribution of values reported by Minton et al. (2005; their Figure 3a). The randomly selected concentration was then multiplied by the volume of foreign ballast discharged by that particular ship (see Table 12 for number of ships in each waterbody). The values for each ship within a waterbody were summed, generating a total propagule dose from which the PCIP value was calculated. This process was repeated 10,000 times to create a distribution of PCIPs for each waterbody from which the lower (0.025), median, and upper (0.975) quantile values were determined (Table 12). Figure 6 shows the range of PCIPs for the Pacific Coast generated with this method. Using a range of possible PCIP values allows us to make predictions that do not underestimate the risk of invasion, which might occur if only the mean concentration of organisms is used. (Note that with a fixed historical invasion rate, higher PCIP values result from lower discharge values since the same number of invaders occurred with a lower propagule pressure.) Because we did not have individual ship records for the Great Lakes during 1991, we could not generate the PCIP distributions and instead used the mean ballast water organism concentration from the IMO baseline study (4640 m^{-3}, MEPC, 2003b) to calculate the PCIP for the Great Lakes.

Estimates of Historical Invasion Rates:

The total numbers of invaders reported between 1981 and 2006 were synthesized for the contiguous United States Pacific Coast, East Coast, and Gulf Coast as well as for 17 individual coastal waterbodies (Table 12). The 1981 to 2006 time period is before the implementation of mandatory mid-ocean ballast water exchange for coastal waterbodies, allowing the use of the estimates of organism concentrations in unexchanged ballast. A 25 year time period was chosen to smooth out short term variations in invasion rates as well as variations in monitoring efforts. A longer time period also helps to mitigate effects of the lag between an actual invasion event and when the species is first discovered (e.g., Costello and Solow, 2003).

The number of invaders is based on non-native invertebrates and macroalgae >50 microns; fishes and vascular plants were not included. Besides being reported in each coast or waterbody within the 25 year window, the species included in the analyses had to be considered established and potentially introduced via ballast water. The coastal invaders were classified into three salinity tolerance regimes: marine/estuarine (>20 psu), brackish (0.5-20 psu), and freshwater (<0.5 psu). This broad classification allows an evaluation of the importance of freshwater invaders in river-dominated estuaries such as the Columbia River. Because of the poor resolution between native versus nonindigenous phytoplankton species in coastal waters (Carlton, 2009), no attempt was made to estimate the number of invaders in the 10-50 micron size class. The number of invaders was generated from the Smithsonian Institution invasive species database (Fofonoff et al. 2003b) and the majority of the East, Gulf, and Pacific invaders and their vectors are listed in Appendix A of Ruiz et al. (2000).

The 1960 to 1988 time period was chosen for the Great Lakes because it is before the implementation of mandatory ballast water exchange in 1993. During this interval, a total of 17 macrofaunal ballast-associated invaders was reported (http://www.glerl.noaa.gov/res/Programs/ncrais/docs/great-lakes-list.xls, accessed September 26, 2009), resulting in an invasion rate of 0.58 invaders per year. This rate is based on all shipping-related invaders as well as three macrofaunal invaders with unknown vectors. The invasion rate for phytoplankton was similar (Table 12), resulting in a total rate of slightly more than 1 invader per year which is similar to that reported by Ricciardi (2006).

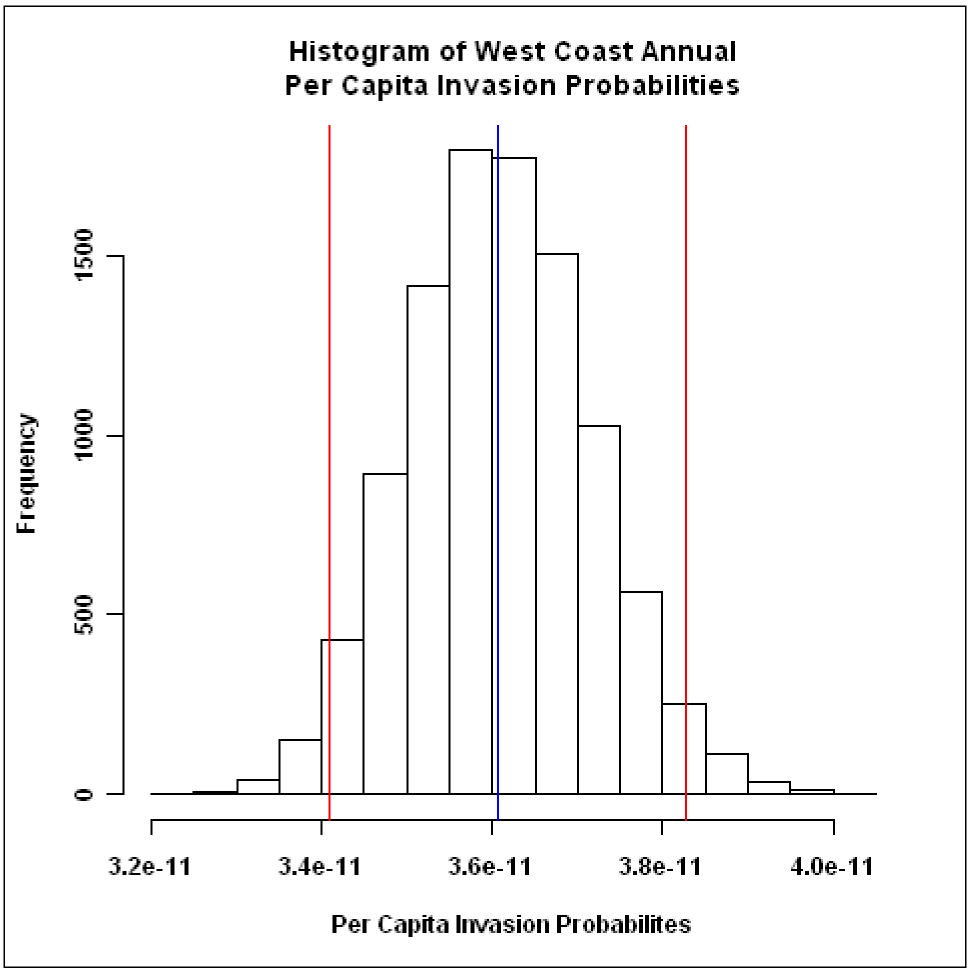


Figure 6: Distribution of per capita invasion probabilities (PCIPs) for the Pacific Coast based on 10,000 random simulations of organism concentrations among the 5998 ships discharging foreign ballast. The red lines indicate the lower 0.025 quantile and the upper 0.975 quantile while the blue line indicates the median. Approximately 95% of the values fall between the red lines.

Uncertainties in Historical Invasion Rates and Safety Factors:
Of the three parameters going into the calculation of a PCIP, the historical invasion rate has the greatest uncertainty and it is worth exploring both the sources of this uncertainty and whether it tends to over or underestimate future invasion rates. One source of this uncertainty is that many coastal nonindigenous species can potentially invade through multiple vectors, such as both ballast water and hull fouling (e.g., Fofonoff et al., 2003a). Inclusion of these "polyvectic" invaders (Ruiz and Carlton, 2003) in the historic invasion numbers in Table 12 potentially inflates the ballast-associated invasion rate, resulting in an artificially high PCIP. Because of differences in the relative importance of different vectors among estuaries, uncertainty related to multiple vectors is probably greater when comparing among estuaries than for the coast-wide estimates. For example, San Diego Bay, which has a high invasion rate relative to the ballast discharge volume, is the home to the largest naval base on the Pacific Coast consisting of approximately 54 naval ships. Ballast discharges from military ships are not included in the volumes in Table 12, but most naval ships tend to discharge relatively small amounts of ballast (see Table 2 in Appendix A of U.S. EPA, 1999), which suggests a higher propagule pressure from hull fouling in San Diego. Hull fouling may also be relatively more important in smaller ports that have low ballast discharge rates but a relatively large number of commercial fishing and recreational boats with no foreign ballast.

Secondary invasions could also inflate estimates of historical ballast-associated invasion rates in individual waterbodies. After the primary invasion and establishment of a new NIS into a biogeographic region, the invader may spread within the biogeographic region via secondary invasions from the initially established population. Likely mechanisms for secondary invasions include ballast water discharges and hull fouling via intracoastal commercial traffic emanating from the infected waterbody (e.g., Simkanin et al., 2009; Cordell et al., 2009) as well as hull fouling on recreational boats. Secondary invasions may also occur via natural dispersal mechanisms, such as currents and rafting, as suggested by occurrence of soft-bottom NIS in Pacific Northwest estuaries with no ballast discharges or oyster aquaculture (Lee et al., 2006; Lee, unpublished data).

An important source of uncertainty that could result in underestimating PCIP values is the underestimation of historical invasion rates. Carlton (2009) identified 12 sources of error leading to invader underestimation including unknown, unreported, misclassified, and rare invaders. In some parts of the world, such as Denmark, South Africa, and Chile where no invasions prior to mid-nineteenth century are recognized, the number of known invaders could be underestimated by as much as 5 to 10 times (Carlton 2009). For California, Cohen (in Falkner et al., 2006) suggested that unrecognized invaders could increase the invasion rate by 50% to 100%. A recent analysis of California invaders lists 457 cryptogenic species versus 358 nonindigenous species (California Dept. of Fish and Game, 2009); the California invasion rate would more than double if all these cryptogenic species were actually nonindigenous. While some of these cryptogenic species are likely unrecognized native sibling species (e.g., Knowlton, 1993), the high number of cryptogenic species in California suggests that the reported number of invaders may underestimate actual numbers by 50% to 100% within the United States.

Other sources of uncertainty could also cause us to underestimate the risk of introducing new invaders through ballast discharges: the relationship between propagule pressure and the probability of invasion could be steeper than the proportional relationship we assume, in particular at very low concentrations (curve d in Figure 2); survival in ballast tanks could improve if voyage durations decrease due to faster ships; and waterbodies may become increasingly susceptible to invasion due to climate change or other environmental changes. While it is not possible to quantify the total uncertainty from these various sources, safety factors on the order of 5 to 20-fold have been proposed when calculating the risk to endangered and threatened species from exposure to pesticides (U.S. EPA, 2004b), and similar ranges could be used in the generation of discharge standards (see Equations 20 and 21). We strongly suggest using a single safety factor rather than multiplying a string of individual safety factors for each source of uncertainty, which quickly results in unrealistic values (see Chapman et al., 1998).

Among Port Patterns of Invasion Risk:

There is considerable range in the PCIP values among the 17 individual ports both along a single coast and across coasts (Table 12). The largest difference is between the Humboldt Estuary and Columbia River, a more than 1600-fold difference. We suspect these among-estuary differences are due to a suite of non-exclusive factors. Part of this range may reflect differences in the invasibility among waterbodies, whether due to differences in biotic resistance or local environmental drivers. For example, the lower invasion probability in the Columbia River compared to other large Pacific Coast ports may be partially explained by wide seasonal and tidal salinity fluctuations (e.g., Hickey et al., 1998) that largely limit estuarine invaders to euryhaline or freshwater species.

One pattern observed on all three coasts is that the smaller ports had more invaders than expected from the amount of foreign ballast water, which resulted in higher PCIP values. Humboldt Bay, a small port in northern California, had only ten ships discharging foreign ballast from 2005 to 2007 (Table 12). Even with this small ballast input, Humboldt had the third largest number of invaders of the 17 estuaries, only exceeded by the San Francisco Estuary and the Los Angeles/Long Beach port. It is possible that these smaller ports have a greater invasibility than larger systems, but we suggest secondary invasions and invasions via mechanisms other than foreign ballast water discharges are relatively more important in these systems, which inflate the PCIP values. In particular, Humboldt Bay’s proximity to the San Francisco Estuary and the prevailing northward oceanographic currents along the coast from San Francisco Estuary (particularly in El Niño years) may provide one mechanism of secondary invasion (Grosholz, 1996; Behrens Yamada et al., 2005) in addition to intracoastal shipping.

We evaluated the potential effect of polyvectic species and secondary invasions on the invasion rate in Humboldt by removing NIS from the Humboldt list if they: 1) had been observed in Pacific Coast estuaries that do not receive ballast water discharges; 2) were found on the outer coast; and/or 3) had a potential vector other than ballast water. Of the 29 potential ballast-water invaders reported from Humboldt between 1980 and 2005, the introduction of only two could not be explained by mechanisms other than foreign ballast water discharges in Humboldt. The corresponding PCIP value (median = 3.58E-09) with the reduced invader list is only about 5% of the value when all potential invaders are included. We suspect that secondary invaders and polyvectic invaders also inflate the PCIP values in the other small ports. Another issue for estimating invasion probabilities in small estuaries is the large statistical variability in estimates based on small sample sizes. Consequently, ports with small amounts of ballast discharge will have high PCIP values even with the occurrence of a single ballast associated invader.

Because of these factors, we believe the PCIP values for the moderate to large ports are more reliable, with moderate/large ports defined as those having an average annual foreign discharge volume of $\geq$100,000 m^3. This threshold was chosen because of a distinct break in ballast discharge volumes that occurs between 31,271 m^3 (San Diego) and 130,296 m^3 (Jacksonville). The 12 moderate/large ports contribute 99.67% of the total ballast from the 17 estuaries. The range in PCIP values among these moderate to large ports is only about 28-fold compared to the more than 1000-fold range when the small ports are included.

Discharge standards can be generated for individual ports by rearranging Equation 19 to calculate the organism concentration in ballast water (C_p) associated with a projected ballast discharge volume (D_p), acceptable risk as represented by the number of new invaders per year (N_p), PCIP value from Table 12 or otherwise calculated, and a safety factor:

Equation 20: $C_p = N_p/(D_p * PCIP * Safety\ Factor)$

Safety factor = number $\geq$1 (unitless)

What value to use for the PCIP in Equation 20 is a risk management decision. The 0.975 quantile represents an upper probability that a propagule discharged from ballast water will become established as a new invader based on the distribution of organism concentrations in the ships discharging into the port/estuary. The median represents an “average” probability of establishment based on the “average” organism concentration in the ships. Similarly, the inclusion and size of any safety factor is also a risk management decision. Because it is in the dominator, the safety factor is set to 1 if no adjustment is made for uncertainties.

Because of the uncertainties surrounding invasion rates for single estuaries, we believe a better alternative is to base the standard on a specified confidence interval (e.g., upper 95% CI) around the PCIP values for the 12 moderate/large ports. An advantage of this approach is that it incorporates the among estuary variation in PCIP values in the calculation of the discharge standard. Using this approach, the formula to calculate the discharge standard is:

Equation 21: $C_p = N_p/(D_p * PCIP_{CI} * Safety\ Factor)$

$PCIP_{CI}$ = probability that a single propagule from ballast discharge will become established as a new invasive species; calculated for a given confidence interval estimate of PCIP for the 12 moderate to large ports.

PCIP values for 12 individual ports can be based on the 0.5 (median) or 0.975 quantile estimates from the simulations of organism concentration for each ship, or some other quantile value from the randomization. Additionally, different confidence levels can be used for $PCIP_{CI}$. Table 13 gives the 90%, 95%, 99%, and 99.9% upper confidence intervals generated for the 12 moderate and large ports around the median and 0.975 quantile values. These are two-tailed confidence intervals so, for example, 5% of the values are larger than the 90% confidence interval values.

Assuming a doubling of the annual ballast water discharge rate on the Pacific Coast to 30 million m^3 (see Table 12), an acceptable risk as represented by an invasion rate of one new invader per thousand years, the upper 99.9% confidence interval value for the 0.975 quantile PCIP for the Pacific Coast, and a 10-fold safety factor, the discharge standard becomes:

Equation 22: $C_p = (1x10^{-3}$ invader/yr) / ($30x10^{6}$ m^3 ballast water/yr * $5.90x10^{-10}$ invader/organism * 10) = 0.006 organisms m^{-3}

The resulting discharge standard of 0.006 organisms m^{-3} is similar to the USCG Phase II standard for >50 micron organisms (0.01 organisms m^{-3}). The value derived from Equation 22 is based on a number of protective assumptions, including doubling the current Pacific Coast ballast discharge volume, using the 0.975 quantile for the estimate of PCIP, using the upper 99.9% CI value, and including a 10-fold safety factor. Modifying the assumptions changes the discharge standard to varying degrees, and one way to visualize the "regulatory landscape" is to plot the invasion probabilities as a contour plot, or "risk diagram", as a function of ballast water discharge volumes and organism concentrations. (Note that while the risk diagrams include long-range predictions, invasion rates for 1000 to 10,000 years in the future are best interpreted as indicating a very low probability of invasion rather than quantitative predictions.) Figure 7 shows the risk diagrams for the Pacific Coast based on three different safety factors (1, 10, and 20), using the PCIP value for the 99.9% confidence interval of the 0.975 quantile value from the 12 moderate/large estuaries. We consider these risk diagrams as a complement to Equation 21, and the R code (R Development Core Team, 2008.) to generate these diagrams based on different input values is given in Appendix A.

Table 13: $PCIP_{CI}$ estimates based on upper 90%, 95%, 99%, and 99.9% confidence intervals around the median and 0.975 quantile PCIP values for the 12 moderate to large estuaries in Table 12.

	Upper 90% CI	Upper 95% CI	Upper 99% CI	Upper 99.9% CI
Median	3.48E-10	3.77E-10	4.41E-10	5.34E-10
0.975 quantile	3.71E-10	4.05E-10	4.80E-10	5.90E-10

Coastal Patterns of Invasion Risk:
Due to the significant potential for secondary invasions, we believe the best alternative to developing discharge standards is to use Equation 20 with PCIP values derived from the aggregated data for an entire coast. The aggregated coastal data eliminate the uncertainty associated with secondary invaders as the historical invasion rate is based on the number of unique invaders to a coast so no invader is counted more than once. This approach is supported by the small variance in PCIP values among the coastal regions. In particular, there is only a 19% difference between the East and Pacific coasts (Table 12). The Gulf Coast PCIP is less than 6-fold smaller than the East or Pacific coasts, while the PCIP value for macrofauna for the Great Lakes is about 2-fold larger than those for the East and Pacific Coasts. Thus, even when comparing across three different coasts and the Great Lakes, there is only slightly more than a 12-fold range in the PCIP values. This relatively small range across diverse environments with different ballast discharge volumes and donor regions indicates that the analysis at this spatial scale captures many of the sources of variation.

We focus our analysis on the Pacific Coast because the extensive research on the distribution of NIS in this region (e.g., Cohen and Carlton, 1995; Cohen et al., 2001; Lee et al., 2003: deRiveria et al., 2005; California Dept. Fish Game, 2009) produces the most complete historical invasion rate. Using the same inputs for an acceptable risk level, ballast water discharge volume, and safety factor as for the estuary calculation (Equation 22), and the upper 0.975 quantile PCIP value specific to the Pacific Coast, the discharge standard becomes:

Equation 23: $C_p = (1x10^{-3}$ invaders/yr) / (30x10^{6} m^{3} ballast water/yr * 3.83 10^{-11} invaders/organism * 10) = 0.087 organisms m^{-3}

Based on this set of assumptions, the discharge standard for >50 micron organisms would be approximately 100-fold lower than the proposed IMO standard, about 9-fold higher than the Phase II USCG standard, and about 10-fold higher than the standard derived from the multiple estuaries (Equation 22). As another example we set the acceptable risk at one new invader per 100 years, the safety factor to 2, and use the median PCIP value instead of the upper quantile. With these less protective assumptions, the standard is 4.6 organisms m^{-3}, about 2-fold lower than the IMO standard. Both of these predictions are illustrated as risk diagrams in Figure 8.

Assumptions and Limitations:
The approach described here has not been subject to peer review. However, we have a draft of a paper and our goal is to submit it to a peer-reviewed journal in the first half of 2010.

As with any approach used to establish ballast water discharge standards, the per capita invasion probabilities make a number of assumptions. We list the major assumptions in Table 14 along with an assessment of how they affect the calculation of the PCIPs and the discharge standard derived from these probabilities.

The PCIP values for the smaller ports are substantially higher than those for systems with moderate to large ballast discharge volumes. As discussed, we believe this is largely a result of secondary invasions inflating the presumed ballast-associated invasion rate. However, if the higher invasion rates are actually a result of the smaller ports having a greater invasibility, the standards generated from the coast values or the moderate/large ports would not be protective of these systems. Another way that the present analysis could underestimate risk is by failing to account for the introduction of species that can become established with a single or very small number of individuals, such as a parthenogenic species. As discussed in Section II, the only absolute protection against such invaders is a true zero discharge standard.

Our analysis is limited to organisms >50 microns, though the PCIP approach is theoretically applicable to smaller size classes. The practical limitations, however, are the difficulty in distinguishing native from nonindigenous protozoa, phytoplankton, and microbes and the corresponding lack of data on historical invasion rates. As pointed out by Carlton (2009), “no introduced diatoms, dinoflagellates, or other phytoprotists are recognized in San Francisco Bay, at either the morphospecies or genospecies level” despite the abundance of phytoplankton in ballast water. However, it would be possible to conduct an analysis for the Great Lakes given the reported historical invasion rate for phytoplankton (Table 12) if an estimate for the historical ballast water phytoplankton concentrations can be obtained.

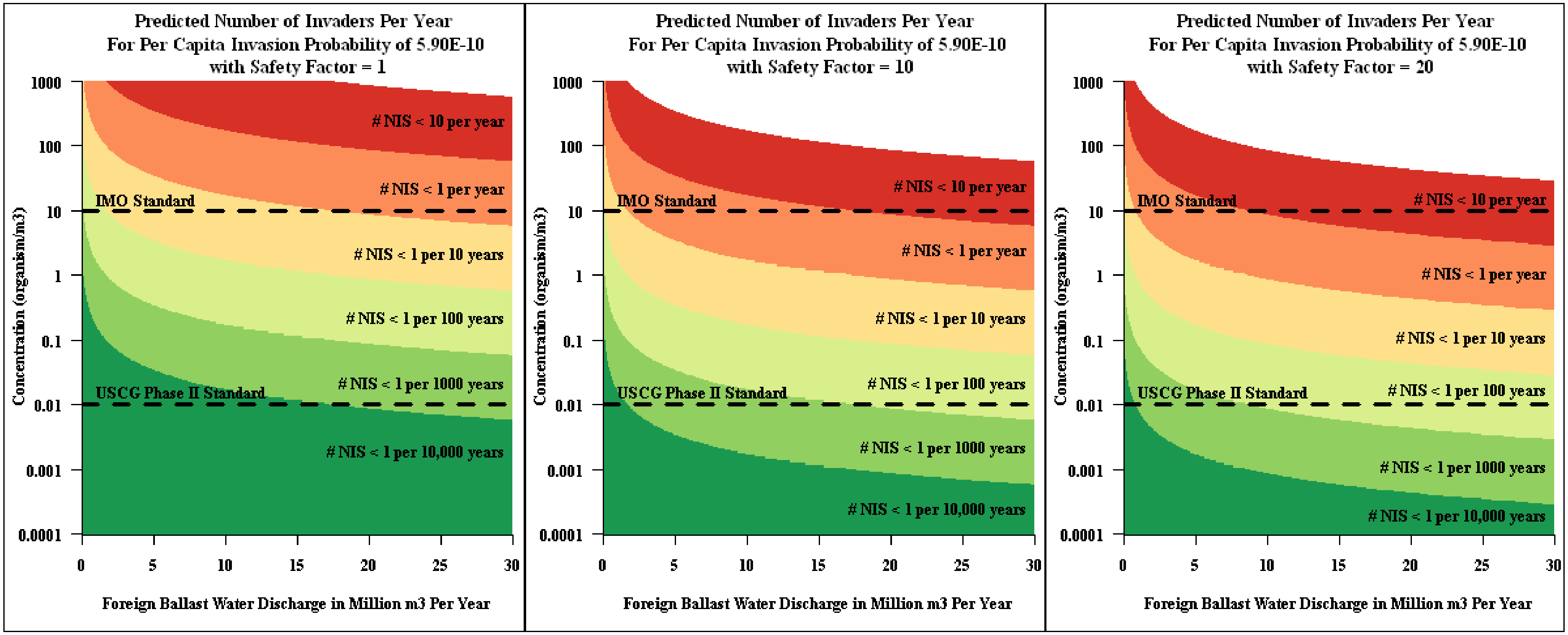


Figure 7: Risk diagrams for the Pacific Coast illustrating the effect of three different safety factors (1, 10, and 20). Calculations are based on the 99.9% confidence interval of the 0.975 quantile value of PCIP from the 12 moderate to large estuaries. A safety factor of 1 means that there was no adjustment for the uncertainties.

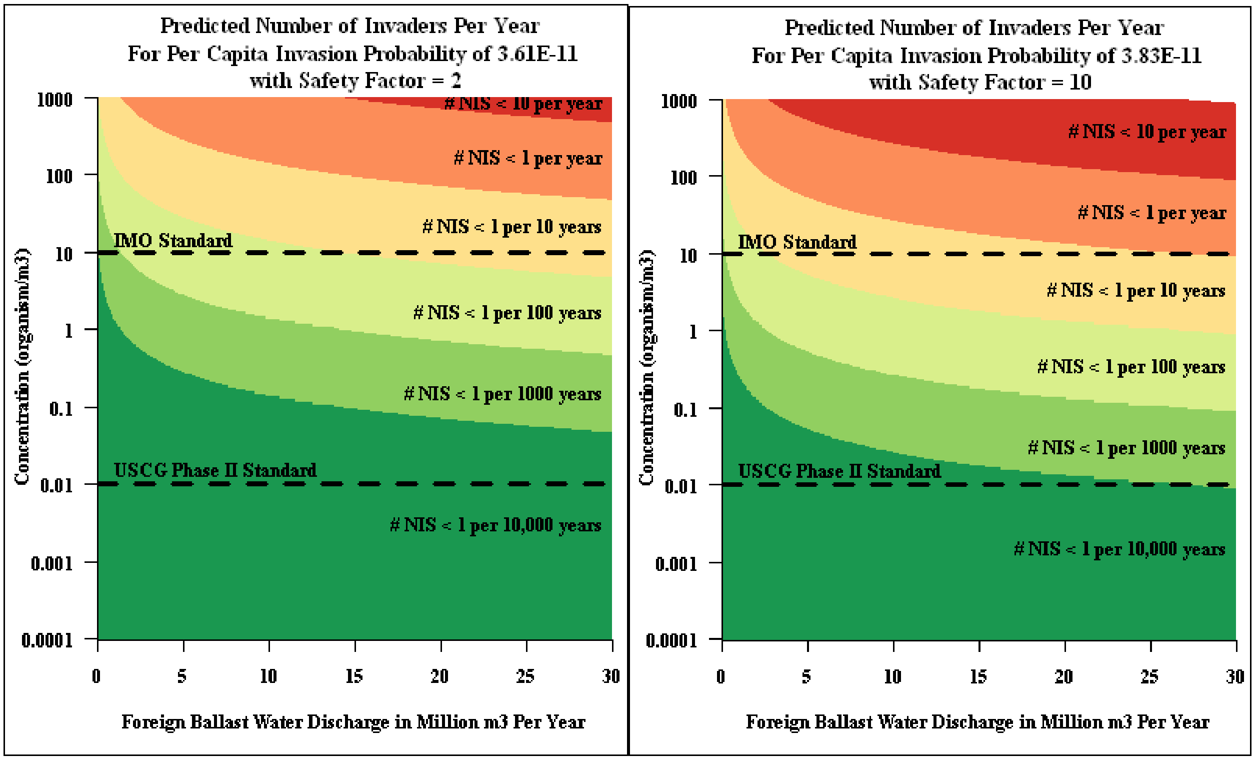


Figure 8: Risk diagrams for the Pacific Coast based on less protective (left diagram) and more protective (right diagram) assumptions. The risk diagram on the left is based on the median PCIP for the Pacific Coast and a safety factor of 2. The diagram on the right is based on the upper 0.975 quantile PCIP value and a safety factor of 10.

By using past invasion rates to predict future rates, fundamental assumptions of the per capita probability approach is that neither the invasion potential of any new invaders or the invasibility of the waterbody itself will change in the future. Actually, these assumptions apply to nearly all the approaches (e.g., use of previously measured population vital rates in PVA models) but the issue is more apparent when using historical rates. If the best colonizers tended to invade first, then the PCIPs derived from these historical data would over predict the number of new invaders for a given propagule pressure. However, the apparent increase in the rate of invasion in a number of aquatic ecosystems (e.g., Cohen and Carlton, 1998; Holeck et al., 2004) is the opposite of what would be expected if there had been a general decrease in the virility of new invaders. Changes in the invasibility of aquatic ecosystems are more difficult to assess. In particular, environmental change associated with climate change is a “wild card” for all the approaches to setting discharge standards. Development due to port expansion could also change the invasibility of a system. Probably the only practical near-term solution is to incorporate a safety factor in anticipation of such changes. Over a longer-term, it is possible to periodically evaluate PCIP values for a coast to determine if there have been any substantial changes.

Recommendations/Conclusions:

The per capita invasion probability approach attempts to cut through the “Gordian Knot” of uncertainties associated with predicting ballast water invasions, and Equations 20 and 21 and the risk diagrams (Figures 7 and 8) can be used to set organism-based discharge standards. As with all approaches, however, there are a number of assumptions (see Table 14). Accordingly, our strategy was to develop an approach that allows risk managers the option to develop discharge standards with different risk levels based on different sets of assumptions. Specifically, the following inputs can be set: 1) acceptable invasion risk as measured by an invasion rate; 2) ballast water discharge volume; 3) use of PCIPs based on median ballast water organism concentration or upper quantile values; 4) median or an upper confidence interval around the PCIP with the among-port analysis; and 5) magnitude of any safety factor.

The uncertainty around the parameters going into the per capita invasion probability model is relatively small. Even with the historical invasion rate, the uncertainty is only on the order of 2-fold for the Pacific Coast. In comparison, our analysis suggests that there are much greater levels of uncertainty in the population vital rates that are needed for reaction-diffusion or PVA models. Additionally, the model does not have to be parameterized for each species or type of species as with the population modeling approaches. Finally, the data going into the per capita probability approach are readily understandable by managers and the public, which is beneficial in gaining acceptance for any ballast water discharge standard.

Of the three approaches to setting discharge standards (PCIP from individual estuaries; values based on upper confidence intervals from distributions of PCIPs about individual estuaries; PCIP values based on aggregated coastal values), we suggest that the coastal approach has the lowest inherent uncertainty. Furthermore, since most invaders spread along the coast, analysis at this scale is ecologically appropriate. Because of the extensive effort in documenting invaders on the Pacific Coast, the PCIP values for the Pacific Coast are the most reliable and we recommend using this coast to generate discharge standards for marine and estuarine ports within the United States.

The PCIP value for macrofauna for the Great Lakes is about 2-fold larger than those for the East and Pacific coasts, suggesting that there may be a greater likelihood of any individual propagule becoming established as a new invader in the Great Lakes. However, less complete data were available for ballast discharge volume and organism concentrations, and we consider the calculations for the Great Lakes a preliminary analysis. While there is the complicating factor of mandatory ballast water exchange after 1993, it may be possible to generate more up-to-date data for an analysis using the PCIP approach with a detailed study on the Great Lakes. As mentioned above, a study focused on the Great Lakes may also allow an analysis on phytoplankton invasion rates.

Secondary invasions appear to be an important source of uncertainty. To understand the role of secondary invasions better, future surveys for nonindigenous species should not only focus on the larger ports but should also include smaller ports and estuaries with no foreign ballast input. Additionally, further studies of the role of intracoastal shipping and ballast discharges are needed to help elucidate their role in spreading invaders into smaller ports with minimal foreign ballast water discharges.

Table 14: Major assumptions of the per capita invasion probability (PCIP) approach to setting ballast water discharge standards.

Assumption	Effect on Estimate of Per Capita Invasion Probability	Effect on Discharge standard	Mitigation Approaches
Linear dose-response	Likely over estimates invasion probability for many sexual species due to Allee effects; potentially under estimates for asexual and parthenogenic species.	Protective against most sexual invaders; possibly under protective for asexual and parthenogenic species.	Use upper bound estimates for input values and/or safety factor to account for cases when dose-response is more than linear.
Secondary invasions did not contribute to historical invasion rate.	Inflates PCIP to the extent that invaders did not invade via foreign ballast water discharged into the waterbody.	Erroneously results in too low discharge standard.	Exclude small ports from analysis and/or conduct analysis on a coastal scale.
Polyvectic invaders actually invaded via ballast water.	Inflates PCIP to the extent that polyvectic invaders were introduced via some vector other than foreign ballast.	Erroneously results in too low a discharge standard.	Analysis on coastal scale would correct if species invaded via ballast water anywhere on coast.
Exclusion of small ports from across-port calculations.	Generates more accurate PCIPs if invasions in small ports from secondary vectors. Artificially decreases PCIP if actual primary invasions into the small ports.	Depends whether invasions in small ports are from primary or secondary vectors.	Conduct analysis on a coastal scale so that all ports and invaders included.
No change in the invasion potential of new invaders over time.	Decrease in viability of new invaders results in PCIPs based on historical rates over predicting new invasions.	Erroneously results in too low a discharge standard. .	No adjustment unless further data indicates actual change in invader viability.
No change in invasibility of waterbody over time.	Either increases or decreases PCIP depending upon type & magnitude of environmental changes in waterbody.	Protective or under protective depending upon the type & magnitude of changes.	Use upper bound estimates for input values and/or safety factor to account for changes in environment.

IX. EXPERIMENTAL APPROACHES

Henry Lee II

Overview:
Laboratory and field experiments can be used to quantify the likelihood of invasion under controlled environmental conditions and dosing scenarios. Such experiments may represent the cutting edge in invasion science, at least in the Popperian sense, and the frequency of experiments has increased over the last decade (see review of extinction studies in experimental populations by Griffen and Drake, 2008). It appears that freshwater studies have primarily used laboratory experiments while field experiments are used more frequently with marine/estuarine species. Examples of laboratory experiments with freshwater organisms include those by Drake and his collogues (e.g., Drake and Lodge, 2004; Drake, 2006; Griffen and Drake, 2008; Drake and Griffen, 2009). An example of a freshwater field experiment is Bailey et al. (2009) who used field enclosures to parameterize and evaluate the diffusion approximation PVA model. Their results indicated that the proposed IMO standards for >50 micron organisms would reduce the probability of establishment of certain parthenogenic species by three fold. Examples of marine/estuarine field experiments include the studies on the recruitment of native and nonindigenous bryozoans (Clark and Johnston, 2005; Piola and Johnston, 2009).

Assumptions and Limitations:
The successful introduction of any specific species is a rare event. For example, it took the green crab about another century to invade the Pacific Coast after invading the East Coast (Carlton and Cohen, 2003). Quantifying the probability of such rare events is generally impractical using experiments. The main problem is that the number of samples becomes prohibitively large when attempting to quantify probabilities of events with likelihoods of 10^{-3} to 10^{-6}. This is the classic problem when attempting to determine the carcinogenic potency of a compound using laboratory exposures.

Some of the experiments have used high propagule doses, which biases the results to the right side of the propagule supply curve (Figure 2). Experimentally testing the recruitment of a species into an established community at the density in the USCG Phase II standard (0.01 organisms m^{-3}) will prove especially challenging.

Most marine/estuarine species as well as many freshwater species are difficult to culture and spawn in the laboratory. This limits the experiments to the aquatic “white rats” (e.g., use of *Daphnia magna* in Drake and Griffen, 2009). Such species are often “opportunistic” and thus are unlikely to be representative of the full breadth of potential invaders in foreign ballast.

All the freshwater experiments that we are aware of have used planktonic organisms, presumably because of the ease of culture and manipulation. Many of the marine experiments have used bryozoans or barnacles. We are unaware of any studies that have evaluated propagule supply with soft-bottom species, such as polychaetes. This taxonomic limitation potentially biases the results from experiments.

The main advantage of experiments, the tightly controlled environmental and biotic conditions, is also one of its main limitations. The world is much more complex than can be simulated in a beaker or even in a field enclosure. This “dumbing down” of nature in experimental studies may be why “Results from laboratory experiments often conflict with field studies” (Griffen and Drake, 2009).

Recommendations/Conclusions:
We believe it is impractical to derive discharge standards using the experimental approach because of the: 1) impracticality of adequate replication to quantify rare events; 2) limitation in the number and types of species than can be experimentally manipulated; and 3) artificiality and simplification of laboratory experiments and, to a lesser extent, field experiments.

The real power of the laboratory and field experiments is to advance the theory of propagule supply, test the assumptions of the various invasion models, and parameterize the population models that predict the probability of invasion. The recent work by Bailey et al. (2009) and Britton-Simmons et al. (2008) are good examples of how experimental studies can be coupled with population models.

X. STATISTICAL CONSIDERATIONS IN ESTIMATING THE CONCENTRATION OF ORGANISMS IN BALLAST WATER DISCHARGES

Melanie Frazier, Henry Lee II, and Deborah A. Reusser

Overview:

In the previous sections, we evaluated the potential utility and limitations of several approaches for generating ballast water discharge standards; here we address the statistical issues associated with monitoring organisms at very low concentrations. This is not an approach for setting standards; however these issues must be considered when assessing the practicality of verifying a discharge standard either in test facilities or as part of compliance monitoring. The stringent discharge standards that have been proposed by various agencies will require estimating very small concentrations of organisms in ballast water. This will be challenging due to the inherent stochasticity of sampling when estimating concentrations. Furthermore, at low densities, very large volumes of water must be sampled to find enough organisms to begin to estimate concentration. Understanding the limitations and requirements of sampling will help inform the development of protocols that ensure discharge standards are adequately implemented.

Stringent discharge standards are environmentally appealing because they are very protective; however, they present challenges because it is difficult to estimate low concentrations through sampling. The U.S. Coast Guard recently proposed a Phase II discharge standard of 0.01 organisms m^{-3} for organisms >50 µm, a standard 1000 times more stringent than the IMO's (USCG proposal is currently in the Federal Register, 74 Fed. Reg. 44632, August 28, 2009). Some states, such as New York and California, have proposed discharge standards of "zero detectable organisms" (Dobroski et al., 2009). We explore some of the statistical issues that must be considered for either ship-board testing in the field or type-approval testing of treatment systems in controlled facilities. We do not address the logistics of sampling ship ballast water, which are described in references such as Lemieux et al. (2008) and Wright (2007). We also use a "best-case-scenario" approach: we limit our focus to organisms > 50 µm in size, which are the easiest to quantify; we assume no human or equipment error, such that all organisms in a sample volume are counted; and for most scenarios, we assume organisms are randomly distributed in the ballast discharge.

Rationale:

Currently, a great deal of effort is being devoted to selecting a discharge standard that adequately protects against invasive species. An important aspect of testing whether ballast discharges meet these standards during either the testing of treatment systems or compliance monitoring of individual ships is developing sampling protocols that are adequate for a discharge standard. For example, a standard of "zero detectable organisms" may seem very protective, but in reality, the degree of protection depends on the sampling protocol. If a small volume is used to evaluate whether the discharge meets a standard, the sample may contain zero detectable organisms, but the true concentration of organisms may be quite high. For example, even with a relatively high concentration of 100 organisms m^{-3}, only about 10% of 1 L samples will contain one or more organisms. Furthermore, even if zero organisms are detected in a 1 L sample, the upper possible concentration, based on a 95% confidence interval, is about 3,000 organisms m^{-3}. More information about these calculations is presented below. The general point is that more organisms may be released in ballast discharge using a stringent standard paired with a poor sampling protocol than a more lenient standard paired with a stringent sampling protocol. For these reasons, some researchers claim that "part of establishing the criteria is defining the required sampling plan" (Jarvis, 2000).

The current lack of consistent sampling protocols makes it difficult to compare among existing and proposed standards. Even if a single discharge standard is adopted, without consistent sampling protocols the outcome of different ballast management programs will vary dramatically. Furthermore, the efficacy of different ballast treatment technologies cannot be compared without consistent sampling protocols (Phillips, 2005). In this chapter, we explore some of the statistical aspects of estimating the concentration of organisms in ballast discharge using laboratory techniques which count the numbers of living organisms. In Appendix C, we describe some tools that can be used to develop statistically sound sampling protocols.

Sampling Ballast Water Discharges:
Given current methodologies, it is not possible to count every single organism in a ballast tank or discharge (i.e., the "population"); consequently, we must use sampling techniques to estimate the true concentration. Due to the stochastic nature of sampling, multiple samples taken from the same population will have varying numbers of organisms due to random chance. However, if we know how organisms are distributed in their environment, this uncertainty can be estimated and taken into consideration during the development of sampling protocols. A sample taken from a ship's ballast discharge may have a higher concentration than the standard even though the true concentration of organisms is less than the standard. In this situation, if we failed to take into account the inherent stochasticity of sampling, ships that do not violate the standard would be unfairly penalized. Conversely, a sample may have a lower concentration than the discharge standard even though the true concentration of the discharge exceeds the standard. In this situation, if sampling protocols are inadequate then many ships that exceed the standard would not be detected.

Two questions that must be answered to develop adequate sampling protocols, are 1) how many organisms must we observe in a sample before we feel reasonably confident that we can identify ships in violation of the standard; and 2) how few organisms must we observe before we can feel reasonably confident that a ship does not violate the standard? The answers will depend on the size of the sample, the true concentration of organisms, the discharge standard, and the definition of "reasonable confidence".

The answer also depends on how organisms are distributed in the discharged ballast water. The best-case scenario, from a sampling perspective, is a random distribution (Figure 9A), meaning that organisms occur independently of one another. A random distribution will occur in well-mixed ballast water. This distribution may be unlikely because organisms are often aggregated to some extent in their environment. There are several biological reasons for this phenomenon. Organisms may be responding to similar environmental cues, resources or physical forces, such as gravity (Figure 9B); they may be actively seeking conspecifics (Figures 9B and C); or, for organisms with fast population growth rates, reproduction may occur at a faster rate than diffusion or convection away from each other (Figure 9C). Different mechanisms can lead to varying patterns of aggregation, which can have different consequences for sampling. Murphy and colleagues (2002) have shown that the abundance of zooplankton varies with depth in the ballast tanks, indicating that at least one type of aggregation in ballast discharges is likely.

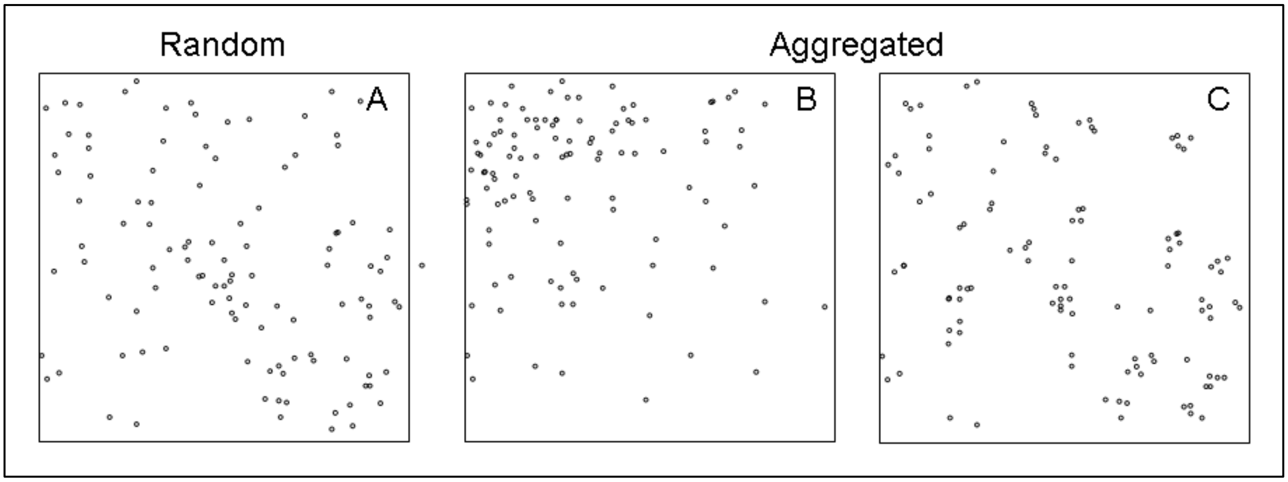


Figure 9: An example of a random distribution (A, Poisson) and two possible variations of aggregated distributions (B and C).

For most of the analyses in this report, we assume that organisms are randomly distributed in ballast tanks and the discharges. From a practical perspective, this was the only option because we do not possess data that can be used to estimate the degree of aggregation in ballast water. Furthermore, Elliott (1971) argues that assuming a random distribution is a reasonable starting point because the Poisson is the default, or null, hypothesis, and therefore, should be assumed until rejected by testing. Elliott also makes the point that for benthic organisms low density populations are effectively randomly distributed in regard to sampling, and therefore a random distribution is often a suitable hypothesis. Whether this applies to organisms discharged in ballast water is unclear. The values presented in this chapter are probably optimistic because: 1) almost all organisms demonstrate at least some aggregation; and 2) for aggregated populations, larger volumes must be sampled to obtain good estimates of concentration.

Further, we assume that the samples are “taken from the discharge line, as near to the point of discharge as practicable, during ballast water discharge whenever possible”, as recommended in the final MEPC G2 ballast water sampling guidelines (MEPC, 2008c), and as such are representative of the actual concentrations discharged. Important aspects of developing sampling protocols may be determining the extent that organisms are aggregated in ballast discharges and whether samples of ballast water discharges are representative of the total number of organisms discharged. We discuss some aspects of sampling aggregated populations later in this chapter.

Sampling Poisson Distributions:

For randomly distributed populations, the Poisson distribution can be used to determine the probability that a given number of individuals will occur in a sample given the true concentration of organisms (see Table 15 for definitions). This information provides the statistical basis of sampling protocols for randomly distributed populations. A defining characteristic of the Poisson distribution is that it is defined by a single parameter, λ, which describes both the mean and variance of the expected counts per unit of sampling effort, thus $\lambda = \mu = \sigma^2$. Lambda can be a real number, and in regard to ballast sampling, it can be interpreted as the true concentration of organisms in the ballast discharge.

For a randomly distributed population the variance increases at exactly the same rate as the mean. This differs from the normal distribution which has two parameters, the mean and variance, which can vary independently of one another. The expected mean and variance scale isometrically with sampling effort. If sample volume doubles, the expected mean and variance of the sample will also double. For these reasons, ten 1 m^3 samples do not provide more information than a single 10 m^3 sample when a population is randomly distributed. However, the first sampling scenario (i.e., ten 1 m^3 samples) provides the data for independently estimating variance, which can be used to determine whether a population is randomly distributed versus aggregated. If the population is randomly distributed, then the mean and variance from multiple samples should not be significantly different from one another (see Elliott, 1971, for more information). An increase in sampling effort, either by taking more sample units or increasing sample volume, improves the average estimate of λ. Ultimately, if all the discharged ballast water was sampled the concentration would equal λ.

Given λ, the probability of N organisms occurring in a sampling unit (individual sample of ballast discharge) is

Equation 23: $P(N) = \dfrac{e^{-\lambda}\lambda^{N}}{N!}$

For example, for a true concentration of 15 organisms m^{-3}, the probability of getting 10 organisms in a sampling unit (i.e., 1 m^3) is

$$P(10) = \frac{e^{-15}(15)^{10}}{10!} = \frac{(3.06\times10^{-7})\times(5.77\times10^{11})}{10\times9\times8\times7\times6\times5\times4\times3\times2\times1} = \frac{176399}{3628800} = 0.0486$$

Although the true concentration of organisms in the ballast tank is 15 organisms m^{-3}, there is a 4.9% chance that a 1 m^3 sample unit will contain 10 organisms (there is about a 12% chance that the sample unit will contain ≤10 organisms). The estimate of parameter λ is represented by the statistic *m*, which, in this sample, equals 10 organisms m^{-3}. This estimate of λ is low given the true concentration of 15 organisms m^{-3}. As the sample volume increases, the sampling statistic, *m*, will on average provide a better estimate of λ.

In the above example, the probability of N events occurring in a sampling unit is determined by λ which represents the average number of events expected to occur per sampling unit. By assuming a constant sampling unit, λ represents an average count with no associated units. However, λ is often expressed as a concentration (organisms m^{-3}) by dividing the average expected count by the volume of the sampling unit. An alternative parameterization of the Poisson distribution can be used which expresses probabilities in terms of the number of events per sampling effort rather than sampling unit. In this case, λ is replaced by the true concentration of organisms, *c*, times the sample volume, *v*, Equation 24: $P(N) = \dfrac{e^{-cv}(cv)^N}{N!}$

This equation is more flexible because it allows the volume of the sample to vary, and it emphasizes that even with a constant population density the Poisson distribution of counts can change by sampling larger or smaller volumes (Bolker, 2008).

Table 15: Definition of statistical terms.

Population	All the organisms in a population, in this case, all the >50 µm organisms in the discharged ballast water.
Sample	A random sample of the population, in this case, a volume of the discharged ballast water in which all >50 µm organisms are counted.
Poisson	A distribution that describes the probability of a given number of "events" (counts, individuals, arrivals, etc) occurring in a unit of time/space if the events are independent of each other. A defining characteristic of the Poisson is that the mean and variance of the expected counts are equal ($\lambda = \mu = \sigma^2$). If organisms in a ballast tank are randomly distributed, then sampling probabilities can be modeled using the Poisson.
λ	Lambda, the single parameter of the Poisson distribution, which is a rate describing the average number of events expected to occur per unit of time/space. In this case, it also describes the true concentration of organisms in the discharged ballast water. This parameter is a real number.
m	A statistic estimating λ, calculated from the average number of events observed during sampling. In this case, *m* is an estimate of the true concentration of organisms in the discharged ballast water based on sampling.
Count	Number of organisms in a sample. This value is an integer.
Negative Binomial	A probability distribution often used to model aggregated populations ($\sigma^2 > \mu$).
θ	Theta, dispersion parameter for the negative binomial distribution. Highly aggregated populations have smaller θ values, and as θ approaches infinity, the negative binomial approximates the Poisson distribution.
Taylor's Power Law	An alternative to the negative binomial for modeling aggregated populations

From equations 23 or 24, probability distributions can be obtained that describe the probability of a sample containing a specific number of organisms given λ and the sample volume (Figure 10). If 1 m^3 of ballast is sampled from the discharge with a concentration of 10 organisms per m^3, the sample could theoretically contain any number of organisms from zero to positive

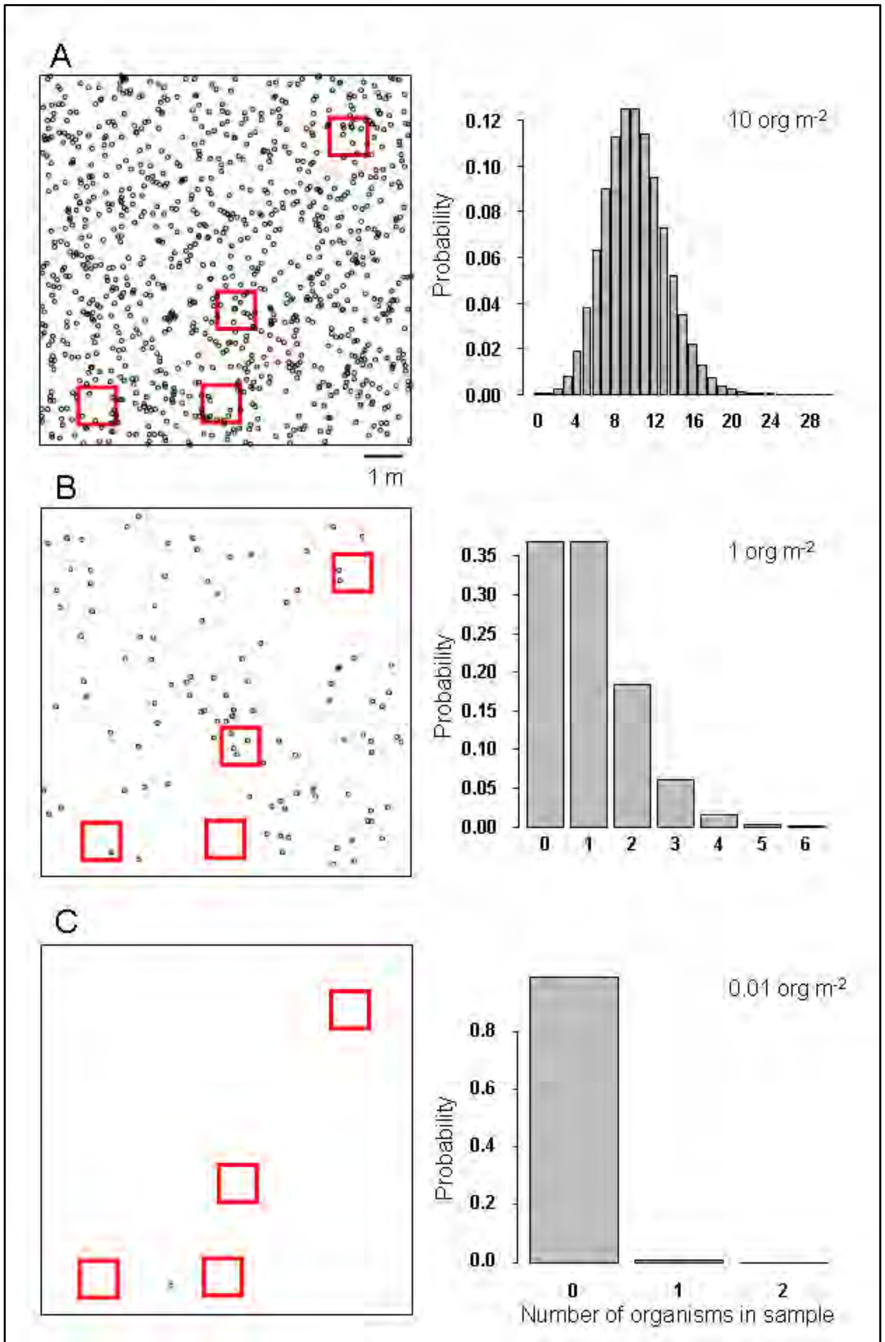


Figure 10: Probability distributions for random samples of 1 m^2 for a randomly distributed population with 10 (A), 1 (B), or 0.01 (C) organisms m^{-2}. Red squares represent random samples. The data are displayed in terms of area with units of m^2, but the probabilities are the same for volumes. Plots on the right indicate the probability that a 1 m^2 sample will contain a given number of organisms. At low concentrations, the concentration of organisms is likely to be estimated as 0 organisms m^{-2}, unless very large volumes are sampled.

infinity (or in the case of a finite volume such as a ballast discharge, the total number of organisms in the discharged ballast), but about 95% of samples will contain 4 to 17 organisms (Figure 10A).

The shape of the Poisson probability distribution, for a fixed sample volume, changes with λ. For a concentration of 10 organisms m^{-3} and a sample volume of 1 m^3, the probability distribution for the number of organisms in a random sample is very similar to a normal distribution (Figure 10A, right). However, there are some key differences between the Poisson and normal distribution. For the Poisson distribution: 1) the model is bounded at 0, indicating there is zero probability of a negative count; 2) when the mean number of organisms in a sample is small (less than 10 or so organisms) due to low concentrations or relatively small sample volumes, the frequency distribution is skewed, with a tail to the right; and 3) the variance can not vary independently of the mean. As the concentration decreases, the frequency distribution becomes increasingly skewed (Figure 10 from A to C) and the probability of obtaining a sample with zero organisms becomes very likely. For concentrations of 1 organism per m^3, the probability of a 1 m^3 sample volume containing 0 organisms is 36.8% (Figure 10B). For a concentration of 0.01 organisms per m^3, the probability is about 99% (Figure 10C). One of the general challenges of sampling at low concentrations is the large number of samples that will have zero detects. In these cases, the estimated concentration is zero, and enormous volumes must be sampled to obtain a better estimate of the true concentration.

Some Sampling Scenarios:

In this section, we translate the information from the theoretical probability distributions into specific sampling scenarios. We hope to illustrate some of the challenges inherent in sampling, as well as to aid in the development of sampling protocols that meet the goals of regulatory agencies. For the following analyses, we use the conditions presented in Table 16.

Table 16: Conditions for ballast water sampling scenarios (unless otherwise stated).

1) In these analyses, we assume discharge standards directly regulate the *concentration* of organisms in ballast discharge. If so, the purpose of sampling is to estimate the true concentration of the ballast discharge, referred to as "average based sampling". An alternative is "maximum instantaneous" discharge standards which establish the maximum number of organisms that can occur in a random sample. An instantaneous discharge standard of <10 organisms $sample^{-1}$ (with a sample unit is 1 m^3) does not equal a concentration based standard of <10 organisms m^{-3} in terms of the allowable concentration of organisms in ballast discharges. The two types of standards have the same outcome only when the discharge standard is 0 detectable organisms. The sampling protocols for instantaneous discharge standards must consider additional statistical factors because the results are very sensitive to the number and volume of the samples.
2) Organisms are randomly distributed in the ballast discharges and can thus be modeled using the Poisson distribution.
3) We assume ALL organisms in a sample are counted with no human or equipment error. Therefore any variation among the samples from a single population is due to the natural stochasticity of sampling.
4) For current ballast sampling techniques, the "sample volume" can be obscured by the steps required to collect and count the organisms. The sample volume must be calculated from the total volume of ballast that is filtered (i.e., concentrated) and the volume of filtrate that is subsampled. The specific steps for sampling can vary, but one technique (Lemieux, 2008) involves filtering a known quantity of ballast water through a net to capture > 50 µm organisms (Gollasch, 2006). The organisms are then rinsed from the net

and resuspended in 1 L of water. From this diluted filtrate, several aliquots of 1 mL are collected to enumerate the number of organisms. If 100 m^3 of ballast is filtered, then the filtrate is diluted with 1 L of water, and the organisms from 20 – 1 mL aliquots are counted, then the total sample volume is 2 m^3 (20 mL of aliquot /1000 mL filtrate × 100 m^3 filtered ballast = 2 m^3), not 100 m^3.

5) Sometimes we report organism counts and sample volumes rather than concentration. These can be converted to concentration by dividing the total number of organisms by the total volume of the sample.

One of the primary problems of sampling low density populations is that large volumes of ballast must be sampled to have a reasonable probability of detecting any organisms. From equation 24, the probability of getting 0 organisms in a sample is e^{-cv}, and therefore, the probability of getting 1 or more organisms is $1- e^{-cv}$. We used this expression to calculate the probability of detecting ≥1 organism for a series of concentrations and sample volumes (Table 17). For a concentration of 0.01 organisms m^{-3} about 300 m^3 of ballast must be sampled to have a 95% probability of detecting at least one organism. For relatively small sample volumes, the probability of detecting an organism is low even at relatively high concentrations. If a 1 L sample is taken from a population with a concentration of 100 organisms m^{-3}, organisms will be detected in fewer than 10% of the samples.

Table 17: Probability of detecting ≥ 1 organism for various sample volumes (100 mL to 100 m3) and ballast water concentrations (0 to 100 organisms m^{-3}). Gray boxes indicate probabilities of detection ≥ 0.95.

	True concentration (organisms per m^3)						
Sample volume, m^3	**0**	**0.001**	**0.01**	**0.1**	**1**	**10**	**100**
0.0001 (100 mL)	0	<0.001	<0.001	<0.001	<0.001	0.001	0.01
0.001 (1 L)	0	<0.001	<0.001	<0.001	0.001	0.01	0.095
0.01 (10 L)	0	<0.001	<0.001	0.001	0.01	0.095	0.632
0.1 (100 L)	0	<0.001	0.001	0.01	0.095	0.632	>0.99
1	0	0.001	0.01	0.095	0.632	>0.99	>0.99
5	0	0.005	0.049	0.393	>0.99	>0.99	>0.99
10	0	0.010	0.095	0.632	>0.99	>0.99	>0.99
25	0	0.025	0.221	0.918	>0.99	>0.99	>0.99
50	0	0.049	0.393	>0.99	>0.99	>0.99	>0.99
100	0	0.095	0.632	>0.99	>0.99	>0.99	>0.99
300	0	0.259	0.950	>0.99	>0.99	>0.99	>0.99

This analysis demonstrates that even when 0 organisms are detected in a sample, the true concentration may be large. A discharge standard of "zero detectable organisms" may appear very protective; however, the true degree of protection depends on the sample volume. From the Poisson distribution, the upper possible concentration (UPC, upper 95% confidence interval) of organisms can be estimated based on the number of organisms in a sample volume. We calculated the UPC when zero organisms were detected in sample volumes ranging from 100 mL to 100 m^3 (Table 18). We primarily focus on confidence intervals from 2-tailed sampling probabilities, but in the case of zero detects, the lower estimate is always zero which is not very informative. For this reason, confidence intervals based on 1-tailed sampling probabilities may be preferred when there are zero detects. If zero organisms are detected in 1 m^3 of ballast, the true concentration could be as high as 3.7 organisms m^{-3}. Given the inherent challenges of sampling ballast water, especially on board a ship, a more realistic sample volume may be around 1 L. For a 1 L sample, the upper concentration could be >3,500 organisms m^{-3} even with zero detects.

Table 18: Upper possible concentration (UPC) of organisms based on one and two tailed 95% exact confidence intervals when zero organisms are detected in a range of sample volumes.

	Upper possible concentration, org m^{-3}	
Sample volume, m^3	**one-tailed**	**two-tailed**
0.0001 m^3 (100 mL)	29,960	36,890
0.001 m^3 (1 L)	2,996	3,689
0.01 m^3 (10 L)	299.6	368.9
0.1 m^3 (100 L)	29.96	36.89
0.5 m^3 (500 L)	5.992	7.378
1 m^3	2.996	3.689
10 m^3	0.300	0.369
100 m^3	0.030	0.037

In an ideal world, we would always detect ballast water with concentrations of organisms that exceed the discharge standard. In reality, this is not possible with current methodologies. The probability of detecting an exceedance depends on: 1) the volume of ballast that is sampled; 2) the stringency of the discharge standard; and, 3) the magnitude of the exceedance. To demonstrate the relationship among these variables, we estimated the likelihood of detecting an exceedance for a discharge standard of <0.01 organism m^{-3} when the sample volume ranged from 1-50 m^3 and the true concentration ranged from 0.01 to 1 organism m^{-3}. For each combination, we simulated 10,000 random samples (*rpois* function, R statistical program, R Development Core Team 2008) and calculated the percentage of samples that were correctly identified as exceeding the discharge standard (Figure 11). Ideally, none of the samples would pass inspection because in all cases the concentration of organisms exceeds the discharge standard. However, as the concentration approaches the discharge standard, increasingly large volumes of ballast must be tested to confidently detect an exceedance. When the true concentration of organisms is 0.75 m^{-3} (75x the proposed U.S. Coast Guard Phase II standard) approximately 4 m^3 of ballast water must be sampled to detect this exceedance 95% of the time (Figure 11A). When the true concentration of organisms is 0.1 m^{-3} (10x the standard) approximately 30 m^3 of ballast water must be sampled (Figure 11B). For perspective on the magnitude of these sample volumes, a Volkswagen Transporter bus has a volume about 14 m^3.

The examples thus far have been theoretical because we begin with a known concentration that exceeds the discharge standard and we calculate the probability of detecting the exceedance given a specific sample volume. These examples are useful because they demonstrate the power and limitations of specific sampling protocols. They are less useful from the perspective of actual sampling, because in reality the true concentration is unknown and must be estimated using sampling techniques. Ultimately, the goal of sampling is to determine whether a ballast discharge exceeds or meets the discharge standard with some pre-established degree of confidence. Two obvious results of sampling are: 1) *Fail*: The number of organisms in the sample is large enough that the true concentration likely exceeds the discharge standard; 2) *Pass*: The number of organisms in the sample is small enough that the true concentration likely meets the discharge standard. There is also a third, *indeterminate* category due to the inherent stochasticity of sampling. A random sample from a ballast discharge may have a concentration that

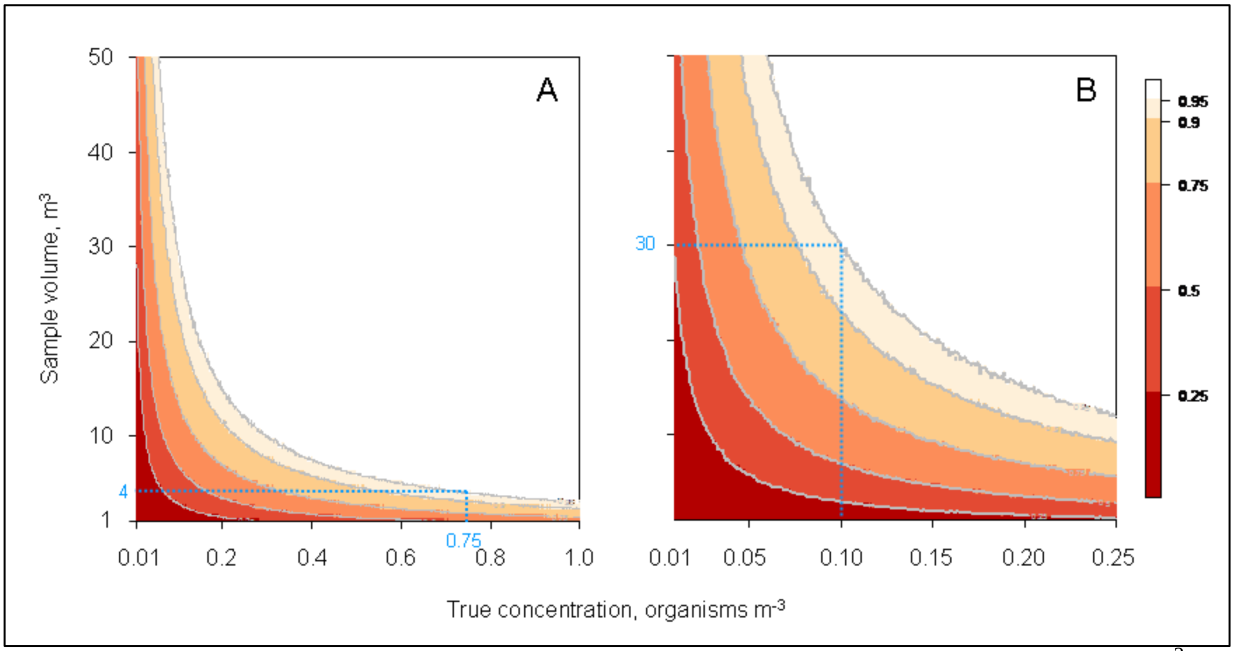


Figure 11: Probability of detecting an exceedance for sample volumes between 1 and 50 m^3 and a discharge standard of 0.01 organisms m^{-3}. The true concentration ranges from (A) 0.01 to 1 organisms m^{-3} or, (B) 0.01 to 0.25 organisms m^{-3}, all of which fail to comply with the discharge standard. The legend describes the proportion of samples in which the exceedance is detected: white regions of plot indicate a >95% probability of detecting the exceedance; the darkest red regions indicate a <25% probability of detecting the exceedance. See text for information about specific examples identified by the blue lines.

exceeds the discharge standard, but the true concentration may actually be less than the discharge standard. For example, if the true concentration of the discharged ballast water is 7 organisms m^{-3} and a volume of 1 m^3 is sampled, about 17% of samples will have 10 or more organisms, and will appear to exceed the current IMO standard of ≤ 10 organisms m^{-3}. The possibility of getting an indeterminate result increases as the sample volume decreases and as the desired level of certainty increases.

We calculated the absolute number of organisms that must be observed in a range of sample volumes to determine – using two-tailed 95% confidence intervals – whether the true concentration exceeds or meets a discharge standard of either 0.01 or 10 organisms m^{-3} (Figure 12). For a very stringent discharge standard, such as the <0.01 organisms m^{-3} proposed by the U.S. Coast Guard, only a few organisms must be observed before a discharge can be classified as exceeding the standard (i.e., concentration > discharge standard). If a single organism is detected in a sample volume of ≤2 m^3 then we can be confident that the standard has been exceeded

(Figure 12A, red region) given that the *lower* value of the 95% confidence interval estimate (0.0125 to 2.786 organisms m^{-3}) is greater than the standard. On the other hand, very large amounts of water must be sampled before a sample can be classified as meeting the standard with the same confidence (i.e. concentration < discharge standard). For a discharge standard of 0.01 organisms m^{-3}, approximately 370 m^3 of ballast water must be sampled, with zero detects, before we can be confident that the tank meets the standard. In this case, the *upper* value of the 95% confidence interval estimate (0 to 0.00997 organisms m^{-3}) is less than the discharge standard (Figure 12A, green region). Another way to think about this is that the probability of detecting 0 organisms in a 370 m^3 sample must be <2.5% (based on two-tailed test) to meet the discharge standard. Of course, the discovery of a single organism in a 370 m^3 sample does not suggest the true concentration exceeds the standard, in fact the ballast discharge in question is still more likely to meet the standard than not. Rather, based on this result we can not distinguish within our desired confidence whether the discharge standard is met given the 95% confidence interval of 0.000068 to 0.015 organisms m^{-3} (Figure 12A, white region). For the IMO discharge standard of <10 organisms m^{-3} (Figure 12B) nearly 0.4 m^3 of ballast discharge must be sampled before the ballast discharge can be classified as passing the standard.

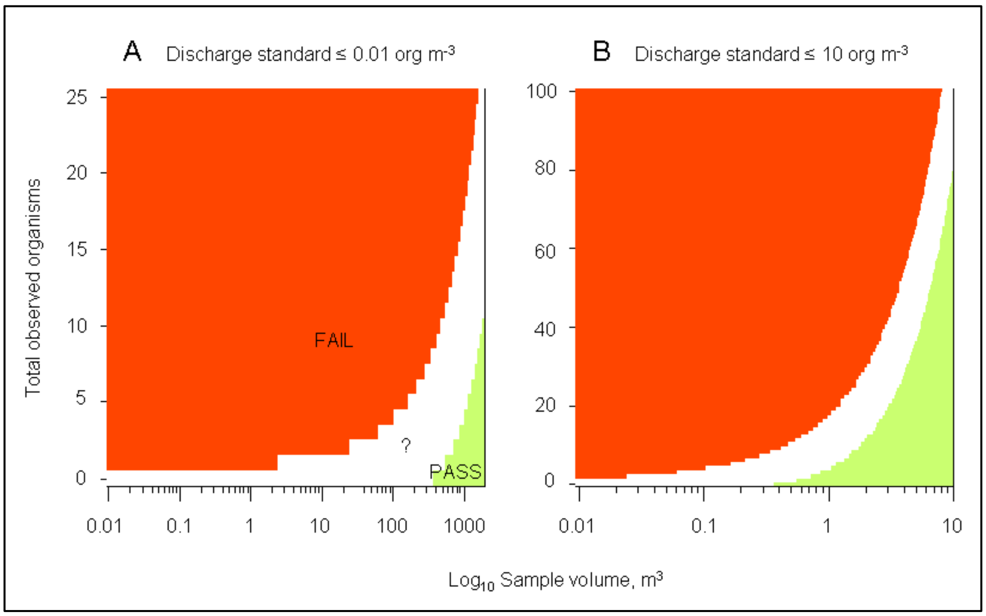


Figure 12: Determining whether ballast water discharge exceeds or meets a discharge standard of <0.01 (A) and <10 (B) organisms m^{-3} (note: axes have different scales). Red regions indicate total organism counts that exceed the standard. Green regions indicate total organism counts that meet the standard. White regions indicate indeterminate results; counts in this region do not pass or fail inspection based on two-tailed 95% confidence intervals.

Aggregated Populations:

Sampling aggregated populations, also known as clumped or contagious populations, is more complicated than sampling randomly distributed populations. One of the defining characteristics of aggregated populations is that the variance is greater than the mean ($\sigma^2 > \mu$, recall that for Poisson distributions $\sigma^2 = \mu$). As variance increases, the true concentration becomes increasingly difficult to accurately estimate because the number of organisms in a random sample becomes increasingly unpredictable. Consequently, aggregated populations must be sampled more intensively to estimate concentration confidently.

Aggregation results from many different ecological and physical processes, making it difficult to apply a single probability distribution to the diverse array of possible patterns of aggregation. Although many distributions have been used to model aggregated populations, the negative binomial is probably the most useful of these models (Elliott, 1971). Like the Poisson distribution, the negative binomial can be used to predict the probability of observing a specific number of organisms in a sample. Unlike the Poisson distribution, the negative binomial is defined by two parameters, the mean (μ) and the dispersion (θ, also called the size parameter). The dispersion parameter is related to the spatial distribution of organisms in their environment. More aggregated populations have smaller dispersion parameters. As the dispersion factor approaches positive infinity, the negative binomial approximates the Poisson distribution. The dispersion parameter of the negative binomial is related to both the mean and the variance (Bolker, 2008). An approximate estimate of this relationship is: $\theta = \mu^2/(\sigma^2 - \mu)$.

As mentioned, one of the general challenges of sampling at low concentrations is the fact that a large number of samples will contain zero organisms. This problem can be compounded when organisms are aggregated. For example, if a 1 m^3 sample of ballast is taken from a randomly distributed population with a true concentration of 1 organism m^{-3}, about 37% of the samples will contain 0 organisms. In contrast, for an aggregated population with a dispersion parameter of 0.1, about 79% of samples will contain 0 organisms (Figure 13). Conversely, the probability of obtaining samples with large numbers of organisms, relative to the true concentration, also increases. For the randomly distributed population, the probability of a sample unit containing > 3 organisms is 1.9%, whereas, for the aggregated population, the probability is 8.3%. If large sample volumes are not taken from aggregated populations, then estimates of concentration are likely to be much lower or higher than the true concentration.

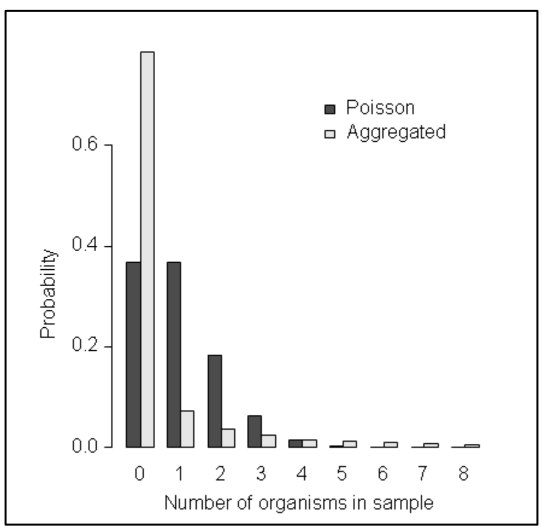


Figure 13: Comparison of sample probabilities from a randomly distributed (Poisson) population vs. an aggregated population with a dispersion parameter of 0.1 (negative binomial) for a sample volume of 1 m^3 and concentration of 1 organism m^{-3}. The probability that a sample will contain 0 organisms is greater for the aggregated population than for the Poisson distributed population.

There are several ways to determine whether a population is aggregated, all of which require multiple sample units from a population to estimate both parameters of the negative binomial distribution (see Elliott, 1971). This is complicated by the fact that estimates of aggregation depend upon the scale of the aggregation pattern relative to the size of the sampling unit (Figure 14). One pattern of aggregation occurs when organisms form clumps that are randomly distributed throughout the environment. In this case, the population can be highly aggregated but if the sample volume is relatively small, such that most sample units contain 0 or 1 organisms, then the population will appear randomly distributed or only slightly aggregated. As the volume of the sample unit increases, the variation in the number of organisms will increase relative to the mean, peaking at the point when the sample volume is about equal to the volume of a single cluster. As sample volume increases beyond this point, the variance will decline relative to the mean because a sample unit will include several clusters. Given these and other issues, the Taylor power law (Taylor, 1961) is an alternative to the negative binomial for modeling aggregated populations that may be applicable for a wider range of distributions than the negative binomial (Elliott, 1971; Downing et al., 1987).

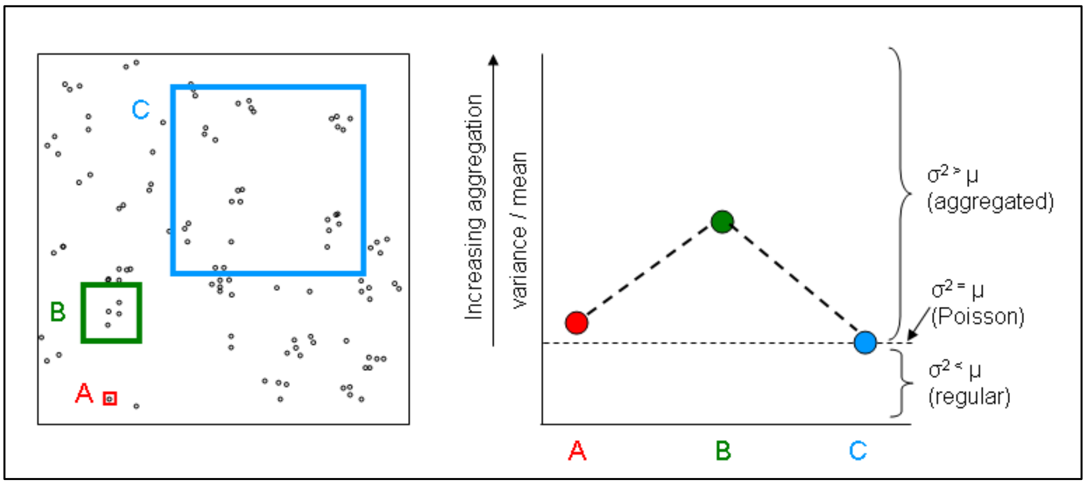


Figure 14: Theoretical example of how the apparent aggregation in the population will differ based on the scale of aggregation relative to the size of the sample unit.

Recommendations/Conclusions:
Instituting standardized sampling protocols is a critical component of implementing ballast discharge standards.

The degree of statistical certainty desired for ballast testing may differ according to the situation. For stringent discharge standards, such as the <0.01 standard proposed by the U.S. Coast Guard, a large quantity of water must be sampled to know with 95% confidence that the true concentration of organisms is less than the discharge standard (Figure 12A, counts in green region are acceptable, counts in red regions are unacceptable, and because counts in white regions are ambiguous they may be classified as unacceptable if a high degree of confidence is desired). This level of certainty is important when testing the performance of ballast treatment systems; however, it may be less critical during compliance monitoring, especially if the primary goals are to detect gross failures or to generate compliance records for individual ships so as to flag those that appear to have poor compliance. For compliance monitoring, one approach may be to employ a three class sampling criteria, such that ships with organism counts in the green region of Figure 12 are acceptable, counts in the red region are unacceptable, and counts in the white region are marginally acceptable.

In situations where indeterminate results are classified as acceptable or marginally acceptable it is critical to ensure that the upper possible concentration of organisms is reasonable from a regulatory perspective. For samples with counts that fall in the intermediate category, the possible concentration of organisms could be quite high depending on the sample volume. This can be true even if zero organisms are detected during sampling (Tables 17 and 18). If zero organisms are detected in a 1 L sample, the upper possible concentration could be nearly as high as 3,000 organisms m^{-3} based on the upper 1-tailed 95% confidence interval. Given this, for ballast discharge standards of "zero detectable organisms" the sample volume must be large enough to ensure that the detection limit is ecologically protective.

Given the current challenges of ship-board testing and the stringency of the current and proposed discharge standards, it will be difficult to sample large enough volumes of ballast water to detect ballast discharges that do not meet the standard, even if the concentration of organisms is 1-3 orders of magnitude greater than the discharge standard. Consequently, the quality control to assure that ballast treatment systems are designed to adequately control the introduction of nonindigenous species may be best achieved primarily through rigorous type-approval of ballast water treatment systems in controlled testing facilities, rather than from after-the-fact compliance ship-board sampling.

Despite the limitations of compliance monitoring in the field this technique may still play an important role in the regulation of ballast discharge standards. This type of testing can detect gross exceedences of the discharge standard, which can be used to identify treatment system failures and problematic ships. Until new sampling technologies are developed, however, ship board testing using existing sampling methods are likely to be inadequate for accurately distinguishing among concentrations in the range of 0.001 to 10 organisms m^{-3}. However, it would be useful to institute a global repository of compliance test results for individual ships through the IMO in order to increase the probability of detecting troublesome patterns. For a discharge standard of <10 organisms m^{-3}, a single 1 m^3 sample containing 15 organisms does not necessarily indicate a ship's treatment system is failing to meet the discharge standard (95% CI: 8.4 to 24.8 organisms m^{-3}). If, however, the same pattern is observed at subsequent discharge events, there is mounting evidence that the treatment system may not be adequately reducing the concentration of organisms in the ballast discharge.

Aggregation may be a significant source of error in many sampling protocols, and estimating the extent of aggregation could be an important aspect of accurately estimating the concentration of organisms in ballast discharge. The extent that a population is aggregated must be determined empirically by taking many replicate samples. The problem is mitigated in the land-based testing facility in Key West, Florida (Lemieux et al., 2008) by continuously sampling throughout the ballast tank. This is achieved by removing all the water from the ballast tank while continuously diverting a relatively small portion of it for testing. This approach is currently not practical for ship-board testing.

In these analyses, we assume the goal of discharge standards is to directly regulate the concentration of organisms in ballast discharges using “average based sampling”. However, if “maximum instantaneous” discharge standards are used instead then additional statistical factors must be considered because the results will be very sensitive to the sample number and volume. For example, if an IMO discharge standard of <10 organisms m^{-3} is enforced using instantaneous sampling, then a ship discharging ballast with a true concentration of 5 organisms m^{-3} will fail about 3.2% of the time based on a single sample of 1 m^3. However, as the number of samples increases the probability of a false failure increases, assuming failure is defined as one or more of the 1 m^3 samples having a concentration of ≥10 organisms m^{-3}. If five 1 m^3 samples are taken from a ballast discharge event, about 15% of the ships will have at least one sample with ≥10 organisms m^{-3}.

XI. COMPARISON OF APPROACHES

Henry Lee II, Deborah A. Reusser, and Melanie Frazier

It is difficult to compare the approaches that have been used to determine the risk of ballast-associated invasions because they do not use a consistent set of input values for ballast water discharges, organism concentrations, or historical invasion rates. Nonetheless, to assist in seeing the "forest from the trees", we present a comparison in Table 19. This comparison summarizes attributes related both to the scientific rigor of the approaches and to their applicability to risk management decisions, in particular as they relate to the development of a national discharge standard. A table can not capture all the nuances or reasoning behind our assessments, and the reader is referred back to the individual sections for more detailed information. Definitions for the attributes in Table 19 are:

Current implementation generates quantitative standards: Does the approach as reviewed in this document actually generate quantitative organism-based discharge standards? A particular approach may not generate quantitative standards, at least as currently implemented, because it is not based on organism concentrations, because the data are not currently available, or because the approach is inherently unsuitable to generate an actual estimate of risk (e.g., it is a relative evaluation among treatments).

Range in uncertainty in standard: What is the apparent range in uncertainty in the discharge standard? This is an estimate of the range in the standard itself, and does not attempt to capture all the potential sources of uncertainty of the input parameters going into the approach. Because the actual organism concentration generated from the zero detectable organism approach is dependent upon the sampling protocol, we compared the upper possible organism concentration from the 95% confidence interval (one-tailed test) for 1 liter sample to a 10 m^3 sample (Table 18). Note that this type of uncertainty would also apply to other approaches.

Key data needs for generation of quantitative standards: These are the most important types of data required to generate a national discharge standard via the identified approach. This is not necessarily a complete list of the data required.

Assumes linear dose response: Does the approach that the invasion rate from ballast discharges is directly proportional to the propagule supply? Note that approaches based on historical invasion rates may actually incorporate Allee effects if the invasion success of historical invaders was dependent upon them exceeding some critical population threshold.

Incorporates invasion risk from multiple species in a discharge: Does the approach assess the risk of invasion from all the species contained within a ballast discharge or does it inherently assume that all the discharged individuals are of a single species?

Incorporates invasion risk from multiple ship discharges: Does the approach assess the risk of establishment from discharges of the same species from multiple ships discharging within the same waterbody?

Based on historical invasion rates: Does the approach directly use historical invasion rates to generate a standard? The uncertainty in these methods will depend, in part, upon the accuracy of these historical invasion rates as well as the extent to which past invasion rates are predictive of future rates.

Based on population dynamics: Does the approach directly use population dynamics, such as growth rates, in predicting invasion risk? The uncertainty in these methods will depend, in part, upon the accuracy of these population vital rates as well as whether they represent the breadth of taxa found in ballast water.

Applicable to all taxa and guilds: Is the standard applicable to all taxonomic groups and guilds? For example, is the standard applicable for holoplanktonic species, such as calanoid copepods, as well as benthic species with a pelagic larval stage or nektonic species, such as fish?

Separates risk assessment from risk management: Does the approach separate the scientific assessment of invasion risk from the risk management decisions, or are the two intermingled? Intermingling the two makes it difficult to evaluate the decision making process rigorously or to determine what new information is required to improve the predictions.

Published in peer-reviewed scientific literature: Has the approach been published in the scientific peer-reviewed literature? Most government reports undergo independent peer review – nonetheless, publication in the peer-reviewed literature indicates some level of acceptance by the broader scientific community. There is an extensive literature on PVA models in general, but the application to ballast water discharges in the DPEIS (USCG, 2008) has not been published in the scientific literature. In addition to the specific Drake et al. (2005) paper on the application of reaction-diffusion models to ballast water, there is an extensive literature on this type of model. Individual experimental studies are generally published in the scientific literature.

Recommended for national standard development: This is the authors' evaluation of whether the approach is potentially suitable for the development of national discharge standards. It is meant to promote further technical review, and we recognize that other evaluations are possible based on the different weighting of the factors. The key factors used in our evaluation include an assessment of the scientific rigor of the approach, the apparent uncertainty in the standards, and whether the current implementation of the approach, or some foreseeable modification, could generate organism-based standards. We also considered whether the approach applies to the full suite of taxa and guilds and can address the combined risk from discharges from multiple ships.

Table 19: Comparison of approaches to generate national organism-based discharge standards for >50 micron organisms in ballast discharges. Assessment is based on current implementation; potential modifications are identified when appropriate. "Reality check" is used to denote that the approach could be used to help evaluate whether predictions from other approaches fall within a realistic range. "Recommend for national standard development" is our assessment of whether the approach should be considered for generating quantitative organism-based discharge standards at the national level. See the text for explanations of the attributes.

Approach / Attribute	**Expert Opinion / Management Consensuses**	**Zero Detectable Organisms**	**Natural Invasion Rate**	**Reaction – Diffusion**	**Population Viability Analysis**	**Per Capita Invasion Probabilities**	**Experimental**
Current implementation generates quantitative standards	Yes	Yes	Yes (prelim. for CA)	No (volume based)	No (relative comparison)	Yes	No
Apparent range of uncertainty in standard	10,000 fold (range of conc. proposed in IMO negotiations – 0.01 to 100 org m^{-3})	Uncertain since detectable conc. in samples have not yet been defined - could be as much as 10,000 fold (upper possible conc. w/1L vs. 10 m^3 sample)	100-fold (3 experts) or 10,000-fold (our analysis)	About 200 fold (approx range in "max. safe release volumes")	<2 fold (w/12 spp. in ballast) to 10,000 fold (multiple voyages – our analysis)	6-fold (among coasts) or 12-fold (w/Great Lakes)	NA
Key data needs for generation of quantitative standards	Unknown since decision process not transparent	Development of statistically rigorous sampling protocol	Natural invasion rates in range of ecoregions	Instantaneous population growth rates for a range of taxa	Instantaneous population growth rates & instantaneous variance of the population growth rate for a range of taxa	None	Extensive experimentation w/range of taxa
Assumes linear dose response	Unknown since decision process not transparent	No (assumes a single individual can become established)	Yes	No (can incorporate Allee effects)	No (can incorporate Allee effects)	Yes	NA (can be used to determine nature of a dose response)

Approach / Attribute	Expert Opinion / Management Consensuses	Zero Detectable Organisms	Natural Invasion Rate	Reaction – Diffusion	Population Viability Analysis	Per Capita Invasion Probabilities	Experimental
Incorporates invasion risk from multiple species in a discharge	Yes?	Yes	Yes	No?	Yes	Yes	No
Incorporates invasion risk from multiple ship discharges	Yes?	Yes	Yes	No	No (modify to incorporate multiple ships?)	Yes	No
Based on historical invasion rates	No	No	Yes	No	No	Yes	No
Based on population dynamics	No	No	No	Yes	Yes	No	Yes
Applicable to all taxa and guilds	Yes?	Yes	Yes? (depends on taxa included in analysis)	No (limited to short-lived holoplanktonic species)	Yes? (depends upon which species the pop. data can be obtained)	Yes	No (limited to taxa adaptable to experiments)
Separates risk assessment from risk management	No	No?	Yes	Yes	Yes	Yes	Yes
Published in peer-reviewed scientific literature	No	No	No	Yes (extensive literature on reaction-diffusion models)	No (extensive literature on PVA models)	No (in process)	Yes (individual experiments)
Recommended for national standard development	No (use as “reality check”)	No	No (possible use as “reality check”)	No (use as “reality check” for holoplanktonic species)	Yes (if sufficient pop. data available for predictions of actual vs. relative risk)	Yes	No (use as “reality check” and test assumptions)

XII. REFERENCES

Andersen, M. 2005. Potential applications of population viability analysis to risk assessments for invasive species. Human and Ecological Risk Assessment 11:1083-1095.

Bailey, S.A., Velez-Espino, L.A., Johannsson, O.E., Koops, M.A., and Wiley, C.J. 2009. Estimating establishment probabilities of *Cladocera* introduced at low density: an evaluation of the proposed ballast water discharge standards. Canadian Journal of Fisheries and Aquatic Sciences 66:261-276.

Banas, N.S, Hickey, B.M., and MacCready, P. 2004. Dynamics of Willapa Bay, Washington: A highly unsteady, partially mixed estuary. Journal of Physical Oceanography 34:2413-2427.

Beissinger, S.R., and McCullough, D.R. (eds.) 2002. *Population Viability Analysis*. University of Chicago Press, Chicago, IL. 577 pp.

Behrens Yamada, S., Dumbauld, B.R., Kalin, A., Hunt, C.E., Figlar-Barnes, R., and Randall, A. 2005. Growth and persistence of a recent invader *Carcinus maenas* in estuaries of the northeastern Pacific. Biological Invasions 7:309-321.

Berec, L., Angulo, E., and Courchamp, F. 2006. Multiple Allee effects and population management. Trends in Ecology and Evolution 22:185-191.

Blueweiss, L., Fox, H., Kudzma, V., Nakashima, D., Peters, R., and Sams, S. 1978. Relationships between body size and some life history parameters. Oecologia 37:257-272.

Bolker, B.M. 2008. *Ecological Models and Data in R*. Princeton University Press, Princeton, NJ. 408 pp.

Box, G.E.P. and Draper, N.R. 1987. *Empirical Model-Building and Response Surfaces*. John Wiley and Sons, New York, NY. 424 pp.

Boyd, M.J., Mulligan, T.J., and Shaughnessy, F.J. 2002. Non-Indigenous Marine Species of Humboldt Bay, California: A Report to the California Department of Fish and Game. 118 pp. (http://dscholar.humboldt.edu:8080/dspace/bitstream/2148/463/1/non_indigenous_marine_boyd_etal_2002.pdf)

Britton-Simmons, K.H. and Abbott, K.C. 2008. Short and long term effects of disturbance and propagule pressure on a biological invasion. Journal of Ecology 96:68-77.

California Department of Fish and Game. 2009. California Aquatic Non-Native Organism Database (CANOD). (http://www.dfg.ca.gov/ospr/about/science/misp.html)

California State Lands Commission. 2009. Performance Standards for the Discharge of Ballast Water for Vessels Operating in California Waters. (http://www.slc.ca.gov/Regulations/Documents/Article_4.7.pdf)

Carlton, J.T. 1996. Pattern, process, and prediction in marine invasion ecology. Biological Conservation. 78:97-106.

Carlton, J. T. 2001. *Introduced Species in U.S. Coastal Waters: Environmental Impacts and Management Priorities*. Pew Oceans Commission, Arlington, VA. 36 pp.

Carlton, J.T. (ed.). 2007. *The Light and Smith Manual: Intertidal Invertebrates from Central California to Oregon.* 4th Edition. University of California Press, Berkeley, CA. 1001 pp.

Carlton, J.T. 2009. Deep Invasion Ecology and the Assembly of Communities in Historical Time. In: Rilov, G. and Crooks, J.A. (eds.) *Biological Invasions in Marine Ecosystems: Ecologial, Management, and Geographic Perspectives (Ecological Studies)*. Springer-Verlag, Berlin. pp. 13-56.

Carlton, J.T. and Cohen, A.N. 2003. Episodic global dispersal in shallow water marine organisms: the case history of the European shore crabs *Carcinus maenas* and *C. aestuarii*. Journal of Biogeography 30:1809-1820.

Carlton, J.T. and Geller, J.B. 1993. Ecological roulette: the global transport of nonindigenous marine organisms. Science 261:78-82.

Carlton, J.T., Reid, D. and van Leeuwen, H. 1995. The role of shipping in the introduction of nonindigenous aquatic organisms to the coastal waters of the United States (other than the Great Lakes) and an analysis of control options. US Coast Guard. Technical Report No. CG-D11-95, Washington, DC. 373 pp.

Chapman, P.M., Fairbrother, A., and Brown, D. 1998. A critical evaluation of safety (uncertainty) factors for ecological risk assessment. Environmental Toxicology and Chemistry 17:99-108.

Choi, K.-H., Kimmerer, W., Smith, G., Ruiz, G.M., and Lion, K. 2005. Post-exchange zooplankton in ballast water of ships entering the San Francisco Estuary. Journal of Plankton Research 27:707-714.

Chonsuvivatwong, V. 2008. epicalc: Epidemiological calculator. R package version 2.8.0.1. http://CRAN.R-project.org/

Clark, G.F. and Johnston, E.L. 2005. Manipulating larval supply in the field: a controlled study of marine invasibility. Marine Ecology Progress Series 298:9-19.

Cohen, A.N., Berry, H.D., Mills, C.E., Milne, D., Britton-Simmons, K., Wonham, M.J., Secord, D.L., Barkas, J.A., Bingham, B., Bookheim, B., Byers, J.E., Chapman, J.W., Cordell, J.R., Dumbauld, B., Fukuyama, A., Harris, L.H., Kohn, A.J., Li, K., Mumford, T.F., Radashevsky, V., Sewell, A.T., and Welch., K. 2001. Report of the Washington State Exotics Expedition 2000: A Rapid Assessment Survey of Exotic Species in the Shallow Waters of Elliot Bay, Totten and Eld Inlets, and Willapa Bay. Nearshore Habitat Program, Washington State Department of Natural Resources, Olympia WA. 39 pp. plus appendices.

Cohen, A.N. 2005. Guide to the Exotic Species of San Francisco Bay. San Francisco Estuary Institute, Oakland, CA (www.exoticsguide.org)

Cohen, A.N. and Carlton, J.T. 1995. Nonindigenous Aquatic Species a United States Estuary: A Case Study of the Biological Invasions of San Francisco Bay and Delta. Report to U.S. Fish and Wildlife Service. 246 pp. plus appendices. (http://nsgl.gso.uri.edu/conn/connt95002/connt95002full.pdf)

Cohen, A.N. and Carlton, J.T. 1998. Accelerating invasion rate in a highly invaded estuary. Science 279:555-558.

Collin, R. 2003. Phylogenetic relationships among calyptraeid gastropods and their implications for the biogeography of marine speciation. Systematic Biology 52:618–640.

Colautti, R.I., Grigorovich, I.A. and MacIsaac, H.J. 2006. Propagule pressure: a null model for biological invasions. Biological Invasions 8:1023–1037.

Cordell, J.R., Lawrence, D.J., Ferm, N.C., Tear, L.M., Smith, S.S., and Herwig, R.P. 2009. Factors influencing densities of non-indigenous species in the ballast water of ships arriving at ports in Puget Sound, Washington, United States. Aquatic Conservation: Marine and Freshwater Ecosystems 19:322-343.

Costello, C.J. and Solow, A.R. 2003. On the pattern of discovery of introduced species. Proceedings of the National Academy of Sciences 100:3321–3323.

Coulson, T., Mace, G.M., Hudson, E., and Possingham, H. 2001. The use and abuse of population viability analysis. Trends in Ecology and Evolution 16:219-221.

Courchamp, F., Clutton-Brock, T., and Grenfell, B. 1999. Inverse density dependence and the Allee effect. Trends in Ecology and Evolution 14:405-410.

Daniels, R.A. and Peteet, D. 1998. Fish scale evidence for rapid post-glacial colonization of an Atlantic coastal pond. Global Ecology and Biogeography Letters 7:467-476.

de Queiroz, A. 2005. The resurrection of oceanic dispersal in historical biogeography. Trends in Ecology and Evolution 20:68-73.

Dennis, B., Munholland, P.L., and Scott, J.M. 1991. Estimation of growth and extinction parameters for endangered species. Ecological Monographs 61:115-143.

deRivera, C.E., Ruiz, G.M., Crooks, J.A., Wasson, K., Longhart, S.I., Fofonoff, P., Steves, B.P., Rumrill, S.S., Brancato, M.S., Pegau, W.S., Bulthuis, D.A., Preisler, R.K., Schoch, G.C., Bowlby, E., DeVogelaere, A., Crawford, M.K., Gittings, S.R., Hines, A.H., Takata, L., Larson, K., Huber, T., Leyman, A.M., Collinetti, E., Pasco, T., Shull, S., Anderson, M., and Powell, S. 2005. Broad-scale nonindigenous species monitoring along the West Coast in national marine sanctuaries and national estuarine research reserves. Report to the National Fish & Wildlife Foundation. 72 pp. plus appendices. (http://cain.nbii.gov/portal/community/Communities/Geographic_Perspectives/Pacific_Northwest/Regional_Planning_Documents/Invasive_Species/).

Desmond, J.S., Deutschman, D.H., and Zedler, J.B. 2002. Spatial and temporal variation in estuarine fish and invertebrate assemblages: analysis of an 11-year data set. Estuaries 25:552-569.

Dobbs, F.C. and Rogerson, A. 2005. Ridding ships' ballast water of microorganisms. Environmental Science and Technology 39: 259A-264A.

Dobroski, N., Scianni, C., Gehringer, D., and Falkner, M. 2009a. 2009 Assessment of the Efficacy, Availability and Environmental Impacts of Ballast Water Treatment Systems for Use in California Waters. Produced for the California State Legislature. 76 pp. plus appendices (http://www.slc.ca.gov/Spec_Pub/MFD/Ballast_Water/Documents/2009CSLCTechReportFinal.pdf)

Dobroski, N., Scianni, C., Takata, L., and Falkner, M. 2009b. October 2009 Update: Ballast Water Treatment Technologies for Use in California Waters. Produced for the California State Legislature. 19 pp. (http://www.slc.ca.gov/Spec_Pub/MFD/Ballast_Water/Documents/2009CSLC_TechUpdate_final.pdf)

Downing, J.A., Perusse, M., and Frenette, Y. 1987. Effect of interreplicate variance on zooplankton sampling design and data analysis. Limnology and Oceanography 32:673-680.

Drake, J.M. 2004. Allee effects and the risk of biological invasion. Risk Analysis 24:795-802.

Drake, J.M. 2006. Extinction times in experimental populations. Ecology 87:2215–2220.

Drake, J.M. and Bossenbroek, J.M. 2004. The potential distribution of zebra mussels in the United States. Bioscience 54:931-941.

Drake, J.M. and Griffen, B.D. 2009. Speed of expansion and extinction in experimental populations. Ecology Letters 12:772-778.

Drake, J.M. and Lodge, D.M. 2004. Effects of environmental variation on extinction and establishment. Ecology Letters 7:26–30.

Drake, J.M., Costello, C., and Lodge, D.M. 2005. When did the discovery rate for invasive species in the North American Great Lakes accelerate? Bioscience 55:4.

Drake, J.M., Lodge, D.M., and Lewis, M. 2005. Theory and preliminary analysis of species invasions from ballast water: Controlling discharge volume and location. American Midland Naturalist 154:459–470.

Drake, L.A., Doblin, M.A., and Dobbs, F. 2007. Potential microbial bioinvasions via ships' ballast water, sediment, and biofilm. Marine Pollution Bulletin 55:333-341.

Drury, K.L.S., Drake, J.M., Lodge, D.M. and Dwyer, G. 2007. Immigration events dispersed in space and time: Factors affecting invasion success. Ecological Modelling 206:63-78.

Duggan, I.C., Bailey, S.A., Colautti, R.I., Gray, D.K., Makarewicz, J.C., and MacIsaac, H.J. 2003. Biological invasions in Lake Ontario: past, present and future. In: Munawar, M. (ed.) *State of Lake Ontario: Past, Present and Future.* Ecovision World Monograph Series, Aquatic Ecosystem Health & Management Society, New Delhi. pp. 541-558.

Eckert, G.L. 2003. Effects of planktonic period on marine population fluctuations. Ecology 84:372-383. (Supplemental data available in Ecological Archives E084-009-A1 at http://esapubs.org/archive/archive_E.htm).

Eckert, G.L. 2009. A synthesis of variability in nearshore Alaskan marine populations. Environmental Monitoring and Assessment 155:593-606.

Eldridge, L.G. 2006. Numbers of Hawaiian Species for 2003 – 2005. Bishop Museum Occasional Papers 88:62-79.

Elliot, J.M. 1971. *Some methods for the statistical analysis of samples of benthic invertebrates.* Freshwater Biological Association Scientific Publication No. 25.

Falkner, M., Takata, L., and Gilmore, S. 2006. California State Lands Commission Report on Performance Standards for Ballast Water Discharges in California Waters. Report produced for California State Legislature. Appendix 5 (Memo on a Natural Invasion Rate Standard) and Appendix 6 (Addendum to the Memo on a Natural Invasion Rate Standard) in Appendix A (Majority Report and Recommendations [sic] of the California Advisory Panel on Ballast Water Performance Standards. (http://www.slc.ca.gov/Spec_Pub/MFD/Ballast_Water/Documents/Appendix_A.pdf)

Faria, J.C. 2009. Resources of Tinn-R GUI/Editor for R Environment. UESC, Ilheus, Brazil.

Fenchel, T. 2005. Cosmopolitan microbes and their 'cryptic' species. Aquatic Microbial Ecology 41:49-54.

Fieberg, J. and Ellner, S.P. 2000. When is it meaningful to estimate an extinction probability? Ecology 81:2040-2047.

Finlay, B.J. 2002. Global dispersal of free-living microbial eukaryote species. Science 296:1061-1063.

Fofonoff, P.W., Ruiz, G.M., Steves, B., and Carlton, J.T. 2003a. In ships or on ships? Mechanisms of transfer and invasion for non-native species to the coasts of North America. In: Ruiz, G.M. and Carlton, J.T (eds.) *Invasive Species: Vectors and Management Strategies*. .Island Press, Washington, DC. pp. 152-182

Fofonoff, P.W., Ruiz, G.M., Steves, B., Hines, A.H., and Carlton, J.T. 2003b. National Exotic Marine and Estuarine Species Information System (NEMESIS). (http://invasions.si.edu/nemesis/overview.html)

Galil, B.S. and Zenetos, A. 2002. A sea change: Exotics in the eastern Mediterranean Sea. In:Leppäkoski, E., Gollasch, S., and Olenin, S. (eds.) *Invasive Aquatic Species of Europe: Distribution, Impacts and Management*. Kluwer Academic Publishers, Dordrecht, The Netherlands. pp. 325-336.

Gascoigne, J. and Lipcius, R.N. 2004. Allee effects in marine systems. Marine Ecology Progress Series 269:49-59.

Gollasch, S. 2006. A new ballast water sampling device for sampling organisms above 50 micron. Aquatic Invasions 1:46-50.

Gollasch, S., David, M., Voigt, M., Dragsund, E., Hewitt, C., and Fukuyo, Y. 2007. Critical review of the IMO international convention on the management of ships' ballast water and sediments. Harmful Algae 6: 585–600.

Gray, D.K., Johengen, T.H., Reid, D.F., and MacIsaac, H.J. 2007. Efficacy of open-ocean ballast water exchange as a means of preventing invertebrate invasions between freshwater ports. Limnology and Oceanography 52:2386-2397.

Gregg, M., Rigby, G., and Hallegraeff, G.M. 2009. Review of two decades of progress in the development of management options for reducing or eradicating phytoplankton, zooplankton and bacteria in ship's ballast water. Aquatic Invasions 4:521-565.

Griffen, B.D. and Drake, J.M. 2008. A review of extinction in experimental populations. Journal of Animal Ecology 77:1274-1287.

Grosholz, E. D. 1996. Contrasting rates of spread for introduced species in terrestrial and marine systems. Ecology 77:1680-1686.

Herborg, L.M., Jerde, C.L., Lodge, D.M., Ruiz, G.M., and MacIsacc, H.J. 2007. Predicting invasion risk using measures of introduction effort and environmental niche models. Ecological Applications 17: 663-674.

Hewitt, C.L, Gollasch, S., and Minchin, D. 2009. The Vessel as a Vector – Biofouling, Ballast Water, and Sediments. In: Rilov, G. and Crooks, J.A. (eds.) *Biological Invasions in Marine Ecosystems: Ecologial, Management, and Geographic Perspectives (Ecological Studies).* Springer-Verlag, Berlin. pp: 117-131.

Hickey, B.M., Pietrafesa, L.J., Jay, D.A., and Boicourt, W.C. 1998. The Columbia River Plume Study: Subtidal variability in the velocity and salinity fields. Journal of Geophysical Research 103:10,339-10,368.

Holeck, K.T., Mills, E.L., MacIsaac, H.J., Dochoda, M.R., Colautti, R.I., and Ricciardi, A. 2004. Bridging troubled waters: Biological invasions, transoceanic shipping, and the Laurentian Great Lakes. BioScience 54:919-929.

Holmes, E.E. 2004. Beyond theory to application and evaluation: Diffusion approximations for population viability analysis. Ecological Applications 14:1272–1293.

Holmes, E.E., Fagan, W.F., Rango, J.J., Folarin, A., Sorensen, J.A., Lippe, J.E., and McIntyre, N.E. 2005. Cross Validation of Quasi-extinction Risks from Real Time Series: An Examination of Diffusion Approximation Methods. NOAA Technical Memorandum NMFS-NWFSC-67. 37 pp. (www.nwfsc.noaa.gov/assets/25/6256_08092005_121845_CrossValidationTM67Final.pdf)

Hoof, R. 2008. Oregon Task Force Report on Shipping Transport of Aquatic Invasive Species.

Hutchinson, G.E. 1965. *The Ecological Theater and the Evolutionary Play*. Yale University Press, New Haven, CT. 139 pp.

IMO. 2004a. Adoption of the Final Act and Any Instruments, Recommendations and Resolutions Resulting from the Work of the Conference. BWM/CONF/36, International Maritime Organization, London. (http://www.epa.gov/owow/invasive_species/BWM-Treaty_36.pdf)

IMO. 2004b. Consideration of the Draft International Convention for the Control and Management of Ships' Ballast Water and Sediments. Ballast Water Discharge Standards - Regulation D-2. BWM/CONF/14. International Maritime Organization, London.

Jarvis, B. 2000. Sampling for microbiological analysis. In Lund, B.M., Baird-Parker, T.C., and Gould, G.W. (eds.) *The Microbiological Safety and Quality of Food Vol. 1*. Aspen Publishers, Gaithersburg, MD. pp. 1691-1732.

Johnston, E.L., Piola, R.F., and Clark, G.F. 2008. Chapter 7. The Role of Propagule Pressure in Invasion Success. In: Rilov, G. and Crooks, J.A. (eds.) *Biological Invasions in Marine Ecosystems: Ecological, Management, and Geographic Perspectives (Ecological Studies)*. Springer-Verlag, Berlin. pp:133-151.

Jossi, J.W., John, A.W.G., and Sameoto, D. 2003. Continuous plankton recorder sampling off the east coast of North America: history and status. Progress in Oceanography 58:313–325.

Kinlan, B.P. and Hastings, A. 2005. Rates of population spread and geographic range expansion: What exotic species tell us. In: Sax, D.F., Stachowicz, J.J., and Gaines, S.D. (eds.) *Species Invasions: Insights into Ecology, Evolution, and Biogeography*. Sinauer Associates, Sunderland, MA. pp. 381-419.

Knowlton, N. 1993. Sibling species in the sea. Annual Review of Ecology and Systematics 24:189-216.

Kolar, C.S. and Lodge, D.M. 2001. Progress in invasion biology: predicting invaders. Trends in Ecology and Evolution 16:199-204.

Kramer, A.M., Dennis, B., Liebhold, A.M., and Drake, J.M. 2009. The evidence for Allee effects. Population Ecology 51:341-354.

Kuhnert, P.M., Hayes, K., Martin, T.G., and McBride, M.F. 2009. Expert opinion in statistical models. In: Anderssen, R.S., Braddock, R.D., and Newham L.T.H. (eds.) 18th World IMACS Congress and MODSIM09 International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand and International Association for Mathematics and Computers in Simulation, July 2009. pp. 4262-4268. (http://www.mssanz.org.au/modsim09/J2/kuhnert_J2.pdf)

Lavoie, D.M., Smith, L.D., and Ruiz, G.M. 1999. The potential for intracoastal transfer of non-indigenous species in the ballast water of ships. Estuarine, Coastal and Shelf Science 48:551–564.

Lee II, H. and Chapman, J.W. 2001. Nonindigenous Species - An Emerging Issue For The EPA. Volume 2: A Landscape In Transition: Effects Of Invasive Species On Ecosystems,Human Health, and EPA Goals. U.S. EPA report by the ORD Regional Science Program. 54 pp. (http://www.epa.gov/owow/invasive_species/workshop/nisvol2.pdf)

Lee II, H., Thompson, B., and Lowe, S. 2003. Estuarine and scalar patterns of invasion in the soft-bottom benthic communities of the San Francisco Estuary. Biological Invasions 5:85-102.

Lee II, H. and Reusser, D.A. 2006. Pacific Coast Ecosystem Information System (*PCEIS*) V. 1.0. United States Environmental Protection Agency and United States Geological Survey (Microsoft Access 2003 database).

Lee II, H., Reusser, D.A., Lamberson, J.O. and Nelson, W.G. 2006. Off the beaten track: Invasion of minimally exposed estuaries in the Columbian Biogeographic Province. 14th Intern. Conf. Aquatic Invasive Species. Key Biscayne, FL, May 14-19 (http://www.icais.org/pdf/Abstracts_2006.pdf)

Lemieux, E.J., Robbins, S., Burns, K., Ratcliff, S., and Herring, P. 2008. Evaluation of representative sampling for rare populations using microbeads. U.S. Coast Guard Research and Development Center. Report No. CG-D-03-09.

Leslie, H.M. 2005. Positive intraspecific effects trump negative effects in high-density barnacle aggregations. Ecology 86:2716–2725.

Lessios, H.A., and Robertson, D.R. 2006. Crossing the impassable: genetic connections in 20 reef fishes across the eastern Pacific barrier. Proceedings of the Royal Society, Series B 273:2201–2208.

Lessios, H.A., Kessing, B.D. and Robertson, D.R. 1998. Massive gene flow across the world's most potent marine biogeographic barrier. Proceedings of the Royal Society, Series B 265:583-588.

Levings, C.D., Cordell, J.R., Ong, S., and Piercey, G.E. 2004. The origin and identity of invertebrate organisms being transported to Canada's Pacific coast by ballast water. Canadian Journal of Fisheries and Aquatic Sciences 61:1–11.

Lewis, M.A. and Kareiva, P. 1993. Allee dynamics and the spread of invading organisms. Theoretical Population Biology 43:141–158.

Locke, A., Reid, D.M., van Leeuwen, H.C., Sprules, W.G., and Carlton, J.T. 1993. Ballast water exchange as a means of controlling dispersal of freshwater organisms by ships. Canadian Journal of Fisheries and Aquatic Sciences 50:2086-2093.

Lockwood, J.L., Cassey, P., and Blackburn, T. 2005. The role of propagule pressure in explaining species invasions. Trends in Ecology and Evolution 20:223-228.

Lodge, D.M., Williams, S., MacIsaac, H.J., Hayes, K.R., Leung, B., Reichard, S., Mack, R.N., Moyle, P.B., Smith, M., Andow, D.A., Carlton, J.T., and McMichael, A. 2006. Biological invasions: Recommendations for U.S. policy and management. Ecological Applications 16:2035-2054.

Ludwig, D. 1999. Is it meaningful to estimate a probability of extinction? Ecology 80:298-310.

Lloyd's Register. 2008. Ballast Water Treatment Technology – Current Status. 32 pp. (http://www.lr.org/NR/rdonlyres/6B8B67B8-C135-4E55-B5B1-4BB6A4A10632/85364/BWT021009.pdf)

McMichael, A.J. and Bouma, M.J. 2000. Global Changes, Invasive Species, and Human Health. In: Mooney, H.A. and Hobbs, R.J. (eds.) *Invasive Species in a Changing World*. Island Press, Washington, DC. pp. 191-210.

MEPC. 2003a. Harmful Aquatic organisms in Ballast Water: Summary of an International Workshop on Ballast Water Discharge Standards. MEPC 49/INF.31, Marine Environment Protection Committee, International Maritime Organization, London. (http://www.sjofartsverket.se/upload/5290/49-INF31.pdf)

MEPC. 2003b. Comments on Draft Regulation E-2 Concentrations of Organisms Delivered in Ships' Ballast Water in the Absence of Any Treatment: Establishing a Baseline for Consideration of Treatment Efficacy. MEPC 49/2/21, Marine Environment Protection Committee, International Maritime Organization, London.

MEPC. 2003c. Harmful Aquatic Organisms in Ballast Water. MEPC 49/2/14, Marine Environment Protection Committee, International Maritime Organization, London. (http://www.sjofartsverket.se/upload/5290/49-2-14.pdf)

MEPC. 2008a. Resolution MEPC.174(58). Guidelines for Approval of Ballast Water Management Systems (G8). MEPC 58/23. Annex 4. Marine Environment Protection Committee, International Maritime Organization, London. (http://www.bsh.de/de/Meeresdaten/Umweltschutz/Ballastwasser/MEPC_125_%2853%29.pdf)

MEPC. 2008b. Resolution MEPC.169(57). Procedure for Approval of Ballast Water Management Systems That Make Use of Active Substances (G9). Marine Environment Protection Committee, International Maritime Organization, London.

MEPC. 2008c. Guidelines For Ballast Water Sampling (G2). Annex 3. Resolution MEPC.173(58). MEPC 58/23. Adopted on 10 October 2008. Marine Environment Protection Committee, International Maritime Organization, London.

McCollin, T., Shanks, A.M., and Dunn, J. 2007. The efficiency of regional ballast water exchange: Changes in phytoplankton abundance and diversity. Harmful Algae 6:531-546.

Miller, A.W., Lion, K., Minton, M.S., and Ruiz, G.M. 2007. Status and Trends of Ballast Water Management in the United States. Third Biennial Report of the National Ballast Information Clearinghouse. (January 2004 to December 2005). Smithsonian Environmental Research Center. Report Submitted to the United States Coast Guard. 62 pp. (http://invasions.si.edu/nbic/reports/NBIC_Biennial_Report3_2004-05.pdf)

Minton, M.S., Verling, E., Miller, A.W., and Ruiz, G.M. 2005. Reducing propagule supply and coastal invasions via ships: effects of emerging strategies. Frontiers in Ecology and the Environment 3:304-308.

Morris, W.F. and Doak, D.F. 2002. *Quantitative Conservation Biology: Theory and Practice of Population Viability Analysis*. Sinauer Associates, Sunderland, MA. 480 pp.

Murphy, K.R., Ritz, D., and Hewitt, C.L. 2002. Heterogeneous zooplankton distribution in a ship's ballast tanks. Journal of Plankton Research 24:729-734.

National Research Council. 1996. *Stemming the Tide: Controlling Introductions of Nonindigenous Species by Ships' Ballast Water*. National Research Council. National Academic Press, Washington, DC. 141 pp.

Nilsson, P.A., Turesson, H., and Brönmark, C. 2006. Friends and foes in foraging: intraspecific interactions act on foraging-cycle stages. Behaviour 143:733-745.

Okubo, A. and Levin, S.A. 2002. *Diffusion and Ecological Problems: Modern Perspectives*. Springer-Verlag, New York, NY. 492 pp.

Pershing, A.J., Greene, C.H., Planque, B., and Fromentin, J-M. 2004. The influences of climate variability on North Atlantic zooplankton populations. In: Stenseth, N.C., Ottersen, G., Hurrell, J.W., and Belgrano, A. (eds.) *Marine Ecosystems and Climate Variation: The North Atlantic: A Comparative Perspective.* Oxford University Press, Oxford. pp. 59-69.

Peterson, A.T. and Vieglais, D.A. 2001. Predicting species invasions using ecological niche modeling: New approaches from bioinformatics attack a pressing problem. Bioscience 51:363-371.

Phillips, S. 2005 (updated 2006). Ballast Water Issue Paper. Report for the Pacific States Marine Fisheries Commission. Portland, OR. 34 pp. (http://www.aquaticnuisance.org/wordpress/wp-content/uploads/2009/01/ballast_water_issue_paper.pdf)

Pimentel, D., Zuniga, R., and Morrison, D. 2005. Update on the environmental and economic costs associated with alien-invasive species in the United States. Ecological Economics 52:273-288.

Piola, R.F. and Johnston, E.L. 2009. Comparing differential tolerance of native and non-indigenous marine species to metal pollution using novel assay techniques. Environmental Pollution 157:2853–2864.

Price, J.P. and Clague, D.A. 2002. How old is the Hawaiian biota? Geology and phylogeny suggest recent divergence. Proceedings of the Royal Society, Series B 269:2429-2435.

R Development Core Team. 2008. *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, (http://www.R-project.org).

Raaymakers, S. 2002. 1st International Ballast Water Treatment Standards Workshop, IMO London, 28-30 March 2001: Workshop Report. GloBallast Monograph Series No. 4. IMO London. (http://globallast.imo.org/monograph%204%20standards%20workshop.pdf)

Reid, D.M. and Carlton, J.T. 1997. Shipping Study 1-A: A Study of the Introduction of Aquatic Nuisance Species by Vessels Entering the Great Lakes and Canadian Waters Adjacent to the United States. Final Report to U.S. Dept. of Transportation and U.S. Coast Guard. Report No. CG-D-17-97. 86 pp.

Reusser, D.A. and Lee II, H. 2008. Predictions for an invaded world: a strategy to predict the distribution of native and non-indigenous species at multiple scales. ICES Journal of Marine Science 65:742–745.

Ricciardi, A. 2006. Patterns of invasion in the Laurentian Great Lakes in relation to changes in vector activity. Diversity and Distributions 12:425-433.

Robertson, D.R., Grove, J.S. and McCosker, J.E. 2004. Tropical transpacific shore fishes. Pacific Science 58:507-565.

Ruiz, G.M. and Carton, J.T. 2003. Chapter 18: Invasion Vectors: A Conceptual Framework for Management. In: Ruiz, G.M. and J.T. Carlton (eds.) *Invasive Species: Vectors and Management Strategies.* Island Press, Washington, DC. pp. 459-504.

Ruiz, G.M. and Reid, D.F. 2007. Current state of understanding about the effectiveness of ballast water exchange (BWE) in reducing aquatic nonindigenous species (ANS) introductions to the Great Lakes Basin and Chesapeake Bay, USA: synthesis and analysis of existing information. NOAA Technical Memorandum GLERL-142. NOAA Great Lakes Environmental Research Laboratory, Ann Arbor, MI. 127 pp. ftp://ftp.glerl.noaa.gov/publications/tech_reports/glerl-142/tm-142.pdf

Ruiz, G.M., Fofonoff, P.W., Carlton, J.T., Wonham, M.J., and Hines, A.H. 2000. Invasion of coastal marine communities in North America: Apparent patterns, processes, and biases. Annual Review of Ecology and Systematics 31:481-531.

Ruiz, G.M., Carlton, J.T., Grosholz, E.D. and Hines, A.H. 1997. Global invasions of marine and estuarine habitats by nonindigenous species: Mechanisms, extent, and consequences. American Zoologist, 37:621-632.

Sakai, A.K., Allendorf, F.W., Holt, J.S., Lodge, D.M., Molofsky, J., With, K.A., Baughman, S., Cabin, R.J., Cohen, J.E., Ellstrand, N.C., McCauley, D.E., O'Neil, P., Parker, I.M., Thompson, J.N., and Weller, S.G. 2001. The population biology of invasive species. Annual Review of Ecology and Systematics 32:305–332.

Sandin, S.A., Smith, J.E., DeMartini, E.E., Dinsdale, E.A., Donner, S.D.,Friedlander, A.M., Konotchick, T., Malay, M., Maragos, J.E., Obura, D., Pantos, O.,Paulay, G., Richie, M., Rohwer, F., Schroeder, R.E., Walsh, S., Jackson, J.B.C., Knowlton, N., and Sala, E. 2008. Baselines and degradation of coral reefs in the northern Line Islands. PLoS ONE 3: e1548. doi:10.1371/journal.pone.0001548. (http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0001548)

Scheltema, R.S. 1986. Long-distance dispersal by planktonic larvae of shoal-water benthic invertebrates among central Pacific islands. Bulletin of Marine Science 39:241-256.

Scheltema, R.S. 1988. Initial evidence for the transport of teleplanic larvae of benthic invertebrates across the east Pacific barrier. Biological Bulletin 174:145-152.

Scheltema, R. S., and I. P. Williams. 1983. Long-distance dispersal of planktonic larvae and biogeography and evolution of some Polynesian and western Pacific mollusks. Bulletin of Marine Science 33:545–565.

Simberloff, D. 1989. Which Insect Introductions Succeed and Which Fail? In: Drake, J.A., Mooney, H.A., di Castri, F., Groves, R.H., Kruger, F.J., Rejmanek, M., and Williamson, M. (eds.) *Biological Invasions: a Global Perspective*. John Wiley and Sons, NewYork, NY. pp. 61-75.

Simberloff, D. 2009. The role of propagule pressure in biological invasions. Annual Review of Ecology Evolution and Systematics 40:81–102.

Simkanin, C., Davidson, I., Falkner, M., Sytsma, M., and Ruiz, G. 2009. Intra-coastal ballast water flux and the potential for secondary spread of non-native species on the US West Coast. Marine Pollution Bulletin 58:366–374.

Sexton, J.P., McIntyre, P.J., Angert, A.L., and Rice, K.J. 2009. Evolution and ecology of species range limits. Annual Review of Ecology Evolution and Systematics 40:415–36.

Stephens, P.A. and Sutherland, W.J. 1999. Consequences of the Allee effect for behaviour, ecology and conservation. Trends in Ecology and Evolution 14:401–405.

Taylor, C.M. and Hastings, A. 2005. Allee effects in biological invasions. Ecology Letters 8:895-908.

Taylor,W.D. and Shuter, B.J. 1981. Body size, genome size, and intrinsic rate of increase in ciliated protozoa. American Naturalist 118:160-172.

Thiel, M. and Gutow, L. 2005. The ecology of rafting in the marine environment. II. The rafting organisms and community. Oceanography and Marine Biology-An Annual Review 43:279-418.

USCG. 2002a. Ballast water treatment standards – East Coast and West Coast workshop summaries. Produced by Battelle for U.S. Department of Transportation/U.S. Coast Guard, Final Report on Contract No. DTCG39-00-D-R00019, March 2002. [From “Report and Recommendation of the California Advisory Panel on Ballast Water Performance Standard”]

USCG. 2002b. Standards for Living Organisms in Ship’s Ballast Water Discharged in U. S. Waters. U.S. Federal Register 67(42):9632 (March 4, 2002). (http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=2002_register&docid=02-5187-filed.pdf)

USCG. 2008. Ballast Water Discharge Standard - Draft Programmatic Environmental Impact Statement. Prepared by the United States Coast Guard, USCG-2001-10486. 221 pp.

USCG. 2009. Proposed Ballast Water Discharge Standard Rulemaking. Fact sheet produced for U.S. Coast Guard Office of Operating and Environmental Standards. (http://www.safinah.co.uk/uploads/assets//PDFs/Ballast_Water_Discharge_Standard.pdf). The proposed rulemaking can be found at: http://www.regulations.gov. Enter docket number USCG-2001-10486 in the Search box.

U.S. EPA. no date. Water Permitting 101. Office of Wastewater Management - Water Permitting. (http://www.epa.gov/npdes/pubs/101pape.pdf)

U.S. EPA. 1986. Ambient Water Quality Criteria for Bacteria – 1986. U.S. Environmental Protection Agency, Office of Water. EPA440/5-84-002. 18 pp. (http://www.epa.gov/waterscience/beaches/files/1986crit.pdf)

U.S. EPA. 1996. U.S. EPA’s NPDES Permit Writers’ Manual. U.S. Environmental Protection Agency, Office of Water. EPA-833-B-96-003. 292 pp. (http://www.epa.gov/npdes/pubs/owm0243.pdf)

U.S. EPA. 1999. Appendix A, Clean Ballast: Nature of Discharge in "Phase I Final Rule and Technical Development Document of Uniform National Discharge Standards (UNDS)". EPA-842-R-99-001.

U.S. EPA. 2003. Bacterial Water Quality Standards for Recreational Waters (Freshwater and Marine Waters) - Status Report. U.S. Environmental Protection Agency, Office of Water. EPA-823-R-03-008. 9 pp. plus appendix.

U.S. EPA. 2004a. An Examination Of EPA Risk Assessment Principles and Practices. Staff Paper Prepared for the U.S. Environmental Protection Agency by members of the Risk Assessment Task Force. EPA/100/B-04/001. 180 pp. (http://www.epa.gov/osa/pdfs/ratf-final.pdf)

U.S. EPA. 2004b. Overview of the Ecological Risk Assessment Process in the Office of Pesticide Programs, U.S. Environmental Protection Agency - Endangered and Threatened Species Effects Determinations. Office of Prevention, Pesticides and Toxic Substances Office of Pesticide Programs Washington, DC. 92 pp. (http://www.epa.gov/espp/consultation/ecorisk-overview.pdf)

U.S. EPA. 2008a. 2008 Final issuance of National Pollutant Discharge Elimination System (NPDES) Vessel General Permit (VGP) for Discharges Incidental to the Normal Operation of Vessels Fact Sheet. (www.epa.gov/npdes/vessels)

U.S. EPA. 2008b. Vessel General Permit. Finalized December 19, 2008. (www.epa.gov/npdes/vessels)

Verling, E., Ruiz, G.M., Smith, L.D., Galil, B., Miller, A.W., and Murphy, K.R. 2005. Supply-side invasion ecology: characterizing propagule pressure in coastal ecosystems. Proceedings of the Royal Society, Series B 272:1249–1257.

Vermeij, G.J. 1991. When biotas meet: Understanding biotic interchange. Science 253:1099-1104.

Vermeij, G.J. 2005. From Europe to America: Pliocene to recent trans-Atlantic expansion of cold-water North Atlantic molluscs. Proceedings of the Royal Society, Series B 272:2545–2550.

Wonham, M.J. and Carlton, J.T. 2005. Trends in marine biological invasions at local and regional scales: the Northeast Pacific Ocean as a model system. Biological Invasions 7:369–392.

Wright, D.A. 2007. Logistics of shipboard and dockside testing of ballast water treatment systems in the United States. In: Gherardi, F. (ed.) *Biological Invaders in Inland Waters: Profiles, Distribution, and Threats.* Springer, The Netherlands. pp. 657-668.

Zongguo, H. 2001. *Marine Species and Their Distribution in China's Seas*. Krieger Publishing Co., Malabar, FL. 599 pp.

Appendix A: Overview of Human Health Microbial Standards

Henry Lee II

Overview:
It is beyond the scope of this document and the expertise of the author to critically review the microbial human health discharge standards proposed by IMO or other entities (see Table 1), and the reader is referred to water quality criteria documents and websites for additional information (e.g., U.S. EPA, 1986, 2003; http://www.epa.gov/beaches/) as well as to reviews on microbes in ballast water (e.g., Dobbs and Rogerson, 2005; Drake et al., 2007). One approach taken by the IMO and the USCG is to use indicator organisms, specifically *Escherichia coli* and intestinal enterococci (Table 1). *E. coli* is usually non-pathogenic but is considered an indicator of fecal contamination. *Enterococcus* is a genus of bacteria that is a sub-group of fecal streptococci, and is also an indicator of fecal contamination. EPA's 1986 guidance (U.S. EPA, 1986) listed both *E. coli* and enterococci as indicators in freshwater but only enterococci for marine waters since it survives longer than *E. coli* in marine waters. The IMO and USCG, however, do not differentiate between fresh and marine waters in their standards.

The genesis of the proposed IMO and USCG Phase I microbial standards is not well defined. They are both set at about twice the criteria for steady state geometric mean densities for "Bathing (Full Body Contact) Recreational Waters" in the 1986 "Ambient Water Quality Criteria for Bacteria" document. These values are based on multiple samples: "generally not less than 5 samples equally spaced over a 30-day period". The USCG Phase II standards and the Wisconsin and interim California standards are equal to the freshwater standards in the 1986 criterion document.

Both the IMO and the USCG also list standards for *Vibrio cholerae* (serotypes O1 and O139) as does California in its interim standards (Table 1). *Vibrio cholerae* is the pathogen causing cholera, and as noted by the MEPC (2003c), "Some cholera epidemics appear to be directly associated with ballast water. One example is an epidemic that began simultaneously at three separate ports in Peru in 1991, sweeping across South America, affecting more than a million people and killing more than ten thousand by 1994. This strain had previously been reported only in Bangladesh." It is not clear to the current authors how the particular standards were derived by the IMO or USCG. It is interesting to note that in a presentation by Professor Rob Bragg ("Understanding Cholera - A Review"; http://www.ufs.ac.za/apps/congress/documents/05/Presentations/107-Prof%20R%20Bragg.ppt) he stated that it took about one million bacteria to start an infection in a healthy person. However, it is not possible to compare this value with the ballast standards because they are given in colony forming units" (cfu). It is also interesting to note that the U.S. EPA recently removed *Vibrio cholerae* from its final Contaminant Candidate List 3 (CCL 3) for drinking water (http://www.epa.gov/ogwdw/ccl/pdfs/ccl3_docs/fs_cc3_final.pdf) because of the low incidence of cholera in the United States.

Recommendation/Conclusions:
As a first step, we suggest that a clearer rationale for the microbial standards be developed. Is the purpose of the standards to protect bathers or is it to protect drinking water? Or are the

standards considered surrogates to help protect against the transport of animal diseases, such as viral hemorrhagic septicemia virus (VHS; see http://biology.usgs.gov/faer/vhs.html)? These are all laudable objectives but the standards, and the indicators, are likely to differ depending upon the most important objective(s).

Consideration should be given to the design of sampling protocols both during land/ship based verification testing and during compliance monitoring. As detailed in the 1986 "Ambient Water Quality Criteria for Bacteria", there are different standards for long-term means and individual samples.

Appendix B: Calculation of Coastal Per Capita Invasion Probabilities

Deborah A. Reusser

Statistical Analysis Using R:
Analysis was done using the statistical program R (R Development Core Team 2008) because it is widely available and free. The scripts were developed in the text editor Tinn-R (Faria 2009). The R script below reads foreign ballast water discharge values for ship discharges for each coast in the United States. The calcPCIP function runs a simulation 10,000 times. For each run, a random organism concentration is selected for each ship based on estimates of Minton et al. (2005) sample data. The function then calculates the high, median and low quantiles of PCIP values for each coast. A histogram of the PCIP values is generated for each coast and written to a png file. Code is also provided that uses the PCIP values to generate contour plots indicating the number of invaders per year given organism concentrations and total amount of ballast water discharged. The code to generate contour plots is given, based on a safety factor of 1. If the safety factor is changed, the text locations will need to be modified to plot correctly on the contour plot. Ballast water discharge data are required, along with an organism density file and historical invasion rate to run this code.

Load the library files needed

```
>library(Hmisc)
>library(MASS)
> library(RColorBrewer)
>library(fields)
```

Identify the column definitions for reading in the file

```
>col.defs<-c(rep("numeric",2))
```

Read in the density Values from the Minton graph

```
>ballastDF <- read.csv("DensityVals.csv", colClasses=col.defs)
```

Create the MeanData table from the density values (N=354)

```
>MeanData <- rep(ballastDF$Density, ballastDF$NumShips)
```

The density values data is a table of the number of ships with organism concentrations of a certain value. The MeanData table contains 354 values with approximate organism concentrations extracted from the table in Minton et al. (2005).

Indentify the columns and read the ballast water file

```
>col.defs <- c(rep("character", 5),"numeric", rep("character",2), rep("numeric",2))
>allBallast<-read.csv("coastforiegnballast.csv", colClasses = col.defs)
```

Identify the columns and read the number of invaders per coast in

```
>col.defs <- c("character", "numeric")
>ballastInvaders<-read.csv("Ballast_Invaders.csv", colClasses = col.defs)
```

Create a summary table containing the sums for each coast

```
>ballastSums<-tapply(allBallast$DISCHARGE, allBallast$Coast, sum)
>bwSumsdf <- data.frame(ballastSums)
>bwSumsdf$coast<-row.names(bwSumsdf)
>bwSumsdf$annualForeign <- bwSumsdf$ballastSums/3
```

Function CalcPCIP runs 10,000 simulations randomly assigning an organism concentration to each discharge event, summing the total organism concentrations for the run and calculating the PCIP for each run. After all runs are completed, a histogram of the PCIP values is written to a png file and the 2.5, .5, 97.5 quantile values are calculated for the set of PCIP values generated.

```
>calcPCIP <-function(bInfo, bData) {
  #Define a dataframe to contain the calculated values
  >RandRun=data.frame(MeanConc=rep(NA,10000), TotalProp=rep(NA, 10000),
PCIP=rep(NA,10000))

  #Run the calculations 10,000 times to get a normal distribution of per capita probabilities
   >for (i in 1:10000) {
      # Get a random array of concentrations for all
      >Conc <- sample(MeanData, size=bInfo$shipCount, replace=TRUE)
      # Calculate the mean concentration for this run and store it
      >RandRun$MeanConc[i] <- mean(Conc)
      # Calculate the number of organisms for each ship for this run
      >Prop<- round(Conc*bData$DISCHARGE,0)
      # Calculate the total organism inoculation from all ships for this run and store it
      >RandRun$TotalProp[i] <- sum(Prop,na.rm=TRUE)
      # Calcuate the annual per capita probability
      >RandRun$PCIP[i] <- bInfo$TotBWInvaders/(RandRun$TotalProp[i]/3)
   >}

# Create a file name and write out the data generated by the Random Run
> csvFile <- paste(bInfo$Coast, "RanRun", ".csv", sep="")
>write.csv(RandRun, file = csvFile, append = FALSE, na = "NA", row.names = TRUE)

#Calculate the lower, median and upper bound of the annual per capita invasion probability
>tmp <- quantile(RandRun$PCIP, probs=c(0.025,.5, 0.975))
>bInfo$medianPCIP <- tmp[2]
>bInfo$hbPCIP <- tmp[3]
>bInfo$lbPCIP <- tmp[1]

# Create a histogram of all calculated annual PCIPs, write the graphic to a png file
# Create the name of the file to be written
>pngFile <- paste(bInfo$Coast, ".png",sep="")
# Open the png file for writing
>png(pngFile)
```

```
# Create a title for the Historgram based on the name of the coast being processed
 >hTitle <- paste("Histogram of",  bInfo$Coast, "Coast Annual\nPer Capita Invasion
Probabilities")
>hist(RandRun$PCIP, font=2, font.lab=2,main=hTitle, xlab="Per Capita Invasion Probabilites")
# add lines for the lower, median and upper quantile PCIP values on the histogram
>abline(v=bInfo$lbPCIP, col="red")
>abline(v=bInfo$hbPCIP, col="red")
>abline(v=bInfo$medianPCIP, col="blue")
# Close the png file
>dev.off()
# Return the dataframe of information for the coast to the calling routine
>return(bInfo)
}
## END FUNCTION
Create a unique list of Coasts in allBallast
>coastlst<-unique(allBallast$Coast)
>allBallastLst <- unique(allBallast$Coast)
>recCount <- length(coastlst)

Create a dataframe to hold the information calculated for each coast
>CoastInfo=data.frame(CoastName=rep(NA,recCount), shipCount=rep(NA, recCount),
TotFB=rep(NA,recCount),TotAnnFB=rep(NA,recCount),TotBWInvaders=rep(NA,recCount),lb
PCIP=rep(NA,recCount), medianPCIP=rep(NA,recCount), hbPCIP=rep(NA,recCount))

Loop  through all the coasts calling the PCIP function
>for(j in 1: length(coastlst)){

     ## Get the name of the current coast ##
     >CoastInfo$CoastName[j] <- coastlst[j]
     ## Get the records for the current coast ##
     >CoastData <- allBallast[allBallast$Coast %in% CoastInfo$CoastName[j],]
     ## Get the count of the number of records for the current coast ##
     >CoastInfo$shipCount[j] <-length(CoastData$Coast)
     ## Get only the records that have foreign ballast discharge ##
     >FBCoastData <- CoastData[CoastData$DISCHARGE > 0,]
     ## Calculate the total foreign ballast
     >CoastInfo$TotFB[j] <- sum(FBCoastData$DISCHARGE)
     ## Calculate the total annual foreign ballast
     >CoastInfo$TotAnnFB[j] <- sum(FBCoastData$DISCHARGE)/3
     ## Store the ballast water invaders per year for a coast
     >CoastInfo$TotBWInvaders[j] <- ballastInvaders$invpyr[ballastInvaders$Coast %in%
CoastInfo$CoastName[j]]
     ## Calculate the PCIP values for the Coast
     >CoastInfo[j,] <- calcPCIP(CoastInfo[j,], CoastData)

  >}
```

Write out the results for each coast to a CSV file
>write.csv(CoastInfo, file = "RegionalPCIP.csv", append = FALSE, na = "NA", row.names = TRUE)

```
# Build a vector of values for 3D plot- Organism Concentrations 0 - 1000
>conc<-c(seq(0.0001, 0.001, by = 0.00001),
        seq(0.0011, 0.01, by = 0.0001),
        seq(0.011, 0.1, by=0.001),
        seq(0.11, 1, by = 0.01),
        seq(1.1, 100, by = .1),
        seq(101, 1000, by=1))

# Build a vector of discharge values from 0 to 30,000,000
>discharge<-seq(0,30000000, length=6001)

# Get the stored value for the upper quantile for West Coast
>probinv<- CoastInfo$hbPCIP[3]

# Set the safety factor
>safetyFactor<- 1

#Create a matrix to contain the number of invaders given a concentration and discharge
>num_invaders=matrix(data=NA, nrow=6001, ncol=2251, byrow="T", dimnames=NULL)

# Fill the matrix looping through each concentration and discharge value
>for (i in 1:6001) {
  >for (j in 1:2251) {
    >num_invaders[i,j]=probinv*discharge[i]*conc[j]*safetyFactor
 > }
>}

# Make a plot of the probabillity Matrix
#  Set the Breaks for the Plot
>brk <- c(0,0.0001, 0.001, 0.01, 0.1,1, 10)

#Create a color pallette of Red Yellow Green with six different colors
>myPal<-brewer.pal(6,"RdYlGn")

# Identify the png the plot will  be written to
>png("WCRegionalPCIPJan2010.png")
>par(xaxs="i", family="serif")
>iTitle <-  paste("Predicted Number of Invaders Per Year \n Given Per Capita Invasion
Probability of", format(probinv,scientific = TRUE, digits=4), " \n West Coast")

# Make the plot
```

```
>image.plot(x=discharge, y=log(conc,10),z=num_invaders, axes=F, breaks=brk, font.lab=2, col=rev(myPal),lab.breaks=names(brk),
 xlab="Foreign Ballast Water Discharge in Million m3 Per Year", ylab="Concentration (organism/m3)", main=iTitle, add=FALSE, legend.shrink=100)
#label the axes
>axis(1, at=c(0, 1000000, 5000000,10000000,15000000,20000000,25000000, 30000000), labels = c(0, '1', '5','10','15','20','25','30'),font=2, las=1)
>axis (2, at = c(-4,-3, -2, -1, 0, 1, 2, 3), labels = c('0.0001','0.001', '0.01', '0.1', '1', '10', '100', '1000'), font=2, las=1)

# Label the plot with the number of NIS per year for each color
>text(27900000,-2.3, "# NIS < 1 per 10,000 years", cex=1, col="black", font=2, adj=c(1,0))
>text(27900000,-.4, "# NIS < 1 per 1000 years", cex=1, col="black", font=2, adj=c(1,0.5))
>text(27900000,.55, "# NIS < 1 per 100 years", cex=1, col="black", font=2,adj=c(1,0.5))
>text(27900000,1.5, "# NIS < 1 per 10 years", cex=1, col="black", font=2, adj=c(1,0))
>text(27900000,2.50, "# NIS < 1 per year", cex=1, col="black", font=2, adj=c(1,0))
>dev.off()
```

Appendix C: R Statistical Tools to Develop/Evaluate Ballast Water Sampling Protocols

Melanie Frazier

Statistical Tools Using R:
Here we describe some tools that can be used to develop and evaluate sampling protocols. For these examples we use the statistical program R (R Development Core Team 2008) because it is widely available, free, and the preferred program for analysis of many researchers. We also suggest working with a data editor such as Tinn-R (Faria 2009). We do not attempt to provide an overview of R; however, some excellent introductory materials can be found at http://cran.r-project.org by following the "Contributed" link. Input and output from R are represented with `courier` font, and input is preceded by ">". The symbol "`<-`" indicates the assignment of a variable name to a variable. R will not read input preceded by "#", which is for user documentation.

Random distributions

To calculate the confidence interval around a concentration based on the results from sampling, the *ci.poisson* function from the *epicalc* package (Chonsuvivatwong 2008) can be used. This function calculates the possible range of concentrations based on the desired confidence interval (alpha = significance level = 1 – CI/100), the total number of observed organisms (events), and the total sample volume (person.time). For example, if 0 organisms are observed in a 0.1 m^3 sample volume, the true concentration may be as high as 36.89 organisms m^{-3} based on the two-tailed 95% confidence interval:

```
> ci.poisson(0, 0.1, alpha=0.05)
 events person.time incidence se exact.lower95ci exact.upper95ci
      0         0.1         0  0               0           36.89
```

If 10 organisms are observed in a 1m^3 sample volume, the concentration is estimated to be between 4.8 and 18.4 organisms based on the 95% confidence interval:

```
> ci.poisson(10, 1, alpha=0.05)
 events person.time incidence se exact.lower95ci  exact.upper95ci
 10     1           10        3.162     4.79                 18.4
```

The Poisson distribution can be further explored using dpois, ppois, qpois, and rpois functions. These functions allow lots of flexibility for evaluating and developing sampling protocols. Poisson distributions are described by a single parameter, λ, which equals both the mean and the variance ($\lambda = \mu = \sigma^2$). As the mean of a Poisson distribution increases, the variance also increases. For ballast water analyses, λ represents the concentration of organisms in the ballast water. For more information about these functions, type the function name preceded by a "?" (i.e., ?dpois) into the R console. For the following examples, we assume a sample volume of 1 m^3.

The dpois function is the probability density function for a Poisson distribution. It calculates the probability of obtaining a specific number of organisms in a sample unit based on λ. For example, if a ballast tank contains 1 organism m^{-3} the probability of a 1 m^3 sample volume containing zero organisms is 36.8%:

```
> dpois(0, lambda=1)
     0.3678794
```

A plot of the probability distribution can be created (see Fig. 9):

```
> counts <- c(0,1,2,3,4,5,6)
> poissonDist <- dpois(counts, lambda=1)
> barplot(poissonDist, ylab="Probability", xlab="Count of
organisms in sample", names.arg=counts)
```

The ppois function is the cumulative distribution function. This is used to calculate the probability of a sample containing ≤ a specified number of organisms. The probability of a 1 m^3 sample volume containing ≤ 3 organisms when the concentration is 1 organism m^{-3} is 98.1%:

```
> ppois(3, lambda=1)
     0.9810118
```

The probability that a sample will contain >3 organisms is 1.9%:

```
> 1 - ppois(3, lambda=1)
     0.01898816
```

or, alternatively:

```
> ppois(3, lambda=1, lower.tail=FALSE)
     0.01898816
```

The qpois function is the quantile function and returns the number of organisms predicted to be in a sample for a given quantile of data (the inverse of ppois). For example, if the concentration of organisms in ballast is 10 m^{-3}, about 95% of 1 m^3 samples will contain 15 or fewer organisms.

```
> qpois(0.950, lambda=10)
     15
```

The rpois function generates random values from a Poisson distribution with a specified lambda. To obtain ten 1 m^3 random samples from a population with concentration 1 organism m^3:

```
> rpois(10, lambda=1)
     1 0 3 1 2 1 0 0 3 2
```

Aggregated distributions

One way to determine whether a population is aggregated is to compare the observed distribution of sample data with an expected distribution derived from the mean and variance of the sample data. A chi-square test can then be used to compare the observed and expected values (this and other methods are described in Jarvis, 2000). Negative binomial distributions are described by two parameters, μ (mean) and θ (dispersion factor, referred to as “size” in R). These parameters can be estimated with maximum likelihood techniques using the fitdistr function from the MASS package from replicate samples taken from a population. Once the parameters have been estimated, the probability distribution for the negative binomial can be used to develop sampling protocols for aggregated populations. The negative binomial functions in R are: dnbinom, pnbinom, qnbinom, and rnbinom.

FOR INFORMATION, PLEASE CONTACT
Lynda Smallwood
100 Howe Avenue, Suite 100-South
Sacramento, California 95825-8202
smallwl@slc.ca.gov
(TDD/TT) 1-800-735-2929
(916) 574-1923
AGENDA AND ITEMS ARE AVAILABLE ON CSLC WEB SITE: www.slc.ca.gov

WEBCAST AVAILABLE AT:

WWW.CAL-SPAN.ORG

AGENDA

MEETING OF THE CALIFORNIA STATE LANDS COMMISSION

JUNE 28, 2010

COURTYARD BY MARRIOTT EMERYVILLE
5555 SHELLMOUND STREET
EMERYVILLE, CALIFORNIA 94608

JOHN CHIANG, STATE CONTROLLER, CHAIR
ABEL MALDONADO, LIEUTENANT GOVERNOR, MEMBER
ANA J. MATOSANTOS, DIRECTOR OF FINANCE, MEMBER

ORDER OF BUSINESS

I. **<u>10:00 A.M. – CLOSED SESSION</u>**

II. **<u>10:15 A.M. – OPEN SESSION</u>**

A SIGN LANGUAGE INTERPRETER WILL BE PROVIDED UPON ADVANCE NOTIFICATION OF NEED BY A DEAF OR HEARING IMPAIRED PERSON. SUCH NOTIFICATION SHOULD BE MADE AS SOON AS POSSIBLE PRIOR TO DATE OF THE EVENT.

IF YOU NEED REASONABLE ACCOMMODATION, TO CONDUCT BUSINESS WITH THE COMMISSION, FOR A DISABILITY AS DEFINED BY THE FEDERAL AMERICANS WITH DISABILITIES ACT AND THE CALIFORNIA FAIR EMPLOYMENT AND HOUSING ACT, PLEASE CONTACT THE COMMISSION IN ADVANCE TO ARRANGE FOR SUCH ACCOMMODATION.

F

III. CONFIRMATION OF MINUTES FOR THE MEETING OF APRIL 6, 2010

IV. EXECUTIVE OFFICER'S REPORT

V. CONSENT CALENDAR C01 - C87 THE FOLLOWING ITEMS ARE CONSIDERED TO BE NON-CONTROVERSIAL AND ARE SUBJECT TO CHANGE AT ANY TIME UP TO THE DATE OF THE MEETING.

ANYONE WISHING TO ADDRESS AN ITEM ON THE AGENDA SHOULD FILL OUT A SPEAKER FORM. WHEN YOU ARE CALLED TO SPEAK, PLEASE STATE YOUR NAME FOR THE RECORD.

LAND MANAGEMENT DIVISION
RECREATIONAL PIER LEASES

C 01 **MICK VORBECK AND DAVID SACA (APPLICANTS):** Consider application for a new Recreational Pier Lease of sovereign land located in Lake Tahoe, adjacent to 3135 and 3145 North Lake Tahoe Boulevard, near Tahoe City, Placer County; for an existing joint-use pier and two mooring buoys previously authorized by the Commission and the retention of two mooring buoys not previously authorized by the Commission. (WP 5529.9; RA# 01409) (A 4; S 1) (Staff: R. Barham)

- Agenda Item
- Exhibit A

C 02 **LAURENCE L. AKIN AND KIM S. AKIN, AS TRUSTEES OR THEIR SUCCESSORS IN INTEREST OF THE LAURENCE L. AKIN AND KIM S. AKIN TRUST AGREEMENT DATED NOVEMBER 29, 1993 (APPLICANTS):** Consider application for a new Recreational Pier Lease of sovereign land located in Lake Tahoe, adjacent to 3290 Edgewater Drive, near Tahoe City, Placer County; for one existing mooring buoy previously authorized by the Commission. (WP 7259.9; RA# 06598) (A 4; S 1) (Staff: R. Barham)

- Agenda Item
- Exhibit A

C 03 **WELLINGTON S. HENDERSON, JR., AS TO A LIFE ESTATE; AND WELLINGTON S. HENDERSON, JR. AND RICHARD L. GREEN AS TRUSTEES OF THE HARRIET WALKER HENDERSON IRREVOCABLE TRUST U/T/A DATED AUGUST 14, 1973, AS TO A REMAINDER INTEREST (APPLICANTS):** Consider application for a new Recreational Pier Lease of sovereign land located in Lake Tahoe, adjacent to 8901 Rubicon Drive, near Meeks Bay, El Dorado County; for an existing pier, boathouse, and two mooring buoys previously authorized by the Commission and the retention of an existing boat hoist not previously authorized by the Commission. (WP 4471.9; RA# 17204) (A 4; S 1) (Staff: R. Barham)

- Agenda Item
- Exhibit A

F

C 04 THE ALEXANDER AND MARGARET SUE VILLICANA FAMILY TRUST, ESTABLISHED FEBRUARY 1, 1977, ALEXANDER VILLICANA AND MARGARET SUE VILLICANA, TRUSTEES (APPLICANTS): Consider application for a new Recreational Pier Lease of sovereign land located in Lake Tahoe, adjacent to 8537 Meeks Bay Avenue, near Meeks Bay, El Dorado County; for an existing pier, boat lift and two mooring buoys previously authorized by the Commission. (WP 7613.9; RA# 03407) (A 4; S 1) (Staff: R. Barham)

- Agenda Item
- Exhibit A

C 05 EDWARD R. FRAZER AND F. HARVEY WHITTEMORE (LESSEES); KAREN ANN HOECK (APPLICANT): Consider termination of Lease No. PRC 8341.9, a Recreational Pier Lease, and an application for a new Recreational Pier Lease of sovereign land located in Lake Tahoe, adjacent to 4590 North Lake Boulevard, near Carnelian Bay, Placer County; for an existing pier, boat lift, and two mooring buoys previously authorized by the Commission. (WP 8341.9; RA# 08609) (A 4; S 1) (Staff: R. Barham)

- Agenda Item
- Exhibit A

C 06 JOSEPHINE B. HAAS, AS TRUSTEE OF THE PETER E. HAAS, JR. 2009 HOMEWOOD TRUST, DATED OCTOBER 12, 2009; JOSEPHINE B. HAAS, AS TRUSTEE OF THE JENNIFER C. HAAS 2009 HOMEWOOD TRUST, DATED OCTOBER 12, 2009; JOSEPHINE B. HAAS, AS TRUSTEE OF THE DANIEL S. HAAS 2009 HOMEWOOD TRUST, DATED OCTOBER 12, 2009; AND JOSEPHINE B. HAAS, AS TRUSTEE OF THE BRADLEY J. HAAS 2009 HOMEWOOD TRUST, DATED OCTOBER 12, 2009 (APPLICANTS): Consider application for a new Recreational Pier Lease of sovereign land located in Lake Tahoe, adjacent to 5690 West Lake Boulevard, near Homewood, Placer County; for an existing pier, boat lift, and two mooring buoys previously authorized by the Commission. (WP 3512.9; RA# 13409) (A 4; S 1) (Staff: R. Barham)

- Agenda Item
- Exhibit A

C 07 AUDREY M. SEARS AND GEORGE TYLER MARSH (APPLICANTS): Consider application for a new Recreational Pier Lease of sovereign land located in Lake Tahoe, adjacent to 8519 Meeks Bay, near Meeks Bay, El Dorado County; for an existing pier and two mooring buoys previously authorized by the Commission. (WP 3656.9; RA# 12609) (A 4; S 1) (Staff: C. Hudson)

- Agenda Item
- Exhibit A

C 08 THOMAS R. KEANE AND SUSAN D. KEANE (APPLICANTS): Consider application for a Recreational Pier Lease of sovereign land located in Lake Tahoe, adjacent to 1250 West Lake Boulevard, Tahoe City, Placer County; for the retention of two existing mooring buoys not previously authorized by the Commission. (W 26389; RA# 16809) (A 4; S 1) (Staff: C. Hudson)

- Agenda Item
- Exhibit A

C 09 WARREN FALLAT, DARCY BLESSING PORTER, KELLAE BLESSING, AND MARGARET D. BOYDEN, AS SOLE TRUSTEE OF THE NOLA DILLON BLESSING TESTAMENTARY TRUST C (APPLICANTS): Consider application for a new Recreational Pier Lease of sovereign land located in Lake Tahoe, adjacent to 3965 Bellview Avenue, near Homewood, Placer County; for an existing pier and two mooring buoys previously authorized by the Commission. (WP 3676.9; RA# 05709) (A 4; S 1) (Staff: C. Hudson)

- Agenda Item
- Exhibit A

C 10 JOSEPH S. CALCAGNO, JR., TRUSTEE OF THE JOSEPH S. CALCAGNO, JR. QUALIFIED PERSONAL RESIDENCE TRUST DATED APRIL 15, 2008; KAREN C. CALCAGNO, TRUSTEE OF THE KAREN C. CALCAGNO QUALIFIED PERSONAL RESIDENCE TRUST DATED APRIL 15, 2008; JAMES C. CALCAGNO AND SUE ELLEN CALCAGNO, TRUSTEES UNDER THE CALCAGNO LIVING TRUST DATED MAY 1, 1996; AND FREDERICK W. SMITH AND CAROLYN I. SMITH, CO-TRUSTEES UNDER THAT CERTAIN DECLARATION OF TRUST DATED JULY 6, 1993 (APPLICANTS): Consider application for a new Recreational Pier Lease of sovereign land located in Lake Tahoe, adjacent to 208 Pine Street, near Tahoma, Placer County; for an existing pier, boat lift, and two mooring buoys previously authorized by the Commission. (WP 6368.9; RA# 05809) (A 4; S 1) (Staff: C. Hudson)

- Agenda Item
- Exhibit A

C 11 RONALD L. JENNY AND JANE E. JENNY, CO-TRUSTEES OF THE JENNY FAMILY TRUST DATED MARCH 4, 2002 (APPLICANTS): Consider application for a new Recreational Pier Lease of sovereign land located in Lake Tahoe, adjacent to 5360 North Lake Boulevard, near Carnelian Bay, Placer County; for an existing pier previously authorized by the Commission and the retention of a portion of an existing boat lift and one mooring buoy not previously authorized by the Commission. (WP 4954.9; RA# 18409) (A 4; S 1) (Staff: N. Lee)

- Agenda Item
- Exhibit A

C 12 **KEN CHRISTIE AND GAIL CHRISTIE; ROSS A. ROBINSON AND VICKI J. ROBINSON (LESSEES/APPLICANTS):** Consider application for an amendment to Lease No. PRC 4143.9, a Recreational Pier Lease, of sovereign land located in Lake Tahoe, adjacent to 3990 North Lake Boulevard, near Carnelian Bay, Placer County; to include two existing mooring buoys not previously authorized by the Commission. (WP 4143.9; RA# 17608) (A 4; S 1) (Staff: N. Lee)

- Agenda Item
- Exhibit A

C 13 **BRIAN C. MCCOSKER AND JACQUELINE S. MCCOSKER (LESSEES/ APPLICANTS):** Consider termination of Lease No. PRC 8792.1, a General Lease – Recreational Use, and an application for a Recreational Pier Lease of sovereign land located in Lake Tahoe, adjacent to 3051 Jameson Beach Road, city of South Lake Tahoe, El Dorado County; for an existing pier previously authorized by the Commission and the retention of two existing mooring buoys not previously authorized by the Commission. (WP 8792.9; RA# 15606) (A 4; S 1) (Staff: N. Lee)

- Agenda Item
- Exhibit A

C 14 **STEVEN LEE BROWN AND MICHELE CONTENT BROWN AS TRUSTEES OF THE THORSON HAYS FAMILY TRUST DATED 8-1-00 (LESSEES/ APPLICANTS):** Consider application for an amendment to Lease No. PRC 8850.9, a Recreational Pier Lease, of sovereign land located in Lake Tahoe, adjacent to 1278 West Lake Boulevard, near Tahoe City, Placer County; to include two existing mooring buoys not previously authorized by the Commission. (WP 8850.9; RA# 13909) (A 4; S 1) (Staff: B. Terry)

- Agenda Item
- Exhibit A

C 15 **DAVID E. GRISWOLD AND MARJORIE S. GRISWOLD, AS CO-TRUSTEES UNDER THE DAVID AND MARJORIE GRISWOLD COMMUNITY PROPERTY TRUST ESTABLISHED SEPTEMBER 3, 1998, BY DAVID E. GRISWOLD AND MARJORIE S. GRISWOLD, AS TRUSTORS (APPLICANTS):** Consider application for a new Recreational Pier Lease of sovereign land located in Lake Tahoe, adjacent to 8217 Meeks Bay Avenue, near Meeks Bay, El Dorado County; for an existing pier and two mooring buoys previously authorized by the Commission. (WP 3602.9; RA# 12709) (A 4; S 1) (Staff: B. Terry)

- Agenda Item
- Exhibit A

C 16 JOSEPH KARP, AS SUCCESSOR TRUSTEE OF THE KARP FAMILY TRUST UTA DATED FEBRUARY 5, 1988 (LESSEE); JOSEPH KARP, SURVIVING TRUSTEE OF THE KARP FAMILY TRUST UTA DATED FEBRUARY 5, 1988 (APPLICANT): Consider termination of Lease No. PRC 5355.9, a Recreational Pier Lease, and an application for a new Recreational Pier Lease of sovereign land located in Lake Tahoe, adjacent to 3770 North Lake Boulevard, Tahoe City, Placer County; for an existing pier and one mooring buoy previously authorized by the Commission and the retention of one additional mooring buoy not previously authorized by the Commission. (WP 5355.9; RA# 16309) (A 4; S 1) (Staff: B. Terry)

- Agenda Item
- Exhibit A

C 17 ROBERT W. ANGELL, AS TRUSTEE OF THE ROBERT W. ANGELL CABIN TRUST DATED AUGUST 3, 1995 AND ELIZABETH A. COOK, AS TRUSTEE UNDER DECLARATION OF TRUST DATED SEPTEMBER 7, 1994 (APPLICANTS): Consider application for a new Recreational Pier Lease of sovereign land located in Lake Tahoe, adjacent to 1260 West Lake Boulevard, Tahoe City, Placer County; for an existing pier and two mooring buoys previously authorized by the Commission and the retention of an existing boat lift not previously authorized by the Commission. (WP 7346.9; RA# 25806) (A 4; S 1) (Staff: B. Terry)

- Agenda Item
- Exhibit A

C 18 EDMUND H. SHEA, III, AS TRUSTEE OF THE AMENDED AND RESTATED MARY SHEA TAHOE PINES QUALIFIED PERSONAL RESIDENCE TRUST (APPLICANT): Consider application for a new Recreational Pier Lease of sovereign land located in Lake Tahoe, adjacent to 3640 Idlewild Way, near Homewood, Placer County; for an existing pier and two mooring buoys previously authorized by the Commission. (WP 3621.9; RA# 24408) (A 4; S 1) (Staff: B. Terry)

- Agenda Item
- Exhibit A

GENERAL LEASES

C 19 GATES TAHOE HOUSE, LLC, A CALIFORNIA LIMITED LIABILITY COMPANY (APPLICANT): Consider application for a new General Lease - Recreational Use, of sovereign land located in Lake Tahoe, adjacent to 1320 West Lake Boulevard, near Tahoe City, Placer County; for an existing pier, boathouse, boatlift, sundeck with stairs, and two mooring buoys previously authorized by the Commission. (WP 5913.1; RA# 23808) (A 4; S 1) (Staff: R. Barham)

- Agenda Item
- Exhibit A

C 20 MARC KENNETH ROOS AND KATHERINE COTSWORTH ROOS, TRUSTEES OF THE ROOS FAMILY REVOCABLE LIVING TRUST AGREEMENT DATED JUNE 22, 2005 (APPLICANTS): Consider application for a General Lease – Recreational Use of sovereign land located in Lake Tahoe, adjacent to 2985 West Lake Boulevard, near Homewood, Placer County; for the retention of one existing mooring buoy not previously authorized by the Commission. (W 26381; RA# 14709) (A 4; S 1) (Staff: R. Barham)

- Agenda Item
- Exhibit A

C 21 AERA ENERGY LLC (APPLICANT): Consider application for a General Permit – Sand Removal Use, to collect sand from the Bolsa Chica tidal inlet near the intersection of Pacific Coast Highway and Seapoint Avenue, Orange County; for routine maintenance purposes. (W 26419) (A 67; S 35) (Staff: J. Brown)

- Agenda Item
- Exhibit A

C 22 ROBERT VELLANOWETH (LESSEE); MICHAEL R. OCHOA (APPLICANT): Consider termination of Lease No. PRC 5377.9, a General Lease – Recreational and Protective Structure Use, and an application for a new General Lease – Recreational and Protective Structure Use, of sovereign land located in the Sacramento River, adjacent to 3071 Garden Highway, city of Sacramento, Sacramento County; for an existing uncovered single-berth floating boat dock with cables, three-pile dolphin, piling, ramp with concrete pad, and bank protection previously authorized by the Commission and the retention of four existing pilings not previously authorized by the Commission. (WP 5377.9; RA# 15109) (A 6; S 5, 9) (Staff: V. Caldwell)

- Agenda Item
- Exhibit A

C 23 ROLLIN T. PAUP AND MARION R. PAUP (LESSEES); MARION R. PAUP AND SANDRA OMAN, TRUSTEES OF THE PAUP MARTIAL TRUST (APPLICANTS): Consider ratification of assignments and termination of Lease No. PRC 6200.1, a General Lease - Commercial Use, and application for a new General Lease - Commercial Use, of sovereign land located in the Sacramento River, adjacent to 14031 River Road (Highway 160), city of Walnut Grove, Sacramento County, for an existing commercial marina known as Landing 63. (WP 6200.1; RA# 01609) (A 8, 15; S 5, 14) (Staff: V. Caldwell)

- Agenda Item
- Exhibit A
- Exhibit B

C 24 CALIFORNIA LAND AND WATER COMPANY (LESSEE): Consider the continuation of rent for Lease No. PRC 7727.1, a General Lease – Recreational Use, of sovereign land located in Montezuma Slough, Grizzly Island, Solano County; for an existing recreational pier. (PRC 7727.1) (A 7, 8; S 2, 5) (Staff: M. Clark)

- Agenda Item
- Exhibit A

C 25 ANTHONY P. DEMATTEI AND GAIL J. DEMATTEI (LESSEES): Consider revision of rent to Lease No. PRC 8578.1, a General Lease – Recreational Use, of sovereign land located in the Sacramento River, adjacent to 4460 West Sherman Island Road, Sherman Island, Sacramento County; for three existing pedestrian access ramps. (PRC 8578.1) (A 15; S 5) (Staff: M. Clark)

- Agenda Item
- Exhibit A

C 26 ANTHONY P. DEMATTEI AND GAIL J. DEMATTEI (APPLICANTS/LESSEES): Consider application for an amendment of Lease No. PRC 8579.1, General Lease - Recreational Use, of sovereign land located in the Sacramento River, near the city of Rio Vista, Sacramento County; to retain a larger than previously authorized existing T-shaped boat dock, landing, ramp, and bridge. (WP 8579.1; RA# 23008) (A 8, 15; S 2, 5) (Staff: M. Clark)

- Agenda Item
- Exhibit A
- Exhibit B

C 27 SACRAMENTO WALDORF SCHOOL ASSOCIATION, INC., A CALIFORNIA NONPROFIT PUBLIC BENEFIT CORPORATION (APPLICANT): Consider application for new a General Lease – Protective Structure Use, of sovereign land located in the American River, adjacent to 3750 Bannister Road, Fair Oaks, Sacramento County; for existing bank protection previously authorized by the Commission. (WP 6728.9; RA# 08809) (A 5; S 1, 6) (Staff: M. Clark)

- Agenda Item
- Exhibit A
- Exhibit B

C 28 ROSETTA RESOURCES OPERATING LP (APPLICANT): Consider application for a General Lease – Right of Way Use, of sovereign land located in Sevenmile Slough, near the town of Isleton, Sacramento County; for the retention of two three-inch diameter natural gas gathering lines encased within two existing eight-inch diameter steel pipelines not previously authorized by the Commission. (W 26373; RA# 10109) (A 15; S 5) (Staff: M. Clark)

- Agenda Item
- Exhibit A
- Exhibit B

C 29 VERDA MARIE COUCHMAN, JERALD PAUL COUCHMAN AND JANIS COLLYER, TRUSTEES OF THE VERDA COUCHMAN REVOCABLE SURVIVOR'S TRUST DATED MARCH 3, 2003; AND VERDA MARIE COUCHMAN, TRUSTEE OF THE HOMER COUCHMAN IRREVOCABLE FAMILY TRUST DATED MARCH 3, 2003 (APPLICANTS): Consider application for a new General Lease – Protective Structure Use, of sovereign land located in the Tuolumne River, adjacent to 3131 Illinois Avenue, city of Modesto, Stanislaus County; for existing bank protection previously authorized by the Commission. (WP 6865.9; RA# 18109) (A 25, 26; S12, 14) (Staff: M. Clark)

- Agenda Item
- Exhibit A

C 30 RAY W. WALKER, TRUSTEE OF THE WALKER LIVING TRUST (LESSEE): Consider revision of rent to Lease No. PRC 5226.1, a General Lease – Commercial Use, of sovereign land located in the Sacramento River, adjacent to 14370 Highway 160, near the town of Walnut Grove, Sacramento County; for an existing uncovered floating boat dock, ramp, fixed walkway, and four pilings. (PRC 5226.1) (A 8, 15; S 5, 14) (Staff: M. Clark)

- Agenda Item
- Exhibit A

C 31 LINDA J. FOLEY, TRUSTEE OF THE FOLEY REVOCABLE TRUST (APPLICANT): Consider application for a new General Lease – Recreational and Protective Structure Use, of sovereign land located in the Sacramento River, adjacent to 4181 Garden Highway, near the city of Sacramento, Sacramento County; for an existing single berth uncovered floating boat dock, ramp, concrete deadman, one piling, dolphin, and bank protection previously authorized by the Commission. (WP 5788.9; RA# 15309) (A 5, 9; S 6) (Staff: M. Clark)

- Agenda Item
- Exhibit A

C 32 OAKDALE IRRIGATION DISTRICT (APPLICANT): Consider application for a new General Lease – Public Agency Use, of sovereign land located in the Stanislaus River, near the city of Oakdale, Stanislaus County; for the creation and restoration of a floodplain, spawning riffles, and side-channel habitat for Chinook salmon and Central Valley steelhead. (W 26400 ; RA# 19909) (A 25, 26; S 14) (Staff: M. Clark)

- Agenda Item
- Exhibit A
- Exhibit B

C 33 CITY OF LOS ANGELES, DEPARTMENT OF WATER AND POWER (LESSEE): Consider application for an amendment to Lease No. PRC 8079.9, General Lease - Public Agency Use, of sovereign lands located in Owens Lake, near Lone Pine, Inyo County; to construct and maintain 3.12 square miles of tillage dust control measures on the bed of Owens Lake. (WP 8079.9; RA# 06208) (A 34; S 18) (Staff: C. Connor)

- Agenda Item
- Exhibit A currently unavailable
- Exhibit B currently unavailable
- Exhibit C currently unavailable
- Exhibit D

C 34 CITY OF SAN CLEMENTE (APPLICANT): Consider application for a new General Lease – Public Agency Use, of sovereign land located in the Pacific Ocean adjacent to North Beach, Linda Lane Beach, T Street Beach North, and T Street Beach South, near the city of San Clemente, Orange County; for the ongoing existing City of San Clemente Opportunistic Beach Replenishment Program previously authorized by the Commission. (WP 8567.9; RA# 08409) (A 73; S 38) (Staff: K. Foster)

- Agenda Item
- Exhibit A
- Exhibit B

C 35 SAN DIEGO UNIFIED PORT DISTRICT (APPLICANT/SUBLESSOR), SUNROAD ASSET MANAGEMENT, INC. (SUBLESSEE): Consider application for a General Lease – Commercial Use and approval of a Sublease, of sovereign lands located in San Diego Bay adjacent to the east end of Harbor Island, city of San Diego, San Diego County; for the renovation, use, and maintenance of an existing floating barge to be used as a restaurant and event facility not previously authorized by the Commission. (W 26298; RA# 02108) (A 39; S 79) (Staff: K. Foster)

- Agenda Item
- Exhibit A
- Exhibit B

C 36 PACIFIC GAS AND ELECTRIC COMPANY (APPLICANT): Consider application for a General Lease – Right of Way Use, of sovereign lands located in the Kings River, in the city of Reedley, Fresno County; for the reconstruction, use, and maintenance of a 70kV overhead transmission line to a 115 kV overhead transmision line not previously authorized by the Commission. (W 26407; RA# 20009) (A 31; S 14) (Staff: K. Foster)

- Agenda Item
- Exhibit A
- Exhibit B

C 37 STEPHEN MURRAY DART, TRUSTEE OF THE GUY MICHAEL DART FAMILY TRUST DATED MARCH 23, 1988; JANE DART TUCKER, TRUSTEE OF THE JANE DART TUCKER REVOCABLE TRUST DATED APRIL 19, 2000; AND STEPHEN M. DART, TRUSTEE OF THE STEPHEN M. DART 2001 FAMILY TRUST DATED JULY 12, 2001 (APPLICANTS): Consider application for a new General Lease – Protective Structure Use, of sovereign lands located in the Pacific Ocean, adjacent to Assessor Parcel Number 008-491-021, near Pebble Beach and Cypress Point, Monterey County; for two existing rock revetment shoreline protective structures previously authorized by the Commission. (WP 7344.1; RA# 07709) (A 27; S 15) (Staff: K. Foster)

- Agenda Item
- Exhibit A
- Exhibit B

C 38 SANTA CATALINA ISLAND COMPANY (LESSEE): Consider application for an amendment to Lease No. PRC 6438.1, General Lease - Commercial Use, of sovereign lands located in Isthmus Cove, Santa Catalina Island, Los Angeles County; for the addition of a floating seasonal dock to the existing seasonal dinghy dock and fixed pier. (WP 6438.1; RA# 24409) (A 38; S 18) (Staff: K. Foster)

- Agenda Item
- Exhibit A currently unavailable
- Exhibit B currently unavailable

C 39 ROBERT L. HULBERT (LESSEE/APPLICANT): Consider termination of Lease No. PRC 8513.1, a General Lease – Recreational Use and issuance of a new General Lease - Recreational Use, of sovereign land located in the Sacramento River, adjacent to 673 Brickyard Drive, City of Sacramento, Sacramento County; for the retention, use and maintenance of an existing floating dock with a single slip boathouse, roof railings, spiral staircase, four pilings, gangway, sewer line, and pump out. (WP 8513.1) (A 9; S 6) (Staff: M. Hays; J. Frey)

- Agenda Item
- Exhibit A
- Exhibit B

C 40 TIMOTHY GRUBB, (APPLICANT): Consider application for a new General Lease – Right of Way Use, of State school land located in a portion of Section 16, Township 36 North, Range 5 West, MDM, near Lakehead, Shasta County; for an existing water storage tank and pipeline previously authorized by the Commission. (WP 6807.2; RA# 06309) (A 2; S 4) (Staff: C. Hudson)

- Agenda Item
- Exhibit A

F

C 41 ANNE FLETCHER JENSEN, AS TRUSTEE OF THE ANNE FLETCHER JENSEN REVOCABLE TRUST (LESSEE); LLOYD T. ROCHFORD AND CAROL A. ROCHFORD, TRUSTEES OF THE ROCHFORD LIVING TRUST, DATED DECEMBER 1, 1999 (APPLICANTS): Consider termination of Lease No. PRC 4058.9, a Recreational Pier Lease, and an application for a new General Lease – Recreational Use, of sovereign land located in Lake Tahoe, adjacent to 3740 North Lake Boulevard, near Carnelian Bay, Placer County; for an existing pier, boathouse with sundeck and stairs, boat hoist, and two mooring buoys previously authorized by the Commission. (WP 4058.1; RA# 09109) (A 4; S 1) (Staff: C. Hudson)

- Agenda Item
- Exhibit A

C 42 SOUTHERN CALIFORNIA MARINE ASSOCIATION (APPLICANT): Consider application for a new General Lease - Commercial Use, of sovereign lands located in San Diego Bay, adjacent to 1380 Harbor Island Drive, city of San Diego, San Diego County; for the installation of a temporary marina facility for the 2010 San Diego Summer Boat Show. (WP 8602.1; RA# 18207) (A 76; S 39) (Staff: G. Kato)

- Agenda Item
- Exhibit A
- Exhibit B

C 43 OTIS RUSSELL JOHNSON, III, FORREST LOWELL JONES, AND DANIEL GEORGE VOLKMANN, III, AS CO-TRUSTEES U/T/A DATED 12/20/84 (LESSEES); BROCKWAY PROPERTY LLC (APPLICANT): Consider termination of Lease No. PRC 5648.9, a Recreational Pier Lease, and an application for a new General Lease - Recreational Use, of sovereign land located in Lake Tahoe, adjacent to 9820 Lake Street, near Brockway, Placer County; for an existing pier and boat hoist previously authorized by the Commission and the retention of two existing mooring buoys not previously authorized by the Commission. (WP 5648.1; RA# 05909) (A 4; S 1) (Staff: N. Lee)

- Agenda Item
- Exhibit A

C 44 LAKESIDE PARK ASSOCIATION, INC. (APPLICANT/LESSEE): Consider application for an amendment to Lease No. PRC 5883.1, General Lease - Commercial and Recreational Use, of sovereign land located in Lake Tahoe, adjacent to 4041 Lakeshore Boulevard, city of South Lake Tahoe, El Dorado County; to authorize maintenance dredging. (WP 5883.1; RA# 20309) (A 4; S 1) (Staff: N. Lee)

- Agenda Item
- Exhibit A

C 45 **DON STUART MASHBIR; THOMAS R. HARRY, TRUSTEE OF THE THOMAS R. HARRY AND CAROLYN D. HARRY FAMILY DECEDENT'S TRUST, ESTABLISHED OCTOBER 23, 1997; MICHAEL R. HARRY; ANNE L. HARRY; THOMAS J. HARRY; CYNTHIA A. HARRY; DEBORA D. GOEHRING; AND ARDEN GOEHRING (LESSEES); SELECTIVE RUBICON PROPERTY, LLC; THOMAS R. HARRY, TRUSTEE OF THE THOMAS R. HARRY AND CAROLYN D. HARRY FAMILY DECEDENT'S TRUST, ESTABLISHED OCTOBER 23, 1997; MICHAEL R. HARRY; ANNE L. HARRY; THOMAS J. HARRY; CYNTHIA A. HARRY; DEBORA D. GOEHRING; AND ARDEN GOEHRING (APPLICANTS):** Consider termination of Lease No. PRC 7449.9, a Recreational Pier Lease, and an application for a new General Lease - Recreational Use, of sovereign land located in Lake Tahoe, adjacent to 8579 Meeks Bay Avenue and 8581 North Lane, near Rubicon Bay, El Dorado County; for an existing joint-use pier and two mooring buoys previously authorized by the Commission. (WP 7449.1; RA# 05309) (A 4; S 1) (Staff: N. Lee)

- Agenda Item
- Exhibit A

C 46 **CALIFORNIA STATE LANDS COMMISSION AND CALIFORNIA COASTAL COMMISSION (PARTIES)**: Consider acceptance of one offer to dedicate a lateral public access easement over land adjacent to State tidelands in the city of Malibu, 26808 Malibu Cove Colony Drive, Los Angeles County. (W 24665) (A 41; S 23) (Staff: S. Nelson)

- Agenda Item
- Exhibit A
- Exhibit B

C 47 **CALIFORNIA STATE LANDS COMMISSION AND CALIFORNIA COASTAL COMMISSION (PARTIES)**: Consider acceptance of one offer to dedicate a lateral public access easement over land adjacent to State tidelands in the city of Malibu, 33368 Pacific Coast Highway, Los Angeles County. (W 24665) (A 41; S 23) (Staff: S. Nelson)

- Agenda Item
- Exhibit A
- Exhibit B

C 48 **CALIFORNIA STATE LANDS COMMISSION AND CALIFORNIA COASTAL COMMISSION (PARTIES)**: Consider acceptance of one offer to dedicate a lateral public access easement over land adjacent to State tidelands in the city of Malibu, 31630 Sea Level Drive, Los Angeles County. (W 24665) (A 41; S 23) (Staff: S. Nelson)

- Agenda Item
- Exhibit A
- Exhibit B

C 49 CITY OF PETALUMA (LESSEE/APPLICANT): Consider rescission of approval of Lease No. PRC 8449.9, a Dredging Lease, and consider application for an amendment to Lease No. PRC 7235.1, General Lease - Commercial Use, of sovereign lands located in the Petaluma Marina, city of Petaluma, Sonoma County; to increase the maximum annual maintenance dredging with disposal of the dredged material at the U.S. Corps of Engineers' designated sites at the Petaluma City Dredge Disposal Area and /or Winter Island. (PRC 7235.1 and PRC 8449.9); (A 6; S 2) (Staff: D. Oetzel)

- Agenda Item
- Exhibit A

C 50 LIVERMORE-AMADOR VALLEY WATER MANAGEMENT AGENCY (APPLICANT): Consider application for a General Lease – Public Agency Use, of sovereign lands located in the San Leandro Shoreline Marsh adjacent to San Francisco Bay, City of San Leandro, Alameda County; for the construction of a new pipeline, and two temporary construction areas and approval of an abandonment agreement for an existing pipeline that is to be filled and abandoned in place. (W 25597; RA# 18609) (A 18; S 9) (Staff: D. Oetzel)

- Agenda Item
- Exhibit A
- Exhibit B
- Exhibit C

C 51 UNITED STATES ARMY CORPS OF ENGINEERS (APPLICANT): Consider application for a License – Public Agency Use, of sovereign lands located at Hamilton Air Field, city of Novato, Marin County; for the excavation and removal of contaminated soils. (SLL 111; WP 8813) (A 6; S 3) (Staff: D. Oetzel, D. Plummer)

- Agenda Item
- Exhibit A currently unavailable
- Exhibit B currently unavailable

C 52 PELICAN HARBOR ASSOCIATES (APPLICANT): Consider application for a Dredging Lease to dredge material from granted lands, minerals reserved to the State; located at Pelican Harbor in Richardson Bay, Marin County; disposal of dredged material at the U.S. Army Corps of Engineers' designated site at Alcatraz (SF-11) and all other sites approved by the U.S. Army Corps of Engineers. (W 26406); RA# 24509) (A 6; S 2) (Staff: D. Oetzel)

- Agenda Item
- Exhibit A

F

C 53 SOUTHERN CALIFORNIA EDISION COMPANY (APPLICANT): Consider application for a General Lease – Right of Way Use, of State school lands located in Section 36, Township 5 South, Range 15 East, SBM, southeast of Desert Center, Riverside County; for the construction, use and maintenance of a 500 kV overhead electric transmission line, two steel lattice towers, and an unimproved access road. (W 26318; RA# 11308) (A 80; S 40) (Staff: J. Porter)

- Agenda Item
- Exhibit A
- Exhibit B

C 54 GEYSERS POWER COMPANY, LLC (APPLICANT): Consider application for a new General Lease – Right of Way Use, of Indemnity School lands located in Section 6, Township 11 North, Range 8 West, MDM, east of Cloverdale, Lake County; for the continued use and maintenance of an existing above-ground 12-inch diameter steam pipeline and an existing unimproved access road, both previously authorized by the Commission. (WP 6793.2; RA# 16109) (A 1; S 2) (Staff: J. Porter)

- Agenda Item
- Exhibit A
- Exhibit B

C 55 GEYSERS POWER COMPANY, LLC (LESSEE): Consider the continuation of rent for Lease No. PRC 8610.2, a General Lease – Right of Way Use, of State Indemnity School lands located east of Cloverdale in Sections 3 and 4, Township 11 North, Range 9 West, MBM, Sonoma County; for a six- to eight-inch diameter water transportation pipeline. (PRC 8610.2) (A 1; S 2) (Staff: J. Porter)

- Agenda Item
- Exhibit A

C 56 EL PASO NATURAL GAS COMPANY (LESSEE): Consider the continuation of rent for Lease No. PRC 7527.2, a General Lease – Right of Way Use, of State Indemnity school lands located in Section 26 and Section 27, Township 9 North, Range 2 East, SBM, southeast of Barstow, San Bernardino County, for conversion, use, and maintenance of an existing 30-inch diameter crude oil pipeline to natural gas. (PRC 7527.2;) (A 34; S 18) (Staff: J. Porter)

- Agenda Item
- Exhibit A

C 57 ARNOLD R. MENDOZA AND MARY M. MENDOZA (APPLICANTS): Consider application for a new General Lease – Recreational Use, of sovereign land located in Huntington Harbour, Huntington Beach, Orange County, for an existing boat dock and access ramp previously authorized by the Commission, and the retention of an existing cantilevered deck not previously authorized by the Commission. (WP 3165.1; RA# 06709) (A 67; S 35) (Staff: D. Simpkin)

- Agenda Item
- Exhibit A
- Exhibit B

C 58 CYNTHIA D. WILLIAMS AND NICK DIBENEDETTO, TRUSTEE OF THE WILLIAMS-DIBENEDETTO TRUST, DATED JULY 30, 2008 (APPLICANTS): Consider application for a new General Lease – Recreational Use, of sovereign land located in Huntington Harbour, Huntington Beach, Orange County, for an existing boat dock and access ramp previously authorized by the Commission, and the retention of an existing cantilevered deck not previously authorized by the Commission. (WP 5749.1; RA# 17209) (A 67; S 35) (Staff: D. Simpkin)

- Agenda Item
- Exhibit A
- Exhibit B

C 59 PEBBLE BEACH COMPANY (APPLICANT): Consider application for a new General Lease – Recreational Use, of sovereign land located in Stillwater Cove, Carmel Bay, Monterey County; for an existing multi-use pier with public access previously authorized by the Commission, and approval of Rules and Regulations for public access to, and use of, the multi-use pier. (WP 2714.1; RA# 11209) (A 27; S 15) (Staff: D. Simpkin)

- Agenda Item
- Exhibit A
- Exhibit B
- Exhibit C

C 60 JOSEPH FAN AND JULIA T. SUN (APPLICANTS): Consider application for a new General Lease – Recreational Use, of sovereign land located in Huntington Harbour, Huntington Beach, Orange County, for an existing boat dock and access ramp previously authorized by the Commission, and the retention of an existing cantilevered deck not previously authorized by the Commission. (WP 5761.1; RA# 18009) (A 67; S 35) (Staff: D. Simpkin)

- Agenda Item
- Exhibit A
- Exhibit B

C 61 ROBERT G. SEBRING AND GAIL SEBRING (APPLICANTS): Consider application for a General Lease – Recreational Use, of sovereign land located in Huntington Harbour, Huntington Beach, Orange County, for the retention, use, and maintenance of an existing cantilevered deck not previously authorized by the Commission. (W 26375; RA# 11709) (A 67; S 35) (Staff: D. Simpkin))

Item and Exhibit(s) currently unavailable

C 62 IRENE COOPER (APPLICANT): Consider application for a new General Lease – Recreational Use, of sovereign land located in Huntington Harbour, Huntington Beach, Orange County, for an existing boat dock and access ramp previously authorized by the Commission, and the retention of an existing cantilevered deck not previously authorized by the Commission. (WP 3247.1; RA# 17009) (A 67; S 35) (Staff: D. Simpkin)

- Agenda Item
- Exhibit A
- Exhibit B

C 63 CITY OF FOSTER CITY (APPLICANT): Consider application for a General Lease – Public Agency Use, of sovereign land adjacent to Assessor Parcel Number 094-130-030, City of Foster City, San Mateo County; for the retention, use, and maintenance of an existing public recreational asphalt pedway not previously authorized by the Commission (W 26403; RA# 22409) (A 19; S 8) (Staff: D. Simpkin)

ITEM HAS BEEN POSTPONED TO A FUTURE MEETING

C 64 DONALD G. GOODWIN (APPLICANT): Consider termination of a General Lease – Recreational Use, and application for a new General Lease – Recreational and Protective Structure Use of sovereign land located in Huntington Harbour, Huntington Beach, Orange County; for the continued use and maintenance of an existing boat dock, access ramp, and cantilevered deck previously authorized by the Commission; and the repairs to an existing bulkhead. (WP 3164.1; RA# 15809) (A 67; S 35) (Staff: D. Simpkin)

- Agenda Item
- Exhibit A
- Exhibit B
- Exhibit C
- Exhibit D

C 65 SAMUEL H. GIESY, JR. (APPLICANT): Consider termination of a General Lease – Recreational Use, and application for a new General Lease – Recreational and Protective Structure Use of sovereign land located in Huntington Harbour, Huntington Beach, Orange County; for the continued use and maintenance of an existing boat dock, access ramp, and cantilevered deck previously authorized by the Commission; and the repairs to an existing bulkhead. (WP 3570.1; RA# 15909) (A 67; S 35) (Staff: D. Simpkin)

- Agenda Item
- Exhibit A
- Exhibit B
- Exhibit C
- Exhibit D

F

C 66 ING LIONG WONG AND CHU FONG WONG, AS TRUSTEES UNDER THE WONG 1986 FAMILY TRUST (CREATED BY A DECLARATION OF TRUST DATED SEPTEMBER 18, 1986) (APPLICANTS): Consider application for a new General Lease – Recreational and Protective Structure Use, of sovereign land located in Huntington Harbour, Huntington Beach, Orange County, for an existing boat dock and access ramp previously authorized by the Commission, the retention of an existing cantilevered deck not previously authorized by the Commission; and repair to an existing bulkhead. (WP 3254.1; RA# 08209, 16209) (A 67; S 35) (Staff: D. Simpkin)

- Agenda Item
- Exhibit A
- Exhibit B currently unavailable
- Exhibit C
- Exhibit D

C 67 MICHAEL C. WOODS, TRUSTEE OF THE MICHAEL C. WOODS TRUST, DATED OCTOBER 10, 1988 (APPLICANT): Consider application for a General Lease – Recreational and Protective Structure Use, of sovereign land located in Huntington Harbour, Huntington Beach, Orange County, for the retention, use, and maintenance of an existing boat dock, access ramp, and cantilevered deck not previously authorized by the Commission; and repairs to an existing bulkhead. (W 26387; RA# 16009) (A 67; S 35) (Staff: D. Simpkin)

- Agenda Item
- Exhibit A
- Exhibit B
- Exhibit C
- Exhibit D

C 68 ROSS VALLEY SANITARY DISTRICT (LESSEE/APPLICANT): Consider termination of General Lease – Public Agency Use, and an application for a new General Lease – Public Agency Use, of sovereign land located along Corte Madera Creek, Marin County; for the construction, use, maintenance, and operation of a new 42-inch diameter force main and bank stabilization not previously authorized by the Commission; and the continued use, maintenance, and operation of an existing 36-inch diameter force main and sewage pumping station previously authorized by the Commission. (WP 4581.9; RA# 22609) (A 6; S 3) (Staff: D. Simpkin)

- Agenda Item
- Exhibit A
- Exhibit B
- Exhibit C

C 69 EDWARD R. FRAZER (LESSEE): Consider revision of rent to Lease No. PRC 5177.1, a General Lease - Recreational Use, of sovereign land located in Lake Tahoe, adjacent to 4796 North Lake Boulevard, near Carnelian Bay, for an existing pier, portion of a cabin, boatlift, and two mooring buoys. (PRC 5177.1) (A 4; S 1) (Staff: B. Terry)

- Agenda Item
- Exhibit A

C 70 ROBERT N. GRANT, AS TRUSTEE OF TITLE SERVICES TRUST DATED MAY 7, 2001 (APPLICANT): Consider application for a General Lease – Recreational Use, of sovereign land located in Lake Tahoe, adjacent to 1270 West Lake Boulevard, near Tahoe City, Placer County; for two existing mooring buoys not previously authorized by the Commission. (W 26380; RA# 13809) (A 4; S 1) (Staff: B. Terry)

- Agenda Item
- Exhibit A

C 71 SHIRLEY H. ALLEN, TRUSTEE, OR THE ACTING SUCCESSOR TRUSTEE OF THE ALLEN FAMILY TRUST FOR THE BENEFIT OF DAVID AND SHIRLEY ALLEN, UNDER INSTRUMENT DATED DECEMBER 29, 1995 (APPLICANT): Consider application for a new General Lease - Recreational Use, of sovereign land located in Lake Tahoe, adjacent to 5472 North Lake Boulevard, near Carnelian Bay, Placer County; for an existing pier, boathouse, sundeck with stairs, and two mooring buoys previously authorized by the Commission. (WP 4183.1; RA# 14408) (A 4; S 1) (Staff: B. Terry)

- Agenda Item
- Exhibit A

C 72 JOHN D. BRADY, TRUSTEE OF THE JOHN D. AND JUDY V. BRADY 1980 REVOCABLE LIVING TRUST AS AMENDED AND RESTATED ON DECEMBER 13, 1990 (APPLICANT): Consider application for a new General Lease - Recreational Use, of sovereign land located in Lake Tahoe, adjacent to Assessor Parcel Number 092-180-008; for an existing pier and boat lift previously authorized by the Commission. (WP 5405.1; RA# 07409) (A 4; S 1) (Staff: B. Terry)

- Agenda Item
- Exhibit A

C 73 TAHOE CRT, LLC, A NEVADA LIMITED LIABILITY COMPANY (APPLICANT): Consider application for a new General Lease - Recreational Use, of sovereign land located in Lake Tahoe, adjacent to 2500 West Lake Boulevard, near Sunnyside, Placer County; for an existing pier with two boat slips, one boatlift, and two mooring buoys previously authorized by the Commission. (WP 4158.1; RA# 08709) (A 4; S 1) (Staff: B. Terry)

- Agenda Item
- Exhibit A

F

C 74 CHAMBERS LANDING PARTNERSHIP (LESSEE/SUBLESSOR); RB WATERFRONTS, A CALIFORNIA LIMITED LIABILITY COMPANY (SUBLESSEE): Consider approval of a sublease under Lease No. PRC 5499.1, a General Lease - Commercial Use, of sovereign land located in Lake Tahoe, adjacent to 6500 West Lake Boulevard, near Homewood, Placer County; for the operation and maintenance of a commercial pier and bar/clubhouse.
(WP 5499.1; RA# 06209) (A 4; S 1) (Staff: B. Terry)

- Agenda Item
- Exhibit A
- Exhibit B

C 75 LAKESIDE PIER ASSOCIATION (APPLICANT): Consider application for a General Lease - Recreational Use, of sovereign land located in Lake Tahoe, adjacent to Assessor's Parcel Number 016-091-47, near Meeks Bay, El Dorado County; for an existing pier previously authorized by the Commission.
(WP 6851.1; RA# 01307) (A 4; S 1) (Staff: B. Terry)

- Agenda Item
- Exhibit A

C 76 POSEIDON RESOURCES (CHANNELSIDE) LLC (CO-LESSEE): Consider application for authorization of an Agreement and Consent to Encumbrancing of Lease, for a General Lease - Industrial Use of sovereign lands located adjacent to Aqua Hedionda Lagoon in the city of Carlsbad, San Diego County; for existing intake and outfall channels used in conjunction with a once-through cooling water system for an upland desalination plant. (PRC 8727.1; RA# 19509) (A 74; S 38) (Staff: S. Young)

- Agenda Item
- Exhibit A

C 77 MARINER'S POINT, A CALIFORNIA GENERAL PARTNERSHIP (LESSEE): Consider application for a new General Lease - Commercial Use, of sovereign lands located in Sunset Bay, Huntington Beach, Orange County; for an existing commercial fuel dock facility previously authorized by the Commission.
(WP 3265.1; RA# 7909) (A 67; S 35) (Staff: S. Young)

- Agenda Item
- Exhibit A
- Exhibit B

C 78 THE KISSEL COMPANY DBA PARADISE COVE LAND COMPANY (APPLICANT): Consider an application for a new General Lease – Commercial Use, of sovereign lands located in the Pacific Ocean, Paradise Cove in Malibu, Los Angeles County; for an existing pier previously authorized by the Commission as a Recreational Use pier. (WP 391.1; RA# 19408) (A 41; S 23)
(Staff: S. Young)

- Agenda Item
- Exhibit A
- Exhibit B

F

LEGAL

C 79 **CALIFORNIA STATE LANDS COMMISSION (PARTY):** Consider authorization for the staff of the California State Lands Commission and/or the Office of the Attorney General to take all steps necessary, including litigation, to cause the removal of boats, barges and other numerous floating objected moored in two locations in Lindsey Slough, near the bridge between Hasting Road and Liberty Island Road, Rio Vista, Solano County. (W 26411) (A 8; S5) (Staff: P. Pelkofer)

Item and Exhibit(s) currently unavailable

C 80 **CALIFORNIA STATE LANDS COMMISSION (PARTY):** Consider authorization for the staff of the California State Lands Commission and/or the Office of the Attorney General to take all steps necessary, including litigation, to cause the removal of two riverboats, the Fresno and the San Leandro, located in Haypress Reach, on the San Joaquin River adjacent to Spud Island in San Joaquin County. (W 26410) (A 15; S 5) (Staff: P. Pelkofer)

Item and Exhibit(s) currently unavailable

ADMINISTRATION

C 81 **CALIFORNIA STATE LANDS COMMISSION (PARTY):** Request authority to enter into agreement to expand invasive species research to develop a rapid method to assess plankton viability in treated ballast water. (C2009-053) (A & S Statewide) (W9777.291) (Staff: M. Falkner, D. Brown)

- Agenda Item

MINERAL RESOURCES MANAGEMENT

C 82 **CITY OF LONG BEACH (APPLICANT):** Consider prior approval of subsidence costs for vertical measurements and studies for the period July 1, 2010 to June 30, 2011, City of Long Beach, Los Angeles County. (W 10444) (A 54, 55; S 27, 28) (Staff: C. Duda, D. Dudak)

- Agenda Item
- Exhibit A
- Exhibit B

C 83 **CIRQUE RESOURCES LP (APPLICANT):** Consider issuance of a negotiated subsurface (no surface use) Oil and Gas Lease, covering State owned lands under the Tule Elk State Reserve, near Elk Hills Oil Field, Kern County. (W 40946) (A 32; S 18) (Staff: J. L. Smith, M. Hamilton)

- Agenda Item
- Exhibit A
- Exhibit B

F

C 84 GILL RANCH STORAGE, LLC AND PACIFIC GAS & ELECTRIC COMPANY (APPLICANTS): Consider issuance of Underground Gill Ranch Natural Gas Storage Lease, Fresno and Madera Counties. (W 40948, W 26343) (A 25, 29; 30; S 14, 16) (Staff: J. L. Smith, M. Hamilton)

- Agenda Item
- Exhibit A
- Exhibit B
- Exhibit C

C 85 AERA ENERGY, LLC (LESSEE): Consider approval of royalty payment penalty reduction in the amount of $5,000 to Aera Energy LLC, Oil and Gas Lease No. PRC 7820, Huntington Beach Oil Field, Orange County. (PRC 7820) (A 70; S 35) (Staff: G. Scott, F. Velez)

ITEM HAS BEEN POSTPONED TO A FUTURE MEETING

MARINE FACILITIES DIVISION

C 86 CALIFORNIA STATE LANDS COMMISSION (PARTY): Consideration of approval of the Sixth and Final Annual Report of the California Oil Transfer and Transportation Emission and Risk Reduction program for the year 2009 (W 9777.263) (A Statewide; S Statewide) (Staff: R. Varma, M. Flowers, G. Gregory)

- Agenda Item
- Exhibit A

INFORMATIONAL

C 87 CALIFORNIA STATE LANDS COMMISSION (APPLICANT) (INFORMATIONAL): Staff Report on the monitoring of possible subsidence, Long Beach Unit, Wilmington Oil Field, Los Angeles County. (W 16001, W 10443) (A 54, 55; S 27, 28) (Negotiator: C. Duda)

- Agenda Item
- Exhibit A

VI. REGULAR CALENDAR

88 CALIFORNIA STATE LANDS COMMISSION: Staff's legislative update and consider taking a position on state legislation regarding Port of San Diego trust revenues (SB 1039) and federal legislation regarding school lands in the desert (S. 2921). (A & S: Statewide) (Staff: M. De Bernardo)

- Agenda Item

89 CALIFORNIA STATE LANDS COMMISSION: Consider a resolution proposed by the Controller supporting the San Francisco Bay Improvement Act of 2010 (HR 5061), which would provide funding for the purposes of San Francisco Bay water quality improvement; wetland, riverine, and estuary restoration and protection; nearshore and endangered species recovery; and adaptation to climate change. (A & S: Statewide) (Staff: M. De Bernardo)

- Agenda Item

F

90 **CALIFORNIA STATE LANDS COMMISSION:** Consider supporting the nomination of San Francisco Bay Estuary as a Ramsar Wetland of International Importance and directing the Executive Officer to send a support letter to the U.S. Fish and Wildlife Service. (A & S: Statewide) (Staff: M. De Bernardo)

- Agenda Item

91 **OAKLAND HARBOR PARTNERS, LLC, PORT OF OAKLAND, CALIFORNIA STATE LANDS COMMISSION (PARTIES):** Consideration of a Boundary Line and Land Exchange Agreement, pursuant to Chapter 542, Statutes of 2004, involving certain parcels located within the Oak Street to Ninth Avenue District, in the city of Oakland, Alameda County. The proposed Boundary Line and Land Exchange Agreement would establish the boundary line between State sovereign public trust lands and after-acquired public trust lands and exchange and terminate any and all property rights, including any public trust interest, in certain parcels in exchange for acquisition by the State of two parcels, commonly known as the Army Reserve Parcels, located within the former Oakland Army Base. (W 26371; AD 548; G01-05.8) (A 19; S 6) (Staff: G. Kato, J. Lucchesi, J. Rusconi)

- Agenda Item
- Exhibit A
- Exhibit B
- Exhibit C
- Exhibits D-P currently unavailable

92 **CALIFORNIA STATE LANDS COMMISSION (PARTY):** Consider approval of the Legislative Report titled "2010 Assessment of the Efficacy, Availability and Environmental Impacts of Ballast Water Treatment Systems for Use in California Waters" (W9777.234, W9777.290) (A Statewide; S Statewide) (Staff: M. Falkner, G. Gregory, M. Meier)

- Agenda Item
- Exhibit A

93 **CITY OF LOS ANGELES, DEPARTMENT OF WATER AND POWER (LESSEE) INFORMATIONAL:** Report on the status of projects involving sovereign lands located in Owens Lake, near Lone Pine, Inyo County, including dust control measures, solar demonstration project, groundwater monitoring wells, and master planning process. (PRC 8079.9; RA# 25109) (A 34; S 17) (Staff: C. Connor)

Item and Exhibit(s) currently unavailable

VII. PUBLIC COMMENT

VIII. CLOSED SESSION

AT ANYTIME DURING THE MEETING THE COMMISSION MAY MEET IN A SESSION CLOSED TO THE PUBLIC TO CONSIDER THE FOLLOWING PURSUANT TO GOVERNMENT CODE SECTION 11126:

F

A. LITIGATION

THE COMMISSION MAY CONSIDER PENDING AND POSSIBLE LITIGATION PURSUANT TO THE CONFIDENTIALITY OF ATTORNEY-CLIENT COMMUNICATIONS AND PRIVILEGES PROVIDED FOR IN GOVERNMENT CODE SECTION 11126(e)

1. THE COMMISSION MAY CONSIDER MATTERS THAT FALL UNDER GOVERNMENT CODE SECTION 11126(e)(2)(A):

   Alameda Gateway, Ltd. v. City of Alameda

   California State Lands Commission v. William J. Barker, Carol Barker, et al.

   California State Lands Commission v. Thomas B. Trost, et al.

   U.S. v. 32.42 Acres of Land, et al.

   Robert Hulbert v. California State Lands Commission, et al.

2. THE COMMISSION MAY CONSIDER MATTERS THAT FALL UNDER GOVERNMENT CODE SECTION 11126 (E)(2)(B) OR (2)(C).

F

DRAFT

2010 ASSESSMENT OF THE EFFICACY, AVAILABILITY AND ENVIRONMENTAL IMPACTS OF BALLAST WATER TREATMENT SYSTEMS FOR USE IN CALIFORNIA WATERS

PRODUCED FOR THE
CALIFORNIA STATE LEGISLATURE

By
California State Lands Commission
June 2010

EXECUTIVE SUMMARY

The Coastal Ecosystems Protection Act (Act) of 2006 expanded the Marine Invasive Species Act of 2003 to more effectively address the threat of nonindigenous species introduction through ballast water discharge. The Act charged the California State Lands Commission (Commission) to implement performance standards for the discharge of ballast water and to prepare a report assessing the efficacy, availability and environmental impacts, including water quality, of currently available ballast water treatment technologies. The performance standards regulations were adopted in October 2007, and subsequent ballast water treatment technology assessment reports was approved by the Commission in December 2007 (see Dobroski et al. 2007) and December 2008 (see Dobroski et al. 2009a). This report summarizes the Commission's conclusions on the advancement of ballast water treatment technology development and evaluation during 2009 and the first half of 2010 and discusses ongoing activities of the Commission's Marine Invasive Species Program regarding the implementation of California's performance standards for the discharge of ballast water.

Progress continues to be made in the development and assessment of treatment systems since previous technology assessment reports (see Dobroski et al. 2007, Dobroski et al. 2009a). Both the quantity and the quality of the recently received data on system performance attest to this fact. The field of treatment technology performance evaluation, however, continues to lag behind the rapidly evolving ballast water treatment industry. Scientific methods to assess the concentration of certain types of viable organisms present in ballast water discharge still must be developed or refined so that Commission staff may rapidly assess vessel compliance with the ballast water performance standards.

California's standards for bacteria and viruses pose a significant challenge. While methods exist to quantify total counts of bacteria and viruses (or virus-like particles) in a sample of ballast water, no techniques are available to assess the viability of all bacteria and viruses, as is required by the California performance standards. The best available technique for bacterial assessment involves the use of a subset or proxy group of

organisms to represent treatment of bacteria as a whole. While this technique is not without some debate, it is scientifically supported by many experts in microbiology and technology assessment (see Dobroski et al. 2009a, Appendix A). The viruses pose a greater challenge. Without strong evidence for the selection of proxy organisms in this size class, Commission staff believes that there are no acceptable methods for verification of compliance with the total viral standard at this time, and that the Commission should proceed with assessment of technologies for the remaining organism size classes in the standards.

Based on the available information and using best assessment techniques, Commission staff reviewed 46 ballast water treatment systems for this report and believes that at least eight treatment systems have demonstrated the **potential** to comply with the Commission's performance standards. Efficacy data for these systems indicate that at least one test met or exceeded California's performance standard for every testable organism/size class, during either land-based or shipboard testing. In addition, three of the eight systems show the potential to meet California's performance standards under more rigorous evaluation criteria. These three passed more than 50% of the time over multiple tests (three or more) at either the land-based or shipboard scale. Additional systems are close to demonstrating the potential for meeting California's standards, and Commission staff are awaiting data from the latest system performance verification testing on these systems.. No system has yet met California's standards 100% of the time for either land-based or shipboard testing. However, Commission staff have consulted with the vendors of systems that have demonstrated the potential to comply with California's standards, and at this time, two vendors (Ecochlor and Qingdao Headway Tech.), are willing to self-certify that their systems will meet California's standards. Evaluations in this report do not constitute endorsement, approval, or guarantee that a ballast water treatment system will meet California's standards for all vessels and all scenarios. The Commission does not have the authority to approve systems.

All eight of the systems that have demonstrated the potential to meet California's standards are currently commercially available. Seven of these systems are marketed as having the capability to treat ballast water at pump rates over 2000 m^3/hr, which would accommodate over 80% of the vessels that operate in California with ballast water capacity over 5000 MT. The manufacturers of six systems attest that their products will operate at much higher pump rates. All three of the systems that show potential for meeting the standards under more rigorous consistency criteria can accommodate much higher pump rates of 4500 m^3/hr or more.

Treatment vendors and vessel operators will also need to assess the potential water quality impacts from treatment systems prior to operation in California waters. All ballast water discharges from vessels must comply with the U.S. Environmental Protection Agency's (EPA) National Pollution Discharge Elimination System (NPDES) Vessel General Permit for Discharges Incidental to the Normal Operation of Vessels, and the California-specific provisions added to the Vessel General Permit through the Clean Water Act Section 401 certification process. Commission staff recommends that treatment vendors also consult the Marine Invasive Species Program's "Ballast Water Treatment Technology Testing Guidelines," which were developed in conjunction with the State Water Resources Control Board (Water Board) and provide additional guidance on relevant California water quality control plans and objectives for vessels intending to discharge treated effluent in State waters. Based on the available data it is clear that not all treatment systems will meet the EPA water quality objectives, particularly for chlorine residuals. Currently, California defers to the EPA Vessel General Permit for regulation of chlorine residuals in discharged ballast water. The eight systems that show the potential to meet California's standards have undergone some toxicity testing, and have received environmental approvals from the International Maritime Organization and/or the State of Washington. Vessel owners and operators will need to consult with the EPA and the Water Board to better assess the potential for water quality impacts from treatment system usage in California waters.

The Commission is preparing to implement the performance standards for new vessels with a ballast water capacity greater than 5000 MT in 2012. This review indicates that systems are available to meet California's performance standards. Commission staff is working closely with the shipping industry and treatment vendors to ensure a smooth transition to the new standards.

At this time, Commission staff recommends that the Legislature allow the implementation of standards for new vessels with a ballast water capacity over 5000 MT to proceed on January 1, 2012. In addition, and in order to ensure full implementation and compliance verification as performance standards move forward, Commission staff also recommend that the Legislature: 1) Support staff involvement with the development of performance standards and evaluation of treatment technologies at the federal and international levels; and 2) Maintain the accessibility and funding levels of the Marine Invasive Species Control Fund, so research can be supported and methods developed for compliance verification as vessels with treatment systems begin to arrive to California in 2011.

Staff will conduct another assessment of available treatment technologies by July 1, 2012 in anticipation of the implementation of the performance standards for existing vessels with a ballast water capacity between 1500 and 5000 MT in 2014.

TABLE OF CONTENTS

ABBREVIATIONS AND TERMS

Act	Coastal Ecosystems Protection Act
CCR	California Code of Regulations
CFR	Code of Federal Regulations
CFU	Colony-Forming Unit
CSLC/Commission	California State Lands Commission
Convention	International Convention for the Control and Management of Ships' Ballast Water and Sediments
CWA	Clean Water Act
EEZ	Exclusive Economic Zone
EPA	United States Environmental Protection Agency
ETV	Environmental Technology Verification Program
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
GESAMP-BWWG	Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection – Ballast Water Working Group
IMO	International Maritime Organization
MEPC	Marine Environment Protection Committee
Michigan DEQ	Michigan Department of Environmental Quality
ml	Milliliter
MPCA	Minnesota Pollution Control Agency
MT	Metric Ton
NIS	Nonindigenous Species
nm	Nautical Mile
NPDES	National Pollution Discharge Elimination System
NRL	Naval Research Laboratory
PRC	Public Resources Code
Staff	Commission staff
STEP	Shipboard Technology Evaluation Program
TRC	Total Residual Chlorine
µm	Micrometer (one millionth of a meter)
USCG	United States Coast Guard
UV	Ultraviolet Irradiation
VGP	Vessel General Permit for Discharges Incidental to the Normal Operation of Commercial Vessels and Large Recreational Vessels
Water Board	California State Water Resources Control Board
WDFW	Washington Department of Fish and Wildlife
WDNR	Wisconsin Department of Natural Resources

DISCLAIMER

This report provides information regarding the ability and availability of ballast water treatment systems to meet California's performance standards for the discharge of ballast water. This report does not constitute an endorsement or approval by the California State Lands Commission (Commission) of any treatment system or system manufacturer. It is the responsibility of the vessel owner/operator to select treatment systems that will ensure that ballast water discharges are in compliance with California's performance standards for preventing species introductions and all other applicable laws, regulations and permits.

I. PURPOSE

This report was prepared for the California Legislature pursuant to Public Resources Code (PRC) Section 71205.3. Among its provisions, PRC Section 71205.3 requires the Commission to adopt performance standards for the discharge of ballast water and to prepare and submit to the Legislature, "a review of the efficacy, availability, and environmental impacts, including the effect on water quality, of currently available technologies for ballast water treatment systems." California's performance standards for the discharge of ballast water were approved in 2007 (see California Code of Regulations (CCR), Title 2, Division 3, Chapter 1, Article 4.7). The Commission completed an initial ballast water treatment technology assessment report in 2007 (see Dobroski et al. 2007) and a revised report in 2009 (see Dobroski et al. 2009a). Additional reports are due to the California Legislature 18 months prior to each of the implementation dates for California's performance standards (see Tables III-1 and III-2). This report fulfills the legislative mandate to assess the availability of ballast water treatment technologies prior to the January 1, 2012 implementation of performance standards for newly built vessels with a ballast water capacity greater than 5000 metric tons (MT). The report summarizes Commission conclusions on the advancement of ballast water treatment technology development and discusses progress by Commission staff in implementing California's performance standards for the discharge of ballast water.

II. INTRODUCTION

Nonindigenous Species and their Impacts

Also known as “introduced,” “invasive,” “exotic,” “alien,” or “aquatic nuisance species,” nonindigenous species (NIS) are organisms that have been transported by human activities to a region where they did not occur historically, and have established reproducing populations in the wild (Carlton 2001). Once established, NIS can have serious human health, economic and environmental impacts in their new environment. One of the most infamous examples is the zebra mussel (*Dreissena polymorpha*), which was introduced from the Black Sea to the Great Lakes in the mid-1980s (Carlton 2008) and was discovered in California in 2008 (California Department of Fish and Game 2008). This tiny striped mussel attaches to hard surfaces in dense populations that clog municipal water systems and electric generating plants, costing approximately $1 billion a year in damage and control for the Great Lakes alone (Pimentel et al. 2005). In San Francisco Bay, the overbite clam (*Corbula amurensis*) is believed to be a major contributor to the decline of several pelagic fish species in the Sacramento-San Joaquin River Delta by reducing the plankton food base of the ecosystem (Feyrer et al. 2003, Sommer et al. 2007). In addition, many human pathogens and contaminant indicator microorganisms have been found in ballast tanks. These include human cholera (*Vibrio cholerae* O1 and O139) (Ruiz et al. 2000), the microorganisms that cause paralytic shellfish poisoning (Hallegraeff 1998), human intestinal parasites (*Giardia lamblia, Cryptosporidium parvum, Enterocytozoon bieneusi*) and microbial indicators for fecal contamination (*Escherichia coli* and intestinal enterococci) (Reid et al. 2007).

In marine, estuarine and freshwater environments, NIS may be transported to new regions through various human activities including aquaculture, the aquarium and pet trade, and bait shipments (Cohen and Carlton 1995, Weigle et al. 2005). In coastal habitats commercial shipping is an important transport mechanism, or “vector,” for invasion. In one study, shipping was responsible for, or contributed to, approximately 80% of invertebrate and algae introductions to North America (Fofonoff et al. 2003, see also Cohen and Carlton 1995 for San Francisco Bay). Ballast water was a possible vector for 69% of those shipping introductions, making it a significant ship-based introduction vector (Fofonoff et al. 2003).

Ballast water is necessary for many functions related to the trim, stability, maneuverability, and propulsion of large oceangoing vessels (National Research Council 1996). Vessels take on, discharge, or redistribute water during cargo loading and unloading, as they take on and burn fuel, encounter rough seas, or transit through shallow coastal waterways. Typically, a vessel takes on ballast water after its cargo is unloaded in one port to compensate for the weight imbalance, and will later discharge that water when cargo is loaded in another port. This transfer of ballast water from “source” to “destination” ports results in the movement of many organisms from one region to the next. In this fashion, it is estimated that more than 7000 species are moved around the world on a daily basis (Carlton 1999).

Ballast Water Management

Attempts to eradicate NIS after they have become widely distributed are often costly and unsuccessful (Carlton 2001). Between 2000 and 2006, over $7 million was spent to eradicate the Mediterranean green seaweed (*Caulerpa taxifolia*) from two small embayments in southern California (Woodfield 2006). Unsuccessful eradication attempts for nuisance NIS generally evolve into control efforts that typically represent an expensive and continual economic commitment. Approximately $10 million is spent annually to control the sea lamprey (*Petromyzon marinus*) in the Great Lakes (Lovell and Stone 2005). Over $10 million has been spent to control the zebra mussel and quagga mussel in California waters since the species were first found in 2007 (Ellis, S., pers. comm. 2010). By the end of 2010, over $12 million will have been spent in San Francisco Bay to control the Atlantic cordgrass (*Spartina alterniflora*) (Spellman, M., pers. comm. 2008). These costs reflect only a fraction of the cumulative expense over time, as species control is an unending process. Prevention is therefore considered the most desirable way to address the NIS issue.

For the vast majority of commercial vessels, ballast water exchange is the primary management technique to prevent or minimize the transfer of coastal (including bay/estuarine) organisms. During exchange, the biologically rich water that is loaded while a vessel is in port or near the coast is exchanged with the comparatively species- and nutrient-poor waters of the mid-ocean (Zhang and Dickman 1999). Coastal organisms adapted to the conditions of bays, estuaries and shallow coasts are not expected to survive and/or be able to reproduce in the mid-ocean due to the differences in biology (competition, predation, food availability) and oceanography (temperature, salinity, turbidity, nutrient levels) between the two regions (Cohen 1998). Mid-ocean organisms are likewise not expected to survive in coastal waters (Cohen 1998).

Performance Standards for the Discharge of Ballast Water

Ballast water exchange is generally considered an interim tool because of its variable efficacy and operational limitations. Studies indicate that the effectiveness of ballast water exchange at eliminating organisms in tanks ranges widely from 50-99% (Cohen 1998, Parsons 1998, Zhang and Dickman 1999, USCG 2001, Wonham et al. 2001, MacIsaac et al. 2002). When performed properly, exchange has been considered an effective tool to reduce the risk of coastal species invasions (Ruiz and Reid 2007). However, new research demonstrates that the percentage of ballast water exchanged does not necessarily correlate with a proportional decrease in organism abundance (Choi et al. 2005, Ruiz and Reid 2007). Some vessels are regularly routed on short voyages or voyages that remain within 50 nautical miles (nm) of shore, and in such cases, the exchange process may create a delay or require a vessel to deviate from the most direct route. Such deviations can extend travel distances, increasing vessel costs for personnel time and fuel consumption.

In some circumstances, ballast water exchange may not be possible without compromising vessel or crew safety. For example, vessels that encounter adverse weather or experience equipment failure may be unable to conduct ballast water exchange safely. Unmanned barges are incapable of conducting exchange without transferring personnel onboard, a procedure that can present unacceptable danger if attempted in the exposed conditions of the open ocean. In recognition of these challenges, state and federal ballast water regulations allow vessels to forego exchange should the master or person in charge determines that it would place the vessel, its crew, or its passengers at risk. Though the provision is rarely invoked in California, the handful of vessels that use it may subsequently discharge unexchanged ballast into state waters, presenting a risk of NIS introduction.

Regulatory agencies and the commercial shipping industry have therefore looked toward the development of effective ballast water treatment technologies as a promising management option. For regulators, such systems would provide NIS prevention, including in situations where exchange may be unsafe or impossible. Technologies that eliminate organisms more effectively than mid-ocean exchange could provide a consistently higher level of protection to coastal ecosystems from NIS. For the shipping industry, the use of effective ballast water treatment systems might allow voyages to proceed along the shortest routes, in all operational scenarios, thereby saving time and money.

Until very recently, financial investment in the research and development of ballast water treatment systems had been limited, and the advancement of ballast water treatment technologies had been slow. Many barriers have hindered the development of technologies, including equipment design limitations, the cost of technology development, and the lack of guidelines for testing and evaluating performance. Perhaps most importantly, some shipping industry representatives, technology developers and investors considered the absence of a specific set of ballast water performance standards as a primary deterrent to progress. Performance standards would set benchmark levels for organism discharge that a technology would be required to achieve for it to be deemed acceptable for use in eliminating the threat of species introductions. Such targets were needed so developers could design technologies to meet the standards (MEPC 2003). Without standards, investors were reluctant to devote financial resources towards conceptual or prototype systems because they had no indication that their investments might ultimately meet future regulations. For the same reason, vessel owners were hesitant to allow installation and testing of prototype systems onboard operational vessels. It was argued that the adoption of performance standards would address these fears, and accelerate the advancement of ballast treatment technologies. Thus in response to the slow progress of ballast water treatment technology development and the need for effective ballast water treatment options, many state, federal and international regulatory agencies have adopted or are in the process of developing performance standards for ballast water discharges.

III. REGULATORY AND PROGRAMMATIC OVERVIEW

A thorough evaluation of the availability of ballast water treatment technologies requires an understanding of the regulatory framework associated with the development and implementation of performance standards for the discharge of ballast water, including knowledge of mechanisms for the testing and evaluation of treatment systems to meet those standards. Currently, there are no formally adopted international, federal or state programs that include performance standards, guidelines or protocols to verify the performance of treatment technologies, and methods to sample and analyze discharged ballast water for compliance purposes. California, other U.S. states, the federal government, and the international community have recently made great strides towards the development of a standardized approach for the management of discharged ballast water. However, existing legislation, standards and guidelines still vary by jurisdiction. The following is a summary of current performance standards-related laws, regulations and permits, and a review of current and proposed processes for treatment system evaluation and compliance verification.

International Maritime Organization

In February 2004, after several years of development and negotiation, International Maritime Organization (IMO) Member States adopted the International Convention for the Control and Management of Ships' Ballast Water and Sediments (Convention) (see IMO 2005). Among its provisions, the Convention imposes performance standards for the discharge of ballast water (Regulation D-2) with an associated implementation schedule based on vessel ballast water capacity and date of construction (Tables III-1 and III-2).

The Convention will enter into force 12 months after ratification by 30 countries representing 35% of the world's commercial shipping tonnage (IMO 2005). As of May 31, 2010, twenty-five countries representing 24.28% of the world's shipping tonnage have signed the convention (IMO 2010). The Convention cannot be enforced upon any ship until it is ratified and enters into force (IMO 2007). Because the Convention was not ratified in time to enter into force before the first performance standards implementation date in 2009, the IMO General Assembly adopted Resolution A.1005(25) (IMO 2007). The resolution delays the date by which new vessels built in 2009 with a ballast water capacity of less than 5000 MT must comply with Regulation D-2 from 2009 until the vessel's second annual survey, but no later than December 31, 2011 (IMO 2007). The resolution also calls for the IMO Marine Environment Protection Committee (MEPC) to address the impending implementation date for vessels constructed in 2010 (IMO 2007). In September 2009, another draft resolution was put forth to encourage the installation of ballast water treatment systems on new build ships based on the existing implementation dates even though the Convention has not yet been ratified (MEPC 2009j). That resolution was adopted at the 60th meeting of the MEPC in March, 2010. However, since the conditions of the resolution are not mandatory, the implementation dates for all other vessel size classes and construction dates remain the same as originally proposed (Table III-2).

Table III-1. Ballast Water Treatment Performance Standards

Organism Size Class	IMO Regulation D-2[1]	California[1,2]
Organisms greater than 50 µm[3] in minimum dimension	< 10 viable organisms per cubic meter	No detectable living organisms
Organisms 10 – 50 µm in minimum dimension	< 10 viable organisms per ml[4]	< 0.01 living organisms per ml
Living organisms less than 10 µm in minimum dimension		< 10^3 bacteria/100 ml < 10^4 viruses/100 ml
Escherichia coli	< 250 cfu[5]/100 ml	< 126 cfu/100 ml
Intestinal enterococci	< 100 cfu/100 ml	< 33 cfu/100 ml
Toxicogenic *Vibrio cholerae* (O1 & O139)	< 1 cfu/100 ml or < 1 cfu/gram wet weight zooplankton samples	< 1 cfu/100 ml or < 1 cfu/gram wet weight zoological samples

[1] See Table III-2 below for dates by which vessels must meet California and IMO Ballast Water Performance Standards.
[2] Final discharge standard for California, beginning January 1, 2020, is zero detectable living organisms for all organism size classes.
[3] Micrometer – one-millionth of a meter
[4] Milliliter – one-thousandth of a liter
[5] Colony-forming unit – a measure of viable bacterial numbers

Table III-2. Implementation Schedule for Performance Standards

Ballast Water Capacity of Vessel	Standards apply to new vessels in this size class constructed on or after	Standards apply to all other vessels in this size class beginning in[1]
< 1500 metric tons	2009 (IMO)[2] /2010 (CA)	2016
1500 – 5000 metric tons	2009 (IMO)[2] /2010 (CA)	2014
> 5000 metric tons	2012	2016

[1] In California, the standards apply to vessels in this size class as of January 1 of the year of compliance. The IMO Convention applies to vessels in this size class no later than the first intermediate or renewal survey, whichever occurs first, after the anniversary date of delivery of the ship in the year of compliance (IMO 2005).
[2] IMO has pushed back the initial implementation of the performance standards for vessels constructed in 2009 in this size class until the vessel's second annual survey, but no later than December 31, 2011 (IMO 2007).

In order to ensure globally uniform application of the requirements of the Convention, the IMO MEPC has adopted 14 implementation guidelines (Everett, R., pers. comm. 2010). Most relevant to this report, Guideline G8, "Guidelines for Approval of Ballast Water Management Systems" (MEPC 2008i), and Guideline G9, "Procedure for Approval of Ballast Water Management Systems That Make Use of Active Substances" (MEPC 2008f), work together to create a framework for the evaluation of treatment systems by the MEPC and Flag State Administration (the country or flag under which a vessel operates) (Figure III-1). Flag States (not the IMO) may grant approval (also known as "Type Approval") to treatment systems that are in compliance with the Convention's Regulation D-2 performance standards based upon recommended procedures detailed in Guideline G8 for full-scale land-based and shipboard testing. A treatment system may not be used by a vessel party to the Convention to meet the D-2 standards unless that system is Type Approved.

In addition to receiving Type Approval from the Flag State Administration, ballast water treatment systems using "active substances" must first be approved by the IMO MEPC based upon procedures developed by the organization (IMO 2005). An active substance is defined by IMO as, "…a substance or organism, including a virus or a fungus, that has a general or specific action on or against Harmful Aquatic Organisms and Pathogens" (IMO 2005). For all intents and purposes, an active substance is a chemical or reagent (e.g. chlorine, ozone) that kills organisms in ballast water. The IMO approval pathway for treatment systems that use active substances is more rigorous than the evaluation process for technologies that do not. As required by Guideline G9, technologies utilizing active substances must go through a two-step "Basic" and "Final" approval process. Active substance systems that apply for Basic and Final Approval are reviewed for environmental, ship, and personnel safety by the IMO Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) – Ballast Water Working Group (BWWG) in accordance with the procedures detailed in Guideline G9. The MEPC may grant Basic or Final Approval based upon the recommendation of the GESAMP-BWWG.

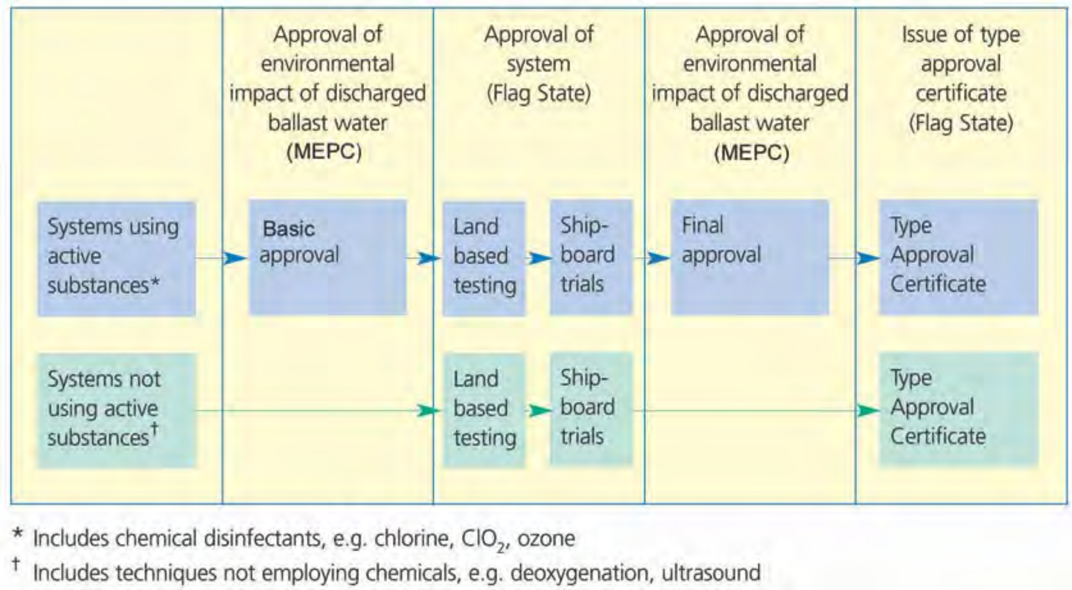


Figure III-1. Summary of IMO approval pathway for ballast water treatment systems. (Modified from Lloyd's Register (2007))

The entire IMO evaluation process, including approval for systems using active substances has been estimated to take between six months and two years to complete (Everett, R., pers. comm. 2007, Lloyd's Register 2007). Once a ballast water treatment system has acquired Type Approval (and the Convention is ratified and in force), the system is deemed acceptable by parties to the Convention for use in international waters in compliance with Regulation D-2.

Because the U.S. has not signed on to the Convention, the U.S. has neither reviewed nor submitted applications to IMO on behalf of any U.S. treatment technology vendors. Until the Convention is both signed by the U.S. and enters into force through international ratification, no U.S. federal agency has the authority (unless authorized by Congress) to manage a program to review treatment technologies and submit applications on their behalf to IMO. United States treatment vendors may approach IMO through association with other IMO Member States, and several have or are in the process of doing so. However, until the U.S. signs on to the Convention, and the Convention is ratified and enters into force, the U.S. is not party to the Convention requirements. Hence, vessels calling on U.S. ports have no authority to use systems approved through the IMO Type Approval process to meet U.S. ballast water management requirements.

One additional guideline related to the implementation of the IMO Convention is relevant to California's ballast water management program. Guideline G2, the "Guidelines for Ballast Water Sampling," provides valuable information, in the absence of U.S. federal guidance, on the location of shipboard sampling points and equipment necessary to collect ballast water samples to assess compliance with the IMO Regulation D-2 performance standards. Guideline G2 defines the preferred sampling point (i.e. the place in the ballast water piping where the sample is taken) and sampling facilities (i.e. the equipment installed to take the sample) for sample collection (BLG 2008). In order to maintain international uniformity, Commission staff based California's regulations governing the collection of ballast water samples on IMO Guideline G2 (see pg. 18, California Legislation and Implementation of Performance Standards, for details).

U.S. Federal Legislation and Programs

Ballast water discharges in the United States are regulated by both the United States Coast Guard (USCG) and the United States Environmental Protection Agency (EPA). Prior to February 6, 2009, ballast water was regulated solely by the USCG through regulations found in Title 33 of the Code of Federal Regulation (CFR) Part 151. The USCG regulations, developed under authority of the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990, which was revised and reauthorized as the National Invasive Species Act of 1996, require ballast water management (i.e. ballast water exchange) for vessels entering U.S. waters from outside of the 200 nm Exclusive Economic Zone (EEZ) of the U.S. Vessels may use onboard treatment systems to meet the current ballast water management requirements if that system is at least as effective as exchange and is approved by the Commandant of the USCG. However, a target has not been developed to define the efficiency of exchange, preventing any evaluation of treatment systems against the efficacy of ballast water exchange. Without a specific target (or performance standard), the USCG has been unable to move forward on the approval of any treatment systems.

On August 28, 2009, the USCG proposed regulations that would establish federal performance standards for living organisms in ships' ballast water discharged in U.S. waters. The proposed regulations would amend 33 CFR Part 151 to include a two-phase ballast water discharge standard and associated implementation schedule. Phase one would require vessels to meet the IMO D-2 standard – a standard roughly 1000 times weaker than California's standards - by 2012, and phase two would require that discharged ballast comply with a standard 1000 times more stringent than IMO – roughly equivalent to California's standards - by 2016. The implementation of the phase two standard is contingent upon a review of the availability of technologies to meet that standard. The proposed regulations would also establish a program to approve ballast water management systems for use in U.S. waters. The public comment period closed on December 4, 2009. The USCG received thousands of comments on the contents of the proposed regulations, and it is possible that the proposed regulation could undergo substantial change before the final rule is issued. At this time, no date has been set for the release of the final regulation.

On February 6, 2009, the EPA joined USCG in the regulation of ballast water in U.S. waters. The EPA regulates ballast water, and other discharges incidental to normal vessel operations, through the Clean Water Act (CWA). This requirement stems from a 2003 lawsuit filed by Northwest Environmental Advocates et al. against the EPA in U.S. District Court, Northern District of California, challenging a regulation originally promulgated under the CWA (Nw. Envtl. Advocates v. U.S. EPA, No. C 03-05760 SI, 2006 U.S. Dist. LEXIS 69476 (N.D. Cal. Sept. 18, 2006)). The regulation at issue, 40 CFR Section 122.3(a), exempted effluent discharges "incidental to the normal operations of a vessel," including ballast water, from regulation under the National Pollution Discharge Elimination System (NPDES). The plaintiffs sought to have the regulation declared *ultra vires,* or beyond the authority of the EPA, under the CWA. On March 31, 2005, the District Court granted judgment in favor of Northwest

Environmental Advocates et al., and on September 18, 2006 the Court issued an order revoking the exemptive regulation (40 CFR Section 122.3(a)) as of September 30, 2008. EPA filed an appeal with the Ninth Circuit U.S. Court of Appeals but was denied in July 2008 (Nw. Envtl. Advocates v. U.S. EPA, No. 03-74795, 2008 U.S. App. LEXIS 15576 (9th Cir. Cal. July 23, 2008)).

In June 2008, EPA released for public comment the draft NPDES "Vessel General Permit for Discharges Incidental to the Normal Operation of Commercial Vessels and Large Recreation Vessels" (VGP). In September 2008, the District Court granted a motion to delay the vacature of the 122.3(a) regulation from September 30 to December 19, 2008. The implementation of the permit was later delayed to February 6, 2009 to provide the regulated community with additional time to comply.

Under the VGP, all vessels greater than 300 gross registered tons, or with a ballast water capacity greater than 8 cubic meters, must submit a Notice of Intent with EPA in order to receive permit coverage. Vessels greater than 79 feet but less than 300 tons receive automatic permit coverage. In large part, the VGP maintains the current regulation of ballast water discharges by the USCG through 33 CFR Part 151. The VGP does not currently include performance standards for the discharge of ballast water. Performance standards may be included in the next iteration of the permit in 2013 based on the outcome of the USCG rulemaking on ballast water performance standards, or if they are proposed independently by EPA. In either case, EPA would have to determine if treatment technologies are commercially available and economically achievable to meet standards in order to include them in the 2013 VGP.

The EPA VGP and the USCG regulations do not relieve vessel owners/operators (permittees) of the responsibility of complying with applicable state laws and/or regulations. Many states with authority to implement the CWA have added specific provisions, including performance standards, for vessel discharges in state waters to the EPA's general permit through the CWA Section 401 certification process. Thus we do not expect to see any impact from the implementation of the NPDES permit on individual states' ability to implement performance standards for the discharge of ballast water in state waters, including California. Vessels will, however, have to comply with both state and federal regulations for ballast water management under the VGP and the USCG regulations. This may result in vessels having to exchange ballast water to comply with federal management requirements under the VGP and USCG regulations and also treat ballast water to comply with state regulations. Federal legislation may be required to clarify this potentially confusing situation.

While the federal implementation of performance standards for the discharge of ballast water remains uncertain, two federal programs have been working to support the development of treatment technologies and facilitate the testing and evaluation of those systems: 1) The USCG Shipboard Technology Evaluation Program (STEP), and 2) The EPA's Environmental Technology Verification (ETV) program.

The USCG STEP is intended to facilitate the development of ballast water treatment technologies. Vessel owners and operators accepted into STEP may install and operate specific experimental ballast water treatment systems on their vessels for use in U.S. waters. In order to be accepted, treatment technology developers must assess the efficacy of systems for removing biological organisms, residual concentrations of treatment chemicals, and water quality parameters of the discharged ballast water (USCG 2004). STEP provides incentives for vessel operators and treatment developers to test promising new technologies. Vessels accepted into the program are authorized to operate the system to comply with existing USCG ballast water management requirements and will be grandfathered for operation under future ballast water discharge standards for the life of the vessel or the treatment system, whichever is shorter. As of June 2010, six vessels have been accepted into STEP (USCG 2010). The lengthy STEP review process and recent uncertainties regarding testing protocols have delayed significant testing on STEP vessels thus far, however, the USCG has plans to streamline the review process for future applicants (USCG 2008). USCG plans to continue STEP even after the implementation of performance standards, as the STEP will serve to facilitate system shipboard testing for USCG approval, and will continue to promote vessel access for the research and development of promising experimental technologies (Moore, B., pers. comm. 2010; Everett, R., pers. comm. 2010).

The EPA ETV program is an effort to accelerate the development and marketing of environmental technologies. The USCG and the EPA established a formal agreement to implement an ETV program focused on ballast water management. Under this agreement, the ETV program developed a draft protocol in 2004 for verification of the performance of ballast water treatment technologies. Subsequently, the USCG established an agreement with the Naval Research Laboratory (NRL) to evaluate, refine, and validate this protocol and the test facility design required for its use. This validation project resulted in the construction of a model ETV Ballast Water Treatment System Test Facility at the NRL Corrosion Science and Engineering facility in Key West, Florida. The innovative research conducted at the NRL facility is intended to result in technical procedures for testing ballast water treatment systems for the purpose of approval and certification. Based on the information collected during the evaluation of the 2004 draft protocol, ETV staff, in consultation with an advisory panel (of which Commission staff is a member), is currently developing a revised final treatment technology verification protocol, which was released in draft form for public comment in March 2010.

U.S. State Legislation and Programs

States have taken two approaches to the implementation of ballast water management and specifically performance standards for the discharge of ballast water. Some states have specific authority granted by state legislation to establish performance standards either by regulation or permit. Other states have added specific provisions establishing performance standards to the VGP through the Section 401 certification process. The following is a summary of ballast water performance standards by state and how each has approached implementation.

CWA Section 401 Certifications Under the Vessel General Permit (VGP)

Section 401 of the Clean Water Act requires states to approve federal permits and allows states to add requirements, if necessary, above and beyond those present in the federal permit. A number of states established ballast water management programs in 2009 through the VGP. States that specifically included the establishment of performance standards in their 401 certification include: Illinois, Indiana, New York, Ohio, and Pennsylvania. Illinois, Indiana and Ohio require vessels to comply with the IMO D-2 standard (see Table III-1) by 2012 for newly built vessels or 2016 for existing vessels. Pennsylvania established a two-phase standard that requires vessels built prior to 2012 to install treatment systems that meet the IMO D-2 standard by 2012, and vessels built on or after 2012 to meet California's performance standards (roughly equivalent to1000 times the IMO D-2 standard). Finally, New York will require all vessels to install treatment systems that meet a standard roughly equivalent to 100 times the IMO D-2 standard by 2012. Vessels constructed on or after 2013 must install systems that meet California's performance standards.

Non-VGP State Ballast Water Programs that Include Performance Standards

Michigan

Michigan passed legislation in June 2005 (Act 33, Public Acts of 2005) requiring a permit for the discharge of any ballast water from oceangoing vessels into the waters of the state beginning January 2007. Through the general permit (Permit No. MIG140000) developed by Michigan Department of Environmental Quality (DEQ), any ballast water discharged must first be treated by one of four methods (hypochlorite, chlorine dioxide, ultraviolet radiation preceded by suspended solids removal, or deoxygenation) that have been deemed environmentally sound and effective in preventing the discharge of NIS. In state waters, vessels must use treatment technologies in compliance with applicable requirements and conditions of use as specified by Michigan DEQ. Vessels using technologies not listed under the Michigan general permit may apply for individual permits if the treatment technology used is deemed, "environmentally sound and its treatment effectiveness is equal to or better at preventing the discharge of aquatic nuisance species as the ballast water treatment methods contained in [the general] permit," (Michigan DEQ 2006).

Minnesota

Effective July 1, 2008, Minnesota state law (S.F. 3056) requires vessels operating in state waters to have both a ballast water record book and a ballast water management plan onboard that has been approved by the Minnesota Pollution Control Agency (MPCA) (MPCA 2008). Additionally, based on the authority in Minn. Stat. 115.07, Minn. R. 7001.0020, subp. D, and Minn. R. 7001.0210, and to implement the recently enacted legislation, the MPCA approved a State Disposal System general permit for ballast water discharges into Lake Superior and associated waterways in September 2008 (MPCA 2008). Under the permit, all vessels (oceangoing and lakes-only) transiting Minnesota waters must comply immediately with approved best management practices. No later than January 1, 2012, new vessels will be required to comply with the IMO D-2 performance standards for the discharge of ballast water (see Table III-1), and existing vessels will be required to comply with those standards no later than January 1, 2016 (MPCA 2008).

Washington

The Washington Department of Fish and Wildlife (WDFW), in consultation with their stakeholder Ballast Water Work Group, completed a comprehensive rewrite of the state's ballast water management regulations, which became effective on July 26, 2009. The new rules and information on the state program can be found at: http://wdfw.wa.gov/fish/ballast/ballast.htm. WDFW has initiated new rulemaking to adopt permanent concentration-based standards. A priority for WDFW is to adopt standards that help bring the national and/or U.S. Pacific coast states into greater management consistency. The WDFW no longer independently approves treatment systems for use in state waters and now relies on regional, national or international approvals. Systems previously approved under the interim regulations will remain approved for their original period of use. WDFW staff expects the new standards to be adopted in early 2011 (Pleus, A., pers. comm. 2010).

Wisconsin

As of February 1, 2010, vessels that discharge ballast in Wisconsin waters must comply with the General Permit to Discharge under the Wisconsin Pollutant Discharge Elimination System. The permit was established by the Wisconsin Department of Natural Resources (WDNR) under authority provided by Chapter 283, Wisconsin Statutes. Among its provisions, the permit sets ballast water performance standards roughly equivalent to 100 times the IMO D-2 standard. All vessels constructed on or after 2012 must meet the Wisconsin Standard set forth in the permit. Existing vessels have until 2014 to comply. Prior to the implementation of the standards, WDNR will conduct an assessment of the availability of treatment systems to meet the Wisconsin standards. If the WDNR determines that treatment technologies are commercially unavailable, the permit requires vessels to comply with the IMO D-2 standard in place of the Wisconsin Standard. The existing implementation schedule remains the same.

California Legislation and the Implementation of Performance Standards

Review of Legislation

California's Marine Invasive Species Act of 2003 directed the Commission to recommend performance standards for the discharge of ballast water to the State Legislature in consultation with the State Water Resources Control Board (Water Board), the USCG and a technical advisory panel (see PRC Section 71204.9). The legislation directed that standards should be selected based on the best available technology economically achievable, and should be designed to protect the beneficial uses of the waters of the State.

In 2005, Commission staff convened a cross-interest, multi-disciplinary panel consisting of regulators, research scientists, industry representatives and environmental organizations and facilitated discussions over the selection of performance standards. Many sources of information were used to guide the performance standards selection including: biological data on organism concentrations in exchanged and un-exchanged ballast water, theories on coastal invasion rates, standards considered or adopted by other regulatory bodies, and available information on the efficacy and costs of experimental treatment technologies. Though all sources and panel members provided some level of insight, none could provide solid guidance for the selection of a specific set of standards that would reduce or eliminate the introduction and establishment of NIS. At a minimum, it was determined that reductions achieved by the selected performance standards should improve upon the status quo and decrease the discharge of viable ballast organisms to a level below quantities observed following legal ballast water exchange. Additionally, the technologies used to achieve these standards should function without introducing chemical or physical constituents to the treated ballast water that may result in adverse impacts to receiving waters. Beyond these general criteria, however, there was no concrete support for the selection of a specific set of standards. This stems from the key knowledge gap that invasion risk cannot be predicted for a particular quantity of organisms discharged in ballast water (MEPC 2003), with the exception that zero organism discharge equates to zero risk.

The Commission ultimately put forward performance standards recommended by the majority of the Panel because they encompassed several desirable characteristics: 1) A significant improvement upon ballast water exchange; 2) In-line with the best professional judgment of scientific experts that participated in the development of the IMO Convention; and 3) Approached a protective zero discharge standard. The proposed interim standards were based on organism size classes (Table III-1). The standards for the two largest size classes of organisms (greater than 50 micrometers (µm = one-millionth of a meter) in minimum dimension and 10 – 50 µm in minimum dimension) were significantly more protective than those proposed by the IMO Convention. The majority of the Panel also recommended standards for organisms less than 10 µm including human health indicator species and total counts of living bacteria and viruses. The recommended bacterial standards for human health indicator species, *Escherichia coli* and intestinal enterococci, are identical to those adopted by the EPA in 1986 for recreational use and human health safety (EPA 1986). The implementation schedule proposed for the interim standards was similar to the IMO Convention (Table III-2). A final discharge standard of zero detectable organisms was recommended by the majority of the Panel. The Commission included an implementation deadline of 2020 for this final discharge standard.

The Commission submitted the recommended standards and information on the rationale behind its selection in a report to the State Legislature in January of 2006 (see Falkner et al. 2006). By the fall of that same year, the Legislature passed the Coastal Ecosystems Protection Act (Chapter 292, Statutes of 2006) directing the Commission to adopt the recommended standards and implementation schedule through the California rulemaking process by January 1, 2008. The Commission completed that rulemaking in October, 2007 (see 2 CCR § 2291 *et seq*.).

In anticipation of the implementation of the interim performance standards, the Coastal Ecosystems Protection Act also directed the Commission to review the efficacy, availability and environmental impacts of currently available ballast water treatment systems by January 1, 2008. The review and resultant report was approved by the Commission in December, 2007 (see Dobroski et al. 2007). Additional reviews must be completed 18 months prior to the implementation dates for all other vessel classes and 18 months before the implementation of the final discharge standard on January 1, 2020 (see Table III-2 for full implementation schedule). During any of these reviews, if it is determined that existing technologies are unable to meet the discharge standards, the report must describe why they are not available.

The first technology assessment report (Dobroski et al. 2007) determined that technologies would not be available to meet California's discharge standards for new vessels with a ballast water capacity under 5000 MT by the original 2009 implementation date. In response, the Legislature passed Senate Bill 1781 in 2008 (Chapter 696, Statutes of 2008). Senate Bill 1781 amended PRC Section 71205.3(a)(2) and delayed the implementation of the interim performance standards for new vessels with a ballast water capacity of less than 5000 MT from January 1, 2009 to January 1, 2010. Senate Bill 1781 also required an additional assessment of available ballast water treatment technologies by January 1, 2009 (see Dobroski et al. 2009a) prior to the new

2010 implementation date. Dobroski et al. (2009a) determined that technologies that demonstrated the potential to meet California's performance standards were available. The report recommended that the Commission proceed with the initial implementation of the performance standards in 2010.

Implementing California's Performance Standards

As of January 1, 2010, newly built vessels (vessels for which construction began on or after January 1, 2010) with a ballast water capacity of less than 5000 MT that discharge ballast in California waters must comply with California's performance standards. Vessel construction often takes a year or more, and it is anticipated that the first vessels that must meet the performance standards will not begin to arrive in California until sometime during 2011. Commission staff have consulted with vendors to determine if treatment systems have been or will be purchased in order to meet this first implementation date. At this time, staff are not aware of any specific purchases. Many vessels in the midst of construction are leaving dedicated space for a ballast water treatment system so it may be installed at the last possible moment to ensure that the system purchased is the most up-to-date available. Commission staff are in the process of preparing protocols to assess compliance with the performance standards and will be ready to begin inspection of vessels once new build vessels that fall under the 2010 implementation date arrive in California waters.

As discussed in Dobroski et al. (2007, 2009a), the Commission does not have the authority to approve ballast water treatment systems for use in California waters. Therefore, Commission staff will focus on dockside inspection of vessels for verification of compliance with the performance standards (in accordance with PRC Section 71206). Vessel inspections will consist of both an administrative review of applicable ballast water management plans and reporting documents as well as the collection of ballast water samples for analysis.

Vessels must currently keep an up-to-date ballast water management plan on board as well as copies of all ballast water reporting forms submitted to the Commission within the past two years. Dobroski et al. (2009a) recommended that additional authority be granted to the Commission in order to allow for the collection of specific information about the installation and use of ballast water treatment systems on vessels operating in California waters. This information is necessary to monitor the effective implementation of California's performance standards. In response to the recommendation in Dobroski et al. (2009a), Assembly Bill 248 (Chapter 317, Statutes of 2009) was passed in the fall of 2009, which provides the Commission with the authority to request the aforementioned information on forms to be developed by the Commission. Commission staff is currently in the process of adopting those forms through the rulemaking process.

During an inspection, once Commission staff has reviewed applicable vessel paperwork, a ballast water sample will be drawn from vessels intending to discharge in California waters. California's performance standards are a discharge standard, and thus samples must be drawn from the vessel's ballast water discharge piping. Most vessels do not have the equipment to take samples of ballast water from the discharge line. Therefore, the Commission developed regulations in the fall of 2009 that require vessels to install sampling ports (i.e. sampling facilities) as near to the point of discharge as practicable (2 CCR § 2297). In order to maintain international uniformity, the regulations are based on the IMO Guideline G2 for ballast water sampling with additional input provided by the USCG. The regulations establish design specifications for in-line sampling facilities and set requirements for where the sampling facilities should be installed on the discharge line (i.e. the sampling point). Vessels must install the sampling facilities by the same year that they must comply with California's performance standards.

Commission staff is currently in the process of refining procedures for analysis of the samples collected from the discharge line. Commission staff is working in consultation with technical experts and will make use of the best available scientific techniques to assess viable organism concentration for each of the standards. One issue of concern has been the development of sampling methods and procedures that will verify vessel compliance with an acceptable level of legal and scientific confidence (see King and

Tamburri 2009). The bulk of these arguments are aimed at performance standards for the greater than 50 µm organism size class, specifically for standards that are defined as a given number of live organisms per cubic meter (e.g. IMO and proposed USCG standards). While sampling large volumes of ballast water (i.e. many cubic meters) are necessary to attain adequate statistical confidence to verify a given number of viable organisms are indeed present in each cubic meter, this argument is not necessarily appropriate for California's (as well as New York and Pennsylvania's) performance standards. California's performance standard for the greater than 50 µm organism size class is defined as "no detectable living organisms" and is technically not bound by any volumetric units or the confidence limits associated with those units. Therefore Commission staff believes it is appropriate to sample as large a volume as is feasible (whether that is 50 liters, 500 liters, 5000 liters, or any volume in-between) in order to verify compliance with California's unit-less performance standard. Although it is important to ensure that a reasonable volume of water is sampled during compliance verification, sampling methods must balance the desire for statistical confidence with practical, rapid, and relatively easy techniques for shipboard inspection. As the precision of sampling equipment and analytical techniques improve, Commission staff will regularly discuss sampling methodologies with other states, the federal government and the international community to stay up-to-date on advances in the technology to conduct compliance verification.

Finally, Commission staff will continue to gather information about treatment system development, installation, and use on board vessels, particularly as the standards are implemented for existing vessels and vessels with larger ballast water capacities. This information will guide the development of new regulations which take into account development within the rapidly advancing ballast water treatment technology industry.

IV. TREATMENT TECHNOLOGY ASSESSMENT PROCESS

Public Resources Code (PRC) Section 71205.3 directs the Commission to prepare, "a review of the efficacy, availability, and environmental impacts, including the effect on water quality, of currently available technologies for ballast water treatment systems." In accordance with the law, the Commission has consulted with, “the State Water Resources Control Board, the United States Coast Guard, and the stakeholder advisory panel described in subdivision (b) of [PRC] Section 71204.9.” This stakeholder panel also provided guidance in the development of the performance standards report to the California Legislature (Falkner et al. 2006).

During the preparation of the initial technology assessment report (Dobroski et al. 2007), Commission staff received input from a small technical workgroup prior to consulting with the stakeholder advisory panel. The workgroup met in May 2007 to assess the current availability of treatment systems, the efficacy of those systems, and any potential environmental and water quality impacts. This group included individuals with expertise in ballast water treatment technology development, water quality and biological monitoring and evaluation, naval architecture and engineering, and technology efficacy analysis (see Dobroski et al. 2007 for workshop participants and summary). The conclusions drawn during the workshop in 2007 have continued to provide valuable guidance and direction in the preparation of subsequent reports.

As with previous reports (Dobroski et al. 2007, 2009a), Commission staff conducted an exhaustive literature search to prepare this report. Staff focused its review on recently available scientific articles, performance verification reports, and water quality impact analyses from independent testing organizations. Staff also contacted treatment technology vendors in order to gather the most up-to-date information about system development, testing and approvals. On several occasions, staff held meetings in-person with technology vendors. These face-to-face gatherings have proved to be extremely valuable opportunities to inform vendors about California’s performance standards requirements and to engage in dialogue about system performance verification testing and the Commission’s technology assessment reports.

Due to a rapid increase in the availability of new data on treatment system performance in mid-2009, and a desire by industry to receive updates on the latest technology developments, Commission staff conducted an interim assessment of available treatment technologies in October 2009 (see Dobroski et al. 2009b). The technology update was not legislatively mandated, and was not reviewed by the technical advisory panel. The update was intended as a resource for stakeholders interested in ballast water treatment systems for use in California waters. It also provided Commission staff with an opportunity to begin identifying and focusing on issues of concern for this 2010 legislatively mandated report.

For the preparation of this report, Commission staff compiled available data to develop a treatment system matrix (see Tables V-1, VI-1, VI-3, VI-4, VI-5, VI-6, VII-1 and Appendix A). The 2010 report addresses the availability of treatment systems for vessels with a ballast water capacity greater than 5000 MT. Industry has expressed concern about whether or not treatment systems will be able to effectively treat ballast water on these high volume/high flow rate vessels. Therefore, Commission staff included relevant data on treatment systems' maximum capacities and flow rates for this report. The data was summarized relative to the ballast water capacities and pump flow rates of the vessel fleet operating in California waters in order to determine if systems both meet California's performance standards and are available for this largest size class of vessels. As with previous reports, Commission staff also gathered the latest data on environmental impacts, including effects on water quality, and the economics of treatment system installation and operation. Upon completion of the data analysis, Commission staff drafted a preliminary report for review by the Commission's stakeholder advisory panel (see Appendix B for list of panel members), the Water Board and USCG. The advisory panel met in April 2010 to discuss the current report (see Appendix B for meeting notes). Advisory panel discussions were considered by staff to help guide the development of this final report.

V. TREATMENT TECHNOLOGIES

The goal of ballast water treatment is to remove or kill organisms entrained in ballast water. Given the long history and use of wastewater treatment technologies, the design and production of ballast water treatment systems may seem simple. However, transferring such technological concepts to mobile, space- and energy-limited vessels has proven complex in practice. A system must be effective under a wide range of challenging environmental conditions including variable temperature, salinity, nutrients and suspended solids. It must also function under difficult operational constraints including high flow-rates of ballast water pumps, large water volumes, and variable retention times (time ballast water is held in tanks). Treatment systems must be capable of eradicating a wide variety of organisms ranging from viruses and microscopic bacteria, to free-swimming plankton, and must operate so as to minimize or prevent impairment of the water quality conditions of the receiving waters. The development of effective treatment systems is further complicated by the variability of vessel types, shipping routes and port geography.

Two general platform types have been explored for the development of ballast water treatment technologies. Shoreside ballast water treatment occurs at a land-based facility following transfer from a vessel. Shipboard treatment occurs onboard vessels through the use of technologies that are integrated into the ballasting system. Shipboard treatment systems are attractive because they allow flexibility to manage ballast water during normal operations, while shoreside treatment may be a good option for vessels with small ballast water capacities and/or dedicated port calls.

Shoreside treatment of ballast water is an appealing option, particularly from a regulatory perspective. Permitting and inspection of a fixed shoreside facility is significantly easier than the regulation of discharges from mobile sources such as vessels. Shoreside treatment also provides an option for treatment technologies and methods that are not feasible onboard vessels due to space and/or energy constraints, such as reverse osmosis. Shoreside treatment facilities could be staffed by trained wastewater engineers instead of ships' crew, who may not be specifically trained in the operation and maintenance of water treatment facilities. Additionally, in the event that a shipboard treatment system fails or sea conditions prevent ballast water exchange, shoreside or barge-mounted treatment facilities could provide an important facility where unmanaged ballast water could be held or treated.

Shoreside treatment does pose several challenges, however. Vessels must have the appropriate piping or attachment mechanism to establish a connection with a shoreside facility. An international standard would be necessary to standardize the design of these connections in order to ensure that ships could connect to shoreside facilities throughout the world. Additionally, vessels must be able to discharge ballast at a rate that prevents vessel delays. The cost of these retrofits may be prohibitive (CAPA 2000). Additionally, current wastewater treatment plants are not equipped to treat saline water (Water Board 2002, Moore, S., pers. comm. 2005). If existing municipal facilities are to be used for the purposes of ballast water treatment, they will need to be modified, and a new extensive network of piping and associated pumps will be required to distribute ballast water from vessels at berth to the treatment plants. The establishment of new piping and facilities dedicated to ballast water treatment, while technically feasible, would require the acquisition of land for facility construction, and this would be complex and costly in California's densely populated coastal and port areas. Furthermore, shoreside treatment is not feasible for vessels that must take on or discharge ballast water while underway, for example, if the vessel must adjust its draft to navigate through a shallow channel or under a bridge.

To date only limited feasibility studies have been conducted on shoreside treatment (see references in Falkner et al. 2006). A recent study by McMullin et al. (2008) assessed the feasibility of shoreside treatment at the Port of Milwaukee. The authors concluded that shoreside treatment is a feasible alternative to shipboard treatment, but only under certain conditions. Since vessels must be retrofitted to allow the connection of shoreside pumps to the vessel's ballasting piping, an international standard would likely need to be created. Additionally, procedures would need to be developed for each vessel to maintain its stability and ensure safe deballasting rates during cargo loading. Finally, due to space constraints, the authors determined that the most cost-effective and practical approach to shoreside treatment at the Port of Milwaukee would likely require vessels to discharge ballast to a barge to store or treat the ballast before disposal to land-based facilities. The authors caution against the extrapolation of the report's conclusions to port areas outside of Milwaukee, as each unique region presents its own set of challenges.

In California, shoreside treatment may be a good option for unique terminals such as those with limited but regular vessel calls (e.g. cruise ships). Nonetheless, one study specific to cruise ships indicated that due to the operational practices of cruise ships – many do not deballast in California - and with the current ballast water management and environmental regulatory requirements in California and the Port of San Francisco, there is little demand for shoreside treatment except in emergency situations (Bluewater Network 2006). Additional studies are necessary to determine the feasibility of and demand for shoreside treatment for other vessel types and across the State as a whole. These may include assessments by those involved in the wastewater treatment sector on whether existing technologies could meet California's performance standards. Because the vast majority of time, money, and effort in the development of ballast water treatment technologies during recent years has been focused on shipboard treatment systems, we will focus on shipboard systems for the remainder of this report.

Shipboard systems allow for greater flexibility during vessel operations. Vessels may treat and discharge ballast while in transit, and thus will not need to coordinate vessel port arrival time with available space and time at shoreside treatment facilities. As with shoreside treatment, however, shipboard treatment systems face their own set of challenges. They must be engineered to conform to a vessel's structure, ensure crew safety, and withstand the vibrations and movements induced by the vessel's engine and rough seas. Additionally, shipboard systems must be effective under transit times that range from less than 24 hours to several weeks, and must treat ballast water in compliance with the water quality requirements of recipient regions.

The timing and location of shipboard ballast water treatment can be varied according to the needs of the treatment system and the length of vessel transit. Ballast water may be treated in the pipe (in-line) during uptake or discharge or in the ballast tanks during the voyage (in tank). While mechanical separation (such as filtration) generally occurs during ballast uptake in order to remove large organisms and sediment particles before they enter the ballast tanks, other forms of treatment may occur at any point. Some treatment systems treat ballast water at multiple points during the voyage, such as during uptake and discharge.

Because of the wide range of variables associated with shipboard ballast water treatment, the identification of a single treatment technology for all NIS, ships, and water conditions is unlikely. Each technology may meet the objective of killing or inactivating NIS in a slightly different manner and each could potentially impact the water quality of the receiving environment through the release of chemical residuals or alterations to temperature, salinity, and/or turbidity. Thus a suite of treatment technologies will undoubtedly need to be developed to treat ballast water industry-wide and across all ports and environments.

Treatment Methods

The development of ballast water treatment systems that are effective, environmentally friendly and safe for vessels and crew has been a complex, costly and time consuming process. At the root of many treatment systems are methods that are already in use to some degree by the wastewater treatment industry. A preliminary understanding of these treatment methods forms the basis for more detailed analysis and discussion of ballast water treatment systems. The diverse array of water treatment methods currently under development for use in ballast water treatment can be broken down into five major categories: mechanical, chemical, physical, biological and combination.

Mechanical Treatment

Mechanical treatment traps and removes mid- and large-sized particles from ballast water. Mechanical treatment typically takes place upon ballast water uptake in order to limit the number of organisms and amount of sediment that may enter ballast tanks.

Common options for mechanical treatment include filtration and hydrocyclonic separation.

Filtration works by capturing organisms and particles as water passes through a porous screen or filtration medium, such as sand or gravel. The size of organisms trapped by the filter depends on the mesh size in the case of screen or disk filters, or on the size of the interstitial space for filtration media. In ballast water treatment, screen and disk filtration is more commonly used over filter media, however, there has been some interest in the use of crumb rubber as a filtration medium in recent studies (Tang et al. 2006, 2009). Typical mesh size for ballast water filters ranges from 25 to 100 µm (Parsons and Harkins 2002, Parsons 2003). Most filtration-based technologies also use a backwash process that removes organisms and sediment that become trapped on the filter and clog it. Backwash systems can discharge particles and organisms at the port of origin before the vessel gets underway. Filter efficacy is a function not only of initial mesh size, but also of water flow rate and backwashing frequency.

Hydrocyclonic separation, also known as centrifugation, relies on density differences to separate organisms and sediment from ballast water. Hydrocyclones create a vortex that cause heavier particles to move toward the outer edges of the cyclonic flow where they are trapped in a weir-like device and can be discharged before entering the ballast tanks (Parsons and Harkins 2002). Hydrocyclones used in ballast water treatment generally trap particles in the 50 to 100 µm size range (Parsons and Harkins 2002). One challenge associated with hydrocylone use, however, is that many small aquatic organisms have a density similar to sea water and are thus difficult to separate.

Chemical Treatment

A variety of chemicals (i.e. active substances) are available to kill organisms in ballast water. While the vast majority of chemicals are biocides, some chemicals function to clump or coagulate organisms in order to assist with their mechanical removal. Chemical treatment may take place during ballast uptake, vessel transit, or discharge.

Chemicals may be stored onboard in liquid or gas form, or they may be generated on demand through electrochemical processes.

Chemicals used in ballast water treatment can generally be classified into two major categories: oxidizing and non-oxidizing. Oxidizing agents (e.g. chlorine, chlorine dioxide, bromine, hydrogen peroxide, peroxyacetic acid, ozone) are commonly used in the wastewater treatment sector and work by destroying cell membranes and other organic structures (National Research Council 1996, Faimali et al. 2006). Electrochemical oxidation combines electrical currents with naturally occurring reactants in seawater and/or air (e.g. salt, oxygen) to produce killing agents. For example, electrochemical oxidation can produce products such as hydroxyl radicals, ozone or sodium hypochlorite that are capable of damaging cell membranes. Non-oxidizing biocides, including Acrolein®, gluteraldehyde, and menadione (Vitamin K3), are reported to work like pesticides by interfering with an organism's neural, reproductive or metabolic processes (National Research Council 1996, Faimali et al. 2006).

The ultimate goal of chemicals is to maximize organism mortality while minimizing environmental impact. Environmental concerns surrounding chemical use in ballast water focus on the impacts of residuals or byproducts in treated discharge on receiving waters. The effective use of chemicals in ballast water treatment requires a balance between the amount of time required to achieve inactivation of organisms, with the time needed for those chemicals and residuals to degrade or be neutralized to environmentally acceptable levels. Both of these times vary as a function of ballast water temperature, salinity, organic content and sediment load. As a result, certain chemicals may be more effective than others depending on ballast volume, voyage length, and water quality conditions. Additional concerns about chemical use specific to shipboard operation include corrosion of metals, personnel and ship safety, and vessel design limitations that impact the availability of space onboard for both chemical storage and equipment for dosing.

Physical Treatment

Physical treatment methods include a wide range of non-chemical means to kill organisms present in ballast water. Like chemical treatment, physical treatment may occur on ballast uptake, during vessel transit or during discharge.

Rigby et al. (1999, 2004) discuss the use of waste heat from the ship's main engine as a mechanism to heat ballast water and kill unwanted organisms during vessel transit. However, it would be difficult to heat ballast water to a sufficient temperature to kill all species of bacteria due to lack of sufficient energy/heat available on a vessel (Rigby et al. 1999, Rigby et al. 2004). An alternative approach to heat treatment involves the use of microwaves (Balasubramanian et al. 2008). Currently such a treatment technology would be prohibitively expensive (up to $\$2.55/m^3$), but additional research and development may reduce costs to acceptable levels (Boldor et al. 2008).

Ultraviolet (UV) irradiation is another physical method of sterilization that is commonly used in waste water treatment. UV damages genetic material and proteins, disrupting reproductive and physiological processes and can be highly effective against pathogens (Wright et al. 2006). Both low-pressure and medium-pressure UV systems have been used to treat ballast water on vessels. The pairing of UV light and a catalyst (e.g. titanium dioxide) results in an advanced oxidative process that generates hydroxyl radicals - an effective killing agent.

Additional methods of physical treatment include ultrasound, cavitation and deoxygenation. Ultrasound (ultrasonic treatment) kills through high frequency vibration that creates microscopic bubbles that rupture cell membranes (Viitasalo et al. 2005). The efficacy of ultrasound varies based on the intensity of vibration and length of exposure. Cavitation is another physical treatment method that uses mechanical forces to generate and collapse microscopic bubbles that crush or implode organisms in ballast water. Deoxygenation involves the displacement or “stripping” of oxygen with another inert gas such as nitrogen or carbon dioxide. This process is primarily physical in nature, although the addition of carbon dioxide may trigger a chemical response and result in a reduction in ballast water pH (Tamburri et al. 2006).

Biological Treatment

By far, the least common method of ballast water treatment involves the use of biological organisms to directly kill or produce conditions that will kill organisms present in ballast water. These treatment organisms are considered an “active substance” according to the IMO definition (IMO 2005). One example of biological treatment is the use of yeast to produce low-oxygen (hypoxic) conditions in ballast tanks. In this instance, yeast cells extract the available oxygen in the ballast water tank during cell replication (Bilkovski, R., pers. comm. 2008). The resultant hypoxic environment is toxic to the remaining organisms in the ballast tank. Vendors of biological treatment systems will likely need to address how systems will meet the performance standards, as the organisms responsible for producing the desired killing effect on NIS may trigger non-compliance if detected at sufficient levels in the discharged ballast.

Combination Treatment

The vast majority of ballast water treatment technologies kill organisms by combining mechanical, chemical, physical and/or biological treatment processes, and are categorized as “combination treatment” in this report. In combination treatment, any single treatment method may not be sufficient to treat the ballast water to required standards, but in combination the methods produce the desired result. For example, while filtration is rarely sufficient to remove organisms of all size classes from ballast water, and UV irradiation may be insufficient to deactivate dense clusters of organisms, paired together they may be an effective method of ballast water treatment. The most common combined treatment methods pair mechanical removal with physical or chemical process(es).

Treatment Systems

Twenty-eight treatment technologies were reviewed in the first technology assessment report to the California Legislature (see Dobroski et al. 2007), and 30 treatment systems were reviewed in 2009 (see Dobroski et al. 2009a). For this report, Commission staff compiled and reviewed information on 46 shipboard ballast water treatment systems from developers and vendors located in 16 countries (Table V-1).

Thirty-four of the treatment systems reviewed here utilize a combination of treatment methods, and 32 of those combine mechanical treatment with another treatment method(s). Aside from mechanical separation, the most common method used in ballast water treatment systems is chemical. Of the 46 systems reviewed, 28 use an active substance in the treatment process (Table V-1). Specifically:

- 13 systems use chlorine or the electrochemical generation of sodium hypochlorite
- 7 systems use ozone
- 3 use advanced oxidation or electrochemical processes that generate an array of oxidants including bromine, chlorine, and/or hydroxyl radicals
- 1 system uses chlorine dioxide
- 1 uses ferrate
- 3 systems use other chemicals including a coagulant or biocides not identified at this time

All of the systems that use active substances require IMO Basic and Final Approval prior to operating in compliance with the IMO Convention. These systems will also require additional scrutiny to ensure compliance with all applicable requirements of the EPA Vessel General Permit.

The next most commonly used method of ballast water treatment amongst the 48 systems reviewed is UV irradiation. Fifteen treatment systems use UV as a means to kill or deactivate organisms found in ballast water. All of these systems combine UV treatment with filtration and/or hydrocyclonic mechanical separation methods. Four of these systems have an additional treatment step involving another physical or chemical process.

Only five systems use deoxygenation as a treatment method. Other approaches to ballast water treatment include a heat treatment technology and one that uses electrical pulses to kill organisms (Table V-1).

Table V-1. Ballast Water Treatment Systems Reviewed by Commission Staff

Manufacturer	***Country***	***System Name***	***Technology Type***	***Technology Description***	***Approvals***
21st Century Shipbuilding Co. Ltd.	Korea	Blue Ocean Guardian	combination	filtration + plasma + UV	IMO Basic
Alfa Laval	Sweden	PureBallast	combination	filtration + advanced oxidation technology (hydroxyl radicals)	IMO Basic and Final, Type Approval (Norway)
Aquaworx ATC GmbH	Germany	AquaTriComb	combination	filtration + ultrasound + UV	IMO Basic
atg UV Technology	United Kingdom		combination	hydrocyclone + UV	
ATLAS-DANMARK	Denmark	ABTS	combination	filtration + biocide (ANOLYTE + CATHOLYTE)	
Auramarine Ltd.	Finland	Crystal Ballast	physical	UV-C irradiation	
Brillyant Marine LLC	USA		physical	electric pulse	
Coldharbour Marine	United Kingdom		physical	deoxygenation	
COSCO/Tsinghua University	China	Blue Ocean Shield	combination	hydrocyclone + filtration + UV	IMO Basic
DESMI Ocean Guard A/S	Denmark	DESMI Ocean Guard BWMS	combination	filtration + ozone + UV (advanced oxidation process)	IMO Basic
Ecochlor	USA	Ecochlor™ BWTS	combination	filtration + biocide (chlorine dioxide)	IMO Basic, STEP[1]
EcologiQ	USA/Canada	BallaClean	biological	deoxygenation	
Electrichlor	USA	Model EL 1-3 B	chemical	electrolytic generation of sodium hypochlorite	
Environmental Technologies Inc. (ETI)	USA	BWDTS	combination	ozone + sonic energy	
Ferrate Treatment Technologies LLC	USA	Ferrator	chemical	biocide (ferrate)	

[1] STEP Approval is an experimental use approval that applies to the combination of one vessel and one treatment system. While STEP enrollment includes a rigorous technical and environmental screening it is not a type approval process.

Table V-1 (Continued). Ballast Water Treatment Systems Reviewed by Commission Staff

Manufacturer	***Country***	***System Name***	***Technology Type***	***Technology Description***	***Approvals***
Hamann Evonik Degussa[2]	Germany	SEDNA	combination	hydrocyclone + filtration + biocide (Peraclean Ocean)	IMO Basic and Final, Type Approval (Ger.)
Hamworthy Greenship Ltd.	U.K./Netherlands	SEDINOX	combination	hydrocyclone + electrolytic chlorination	IMO Basic and Final
Hi Tech Marine	Australia	SeaSafe-3	physical	heat treatment	New South Wales EPA
Hitachi/Mitsubishi Heavy Industries	Japan	ClearBallast	combination	coagulation + magnetic separation + filtration	IMO Basic and Final
Hyde Marine	USA	Hyde Guardian	combination	filtration + UV	WA Conditional, Type Approval (U.K.), STEP[1]
Hyundai Heavy Industries Co. Ltd. (1)	Korea	EcoBallast	combination	filtration + UV	IMO Basic and Final
Hyundai Heavy Industries Co. Ltd. (2)	Korea	HiBallast	combination	filtration + electrochlorination + neutralizing agent	IMO Basic
JFE Engineering Corp./ Toagosei Group	Japan	JFE-BWMS	combination	filtration + biocides (sodium hypochlorite) and neutralizing agent (sodium sulfite)	IMO Basic and Final
Kwang San Co. Ltd.	Korea	En-Ballast	combination	filtration + electrochlorination + neutralizing agent (sodium thiosulfate)	IMO Basic
MAHLE Industriefiltration GmbH	Germany	Ocean Protection System (OPS)	combination	filtration + UV	
MARENCO	USA		combination	filtration + UV	WA General Approval
Maritime Solutions Inc.	USA		combination	filtration + UV	
Mexel Industries	France	Mexel®	chemical	biocide	

[1] STEP Approval is an experimental use approval that applies to the combination of one vessel and one treatment system. While STEP enrollment includes a rigorous technical and environmental screening it is not a type approval process.
[2] The Hamann system was temporarily removed from the market due to toxicity concerns (effective 1/31/10).

Table V-1 (Continued). Ballast Water Treatment Systems Reviewed by Commission Staff

Manufacturer	***Country***	***System Name***	***Technology Type***	***Technology Description***	***Approvals***
MH Systems	USA	BW treatment system	combination	deoxygenation + carbonation	
Mitsui Engineering	Japan	SP-Hybrid BWMS Ozone	combination	filtration + mechanical treatment + ozone + neutralization	IMO Basic
NEI	USA	Venturi Oxygen Stripping (VOS)	combination	deoxygenation + cavitation	Type Approval (Liberia), STEP[1]
NK Co. Ltd.	Korea	NK-03 BlueBallast System	chemical	ozone + neutralization (thiosulfate)	IMO Basic and Final, Type Approval (Korea)
ntorreiro	Spain	Ballastmar	combination	filtration + electrochlorination + neutralization (sodium metabisulphite)	
Nutech 03 Inc.	USA	SCX 2000, Mark III	chemical	ozone	
OceanSaver	Norway	OceanSaver BWMS	combination	filtration + cavitation + nitrogen supersaturation + electrodialysis	IMO Basic and Final, Type Approval (Nor.)
OptiMarin	Norway	OptiMarin Ballast System	combination	filtration + UV	Type Approval (Norway)
Panasia Co. Ltd	Korea	GloEn-Patrol	combination	filtration + UV	IMO Basic and Final, Type Approval (Korea)
Pinnacle Ozone Solutions	USA	Aquatic enhancement system	combination	filtration + ozone + UV	
Qingdao Headway Tech Co. Ltd.	China	OceanGuard BWMS	combination	filtration + electrocatalysis + ultrasound	IMO Basic
Resource Ballast Technologies	South Africa	Unitor BWTS	combination	cavitation + ozone + sodium hypochlorite + filtration	IMO Basic and Final
RWO Marine Water Technology	Germany	CleanBallast	combination	filtration + advanced electrolysis	IMO Basic and Final

[1] STEP Approval is an experimental use approval that applies to the combination of one vessel and one treatment system. While STEP enrollment includes a rigorous technical and environmental screening it is not a type approval process.

Table V-1 (Continued). Ballast Water Treatment Systems Reviewed by Commission Staff

Manufacturer	***Country***	***System Name***	***Technology Type***	***Technology Description***	***Approvals***
Severn Trent DeNora	USA	BalPure	chemical	filtration + electrolytic generation of sodium hypochlorite + neutralizing agent (sodium bisulfite)	WA Conditional, IMO Basic, STEP[1]
Siemens	UK/USA/Ger.	SiCure	combination	filtration + electrochlorination	IMO Basic
Sunrui CFCC	China	BalClor	combination	filtration + electrochlorination + neutralizing agent (sodium thiosulfate)	IMO Basic
Techcross Inc.	Korea	Electro-Cleen	chemical	electrochemical oxidation + neutralizing agent (sodium thiosulfate)	IMO Basic and Final, Type Approval (Korea)
Wartsila	Finland		combination	filtration + UV	

[1] STEP Approval is an experimental use approval that applies to the combination of one vessel and one treatment system. While STEP enrollment includes a rigorous technical and environmental screening it is not a type approval process.

VI. ASSESSMENT OF TREATMENT SYSTEMS

The Coastal Ecosystems Protection Act required the adoption of regulations to implement performance standards for the discharge of ballast water. Over 80% of voyages to California ports report that they do not discharge ballast into California waters (Falkner et al. 2007). These vessels will comply with the performance standards simply by retaining all ballast onboard. Vessels that do discharge but use nontraditional sources for ballast water (such as freshwater from a municipal source) will likely meet the discharge standards without needing to use ballast water treatment systems. Vessels that utilize riverine, estuarine, coastal or ocean water as ballast, however, will require ballast treatment prior to discharge. For these vessels, this assessment of treatment system efficacy, availability, and environmental impacts (as required by PRC Section 71205.3(b)) is necessary to understand if systems will be available prior to the implementation of performance standards for newly built vessels with a ballast water capacity greater than 5000 MT in 2012.

Efficacy

Treatment system performance (i.e. efficacy) can be defined as the extent to which a system removes or kills organisms in ballast water. For this report, Commission staff's specific focus is on ability of available treatment systems to meet or exceed California's performance standards for the discharge of ballast water (see Table III-1 for performance standards) for newly built vessels with a ballast water capacity greater than 5000 MT.

Previous reviews of treatment system efficacy (Dobroski et al. 2007, 2009a) faced several challenges. First and foremost, for many systems the lack of available data precluded any form of efficacy assessment. For systems with data available, inconsistent testing methodologies among systems, and occasionally between tests of a single system, made comparison of data nearly impossible. Results varied in scale (bench-top (i.e. laboratory) vs. pilot vs. full-scale) and location (dockside vs. shipboard), and until recently, were often presented in metrics incomparable with California's standards (e.g. as percent reduction instead of concentration of organisms).

An additional challenge when evaluating the available data has been the wide range of data sources. For some systems, data have been provided by vendors in brochures, on the web, or in vendor-authored reports, that have not been evaluated by independent third-parties. Recently, staff has seen a surge in the availability of performance verification data gathered by independent, scientific testing organizations. These independent reports generally provide the most robust, comprehensive review of system performance and environmental acceptability. However, variability remains among scientific testing organizations in terms of the types of analytical and statistical tests in use and methods of data presentation. Commission staff are working with vendors and testing organizations to encourage the standardization of data analysis and presentation.

For this assessment, Commission staff are providing the California Legislature and interested stakeholders with all available sources of information on treatment technology development and operation, including both vendor-supplied and third-party data from all testing scales and locations (lab-based, land-based and shipboard). In all instances, citations are provided for the original source of the data (Table VI-1 and Appendix A). This information is presented so that interested parties can review and evaluate all of the available data and data sources in order to make an informed decision about whether a treatment system may or may not be sufficient for their needs.

Commission staff were able to collect efficacy data on 27 of the 46 treatment systems reviewed in this report (Tables VI-1 and VI-3, Appendix A). As a reference for stakeholders, laboratory data on system performance is summarized in Appendix A. With the exception of the evaluation of system performance for inactivating *Vibrio cholerae*, laboratory data is not used for evaluation purposes in this report because of the large difference in scale between the laboratory and land-based and shipboard investigations. Six systems have only laboratory data available for review. The remaining twenty-one systems have been assessed for potential compliance with California's standards using large scale land-based and/or shipboard data.

No available dataset on treatment system performance can represent the efficacy of that system on all vessel types or under all possible voyage conditions. Many systems have not yet undergone full-scale shipboard testing (see Appendix A for breakdown of data by type of testing facility), the number of tests performed varies from system to system, and those that have been tested on vessels may have only been assessed on one ship or one type of ship under limited testing scenarios. Water condition variables, such as salinity level, turbidity, and temperature can affect the ability of a system to kill organisms. Some systems require minimum ballast water "holding times" for optimal performance, while others appear to perform poorly on extended voyages. The density or diversity (types) of organisms found at the ballast uptake location can also affect system performance. In essence, a system that fails to meet California's standards under one scenario (e.g. short voyage duration) may meet the standards perfectly well under a different one (e.g. longer voyage duration). The reverse situation may also be true.

Because of the limitations of testing data and the variable conditions present in the "real world," this report examines treatment system performance data to determine whether or not systems have demonstrated the **potential** to comply with California's performance standards. The Commission does not have the authority to approve treatment systems for operation in California waters. Positive assessment for the purpose of this report does not guarantee system compliance when operated in California waters, nor does the report suggest or imply system approval. Vessel owners and operators should consult extensively with treatment system vendors to ensure that thorough system verification work has been conducted, and that the system is appropriate for the type and behavior of the vessel in question under normal ballasting conditions. Ultimately vessel owners/operators are responsible for complying with California's performance standards for the discharge of ballast water.

Staff considered the best available data and methods for assessing organism concentration and viability for each of the organism size classes in California's standards (see Table III-1). The latest data have generally been presented according to organism size class, however, some older data, not updated since previous reports, have been presented by organism type (i.e. zooplankton, phytoplankton). In an effort to standardize results among reports, staff evaluated data on zooplankton abundance as representative of the largest size class of organisms (greater than 50 µm in size), and phytoplankton abundance was evaluated on par with organisms in the 10 – 50 µm size class. While these substitutions are not accurate in all instances (e.g. zooplankton species may be less than 50 µm in size), they were used solely for the purpose of this report and are not applicable to vessel compliance verifications.

One challenge associated with the assessment of the bacteria and virus standards is that methods exist to quantify bacteria and viruses (or virus-like particles) in a sample of ballast water, however, no techniques are available to assess the viability of all bacteria and viruses, as is required by the California performance standards (see Dobroski et al. 2009a, Appendix A1 for discussions on this topic). To assess compliance with the bacterial standard, Commission staff used a representative group of organisms (culturable, aerobic, heterotrophic bacteria – hereafter culturable heterotrophic bacteria) to quantify potential compliance with the bacterial standard. Culturable heterotrophic bacteria were selected as a representative for the total bacterial concentration because, unlike total bacteria, there are reliable, widely-accepted standard methods to both enumerate and assess viability of these organisms.

Culturable heterotrophic bacteria are a well-studied group of bacteria, and research is being conducted to examine the relationship between their populations and the larger pool of bacterial species (Dobbs, F., pers. comm. 2008). Staff examined the ability of treatment system to reduce culturable heterotrophic bacteria to levels within the California standard of 1000 bacteria (in this case expressed as colony-forming units (CFU)) per 100 ml of ballast water. At an advisory panel meeting in 2008, panel members debated whether the culturable heterotrophic bacteria – a subset of all bacteria species - should be held to a different standard than that written in the law (see Dobroski et al. 2009a, Appendix C for discussion). Because culturable heterotrophic bacteria represent only a portion of the total population of bacteria (Giovannoni et al. 2007), it was argued that they should be held to a standard in proportion to their relative abundance in nature (for example if heterotrophic bacteria represent 10% of the total population of bacteria, the standard for assessment using this proxy group might be more appropriate if set at 10% of 1000/100 ml or 100 CFU/100 ml). However, this approach to setting a standard requires the selection of a uniform method to culture and quantify bacteria in order to assess the percent of culturable bacteria relative to the total population of all bacteria. Based on techniques available in 1990, culturable bacteria represented 1/10,000th of the total bacterial community present in seawater (Giovannoni et al. 2007). Newer techniques have allowed scientist to culture anywhere from two to sixty percent of bacterial cells in a given water body (Giovannoni et al. 2007). Until such time that a scientific authority clearly establishes the percent composition of culturable heterotrophic bacteria in marine or freshwater, Commission staff will continue to analyze all data using best available techniques and the numerical standard found in the law.

Analysis of viruses remains challenging at this time. While several representative organisms exists for viruses, their relationship to the greater population of all viral species is more tenuous than for bacteria (confer Culley and Suttle 2007). For the purposes of this analysis, Commission staff believes that no widely accepted technique is available to quantify or reliably estimate virus concentrations, and thus systems were not evaluated for compliance with the viral standard. Staff will continue to monitor the development of new assessment techniques for all organism size classes and incorporate them into future technology assessment reports.

Taking into account the limitations of the available data, staff determined the potential for treatment systems to comply with California's performance standards using two approaches. The first assessment approach, presented in Table VI-1, provides a broad review of the data on system performance from both land-based and shipboard testing. The second assessment approach, presented in Table VI-3, takes a closer look at the performance, specifically the success rate of those systems at demonstrating potential to meet California's standards.

In the first broad-scale assessment (presented in Table VI-1), staff accepted one test (averaged across replicates) with data less than the standard as indicative of a system's **potential** to comply with that standard. While this criterion is optimistic, it does highlight the rapid and encouraging development of treatment technologies. This approach is slightly more stringent than that taken in previous reports (Dobroski et al. 2007, 2009a) when systems were only required to meet the standard in one test replicate in order to demonstrate potential compliance. Because of this change in approach, and because laboratory data is no longer included in this analysis, readers should be cautioned against comparing the results in Table VI-1 in this report with table(s) in previous reports.

Systems with at least one test (averaged across replicates) at either land-based or shipboard scale in compliance with the performance standard are scored with a "Y" for having demonstrated the **potential** to comply with California's standards (Table VI-1). Efficacy data with no tests demonstrating potential compliance with the standards are scored with a "N." Systems that presented data for a given size class in metrics not comparable to the standards (e.g. as percent reduction instead of organism concentration) are classified as "Unknown." Cells with hashing indicate lack of available data. The source(s) of the data for each system can be found in the Literature Cited section. See Appendix A for all laboratory data and for specifics about land-based and shipboard testing including number of tests and replicates for each system.

Table VI-1. Summary of systems with available results for assessment of efficacy
Systems with at least one land-based or shipboard test (averaged across replicates) in compliance with the performance standards are denoted by a “Y.”Non-compliance is denoted by a “N,” and those systems with data in metrics not directly comparable to the performance standards were designated as “Unknown.” A cell with hashing indicates that no data was available. Information about systems having only lab-scale data is provided in Appendix A.

Manufacturer	> 50 µm	10 - 50 µm	< 10 µm (bacteria)[1,2]	*E. coli*	Enterococci	*V. cholerae*	References[3]
21st Century Shipbuilding							Lab data only
Alfa Laval	Y	Y	Y	Y	Y	Y[4]	137,138,141
Aquaworx ATC GmbH							
atg UV Technology							
ATLAS-DANMARK							
Auramarine Ltd.	Y	N	N	Y[4]	Y	Y[4]	4,165
Brillyant Marine LLC							
Coldharbour Marine							
COSCO/Tsinghua Univ.							
DESMI Ocean Guard A/S							
Ecochlor	Y	Y	Y	Y	Y	Y[6]	76,133,148
EcologiQ							
Electrichlor							
ETI		N	N				73,74,75
Ferrate Treatment Tech.							Lab data only
~~Hamann Evonik Degussa~~[5]	~~Y~~	~~Y~~	~~Y~~	~~Y~~[4]	~~Y~~[4]	~~Y~~[4]	132,166
Hamworthy Greenship	Y	Y	Y	Y[4]	Y[4]	Y[6]	48,167
Hi Tech Marine	N	Unknown	Y	Y			32,51
Hitachi/Mitsubishi							
Hyde Marine	Y	Y	Y	Y[4]	Y[4]	Y[4]	134,192
Hyundai Heavy Ind. (1)							Lab data only
Hyundai Heavy Ind. (2)							Lab data only
JFE Eng.Corp./TG Corp.							
Kwang San Co. Ltd.							Lab data only

[1] Bacteria were assessed through examination of aerobic culturable heterotrophic bacteria (expressed as colony-forming units).
[2] No methods exist to quantify and assess the viability of viruses at this time.
[3] Numbered references can be found in Literature Cited section.
[4] Concentration at intake was zero, non-detectable or unknown.
[5] Hamann system has been temporarily removed from the market due to toxicity concerns (effective 1/31/10).
[6] *Vibrio* testing conducted on live cultures in a lab.

Table VI-1 (contined). Summary of systems with available results for assessment of efficacy
Systems with at least one land-based or shipboard test (averaged across replicates) in compliance with the performance standards are denoted by a “Y.”Non-compliance is denoted by a “N,” and those systems with data in metrics not directly comparable to the performance standards were designated as “Unknown.” A cell with hashing indicates that no data was available. Information about systems having only lab-scale data is provided in Appendix A.

Manufacturer	> 50 µm	10 - 50 µm	< 10 µm (bacteria)[1,2]	*E. coli*	Enterococci	*V. cholerae*	References[3]
MAHLE							
MARENCO	Y	N	Y				64,65,189
Maritime Solutions Inc.	N	N	Y	Y	Y	Y[4]	79
Mexel Industries							
MH Systems							Lab data only
Mitsui Engineering	N	Unknow n	Unknow n	Unknow n	Unknow n	Unknow n	56,58,59
NEI	Y	Unknow n	N	Y[4]	Unknow n	Y[4]	170,171,172
NK Co. Ltd.							
ntorreiro							
Nutech 03 Inc.	Y	N	Y	Y[4]	Y[4]	Y[4]	50,195
OceanSaver	Y	Y	Y	Y[4]	Y[4]	Y[4]	139,176
OptiMarin	Y	Y	Y	Y[4]	Y[4]	Y[4]	136,140
Panasia Co. Ltd.							
Pinnacle Ozone Solutions							
Qingdao Headway Tech.	Y	Y	Y	Y[4]	Y[4]	Y[4]	142,147
Resource Ballast Tech.	Y	N		Y	Y	Y[4]	2,3
RWO Marine Water Tech.	Y	Y		Y	Y	Y[4]	30,31
Severn Trent DeNora[5]	Y	Y	Y				49
Siemens	N	N	N	Y	Y	Y[4]	78
Sunrui CFCC							
Techcross Inc.	Y	Y	Y	Y[4]	Y[4]	Y[4]	62,63
Wartsila							

[1] Bacteria were assessed through examination of aerobic culturable heterotrophic bacteria (expressed as colony-forming units).
[2] No methods exist to quantify and assess the viability of viruses at this time.
[3] Numbered references can be found in Literature Cited section
[4] Concentration at intake was zero, non-detectable or unknown.
[5] System has added a filter since this data was collected.

Twenty-one treatment systems were reviewed for potential compliance with California's performance standards (Table VI-1). One system, produced by Hamann Evonick Degussa, was pulled from the market in January of 2010 due to toxicity concerns (see de Lafontaine et al. 2008, 2009 for toxicity data). The system's performance data and references are included in Tables VI-1, VI-3, VI-5 and VI-6 of this report for readers to examine. However, because it is currently not a practical option for installation on vessels, it is excluded from narratives and other tables that summarize the potential (efficacy) and availability of systems to meet California's standards.

In the largest organism size class (organisms greater than 50 µm in size), land-based or shipboard data was available for 20 systems, and 15 demonstrated the potential, in at least one test (averaged across replicates), to meet the required standard of no detectable living organisms in discharged ballast water (Table VI-2, Appendix A1). In the 10 – 50 µm size class, 21 systems were reviewed and 10 systems had at least one test that indicated compliance with the standard of less than 0.01 living organisms per ml (Appendix A2).

Table VI-2. Summary of potential treatment system performance (land-based and/or shipboard) with respect to California performance standards

	Organisms Greater than 50	**Organisms 10 – 50**	**Organisms less than 10 (bacteria)[1]**	***Escherichia coli***	**Intestinal enterococci**	***Vibrio cholerae***
Total # Systems with Data Available [2]	20	21	19	18	17	17
Number Systems with Potential to Meet Standard[3]	15	10	13	16	14	15

[1] Bacteria examined using culturable heterotrophic bacteria.
[2] Of out of the 46 total systems assessed in this report, only 27 had testing results available for review, and 21 of those provided results of land-based and/or shipboard testing. Not all 21 covered testing under each of the organism size classes. The total number of systems with results in a given size class is indicated in this category.
[3] This category reflects the number of systems with at least one test (averaged across replicates) demonstrating the potential to comply with the California performance standard (see Table III-1 for standards).

The results of analyses for human health indicator species (*Escherichia coli*, intestinal enterococci and *Vibrio cholerae*) and organisms less than 10 µm (bacteria) are encouraging (see Table VI-2, Appendices A3-A6). Most treatment systems are succeeding in killing human health indicator species. Eighteen systems provided results of *E. coli* concentration in treated ballast water (Appendix A3), and 16 demonstrated potential compliance. Seventeen systems tested for the presence of intestinal enterococci, and fourteen systems demonstrated potential compliance. (Appendix A4).

The low, and sometimes non-detectable, natural concentration of *Vibrio cholerae* in coastal waters makes it difficult to adequately assess system performance at eliminating this species. In land-based and shipboard data examined for this evaluation, the ambient pre-treatment concentrations of *Vibrio cholerae* were frequently so low they could not be detected, or were not reported (see footnote 4 in Table VI-1). In such cases, post-treatment data did not necessarily demonstrate a system's ability or inability to kill the microbe. Those systems that conducted laboratory analysis for *Vibrio cholerae* examined the efficacy of systems at treating live cultures (spiked concentrations) of *Vibrio* that would otherwise not be naturally present in waters used for land-based or shipboard testing. Such laboratory data provides as much, if not more insight into systems' ability to kill *Vibrio* as does data from land-based or shipboard tests. Thus, the evaluation of *Vibrio* data here included results from two laboratory studies (as noted in Table VI-1 and Appendix A5). Seventeen systems examined treated ballast water for toxicogenic *Vibrio cholerae,* and fifteen systems demonstrated potential compliance with the California performance standard (Appendix A5).

Lastly, available data was analyzed for compliance with the bacterial standard of 1000 bacteria or CFU per 100 ml (Table VI-1, Appendix A6). Nineteen systems analyzed system performance at treating culturable heterotrophic bacteria, and 13 demonstrated potential compliance with the standard. As described earlier in this section, methods are not available to assess compliance with the viral standard at this time.

Based on this first assessment approach, eight ballast water treatment systems have demonstrated the **potential** to comply with California's performance standards. These systems are Alfa Laval, Ecochlor, Hamworthy Greenship, Hyde Marine, OceanSaver, OptiMarin, Quingdao Headway Tech., and Techcross Inc. These eight systems have at least one test (averaged across replicates) that can meet each of California's performance standards, excluding the viral standard. Though data for the Hamann Evonik Degussa system also demonstrate the potential to meet California's performance standards using this first assessment approach, the system was pulled from the market in early 2010 and is currently not a viable option for use on ships.

Passage of a single land-based or shipboard test may not be sufficient as a sole indicator for which systems will or will not comply with California's standards when operated under the variable conditions present on vessels. This analysis does, however, provide a good summary of the development status of treatment systems, and this information should be used by stakeholders to further investigate treatment systems that may comply with California's performance standards. A positive assessment for the purpose of this report, however, does not constitute Commission approval or endorsement, nor does it relieve the vessel owner/operator of the responsibility for complying with California's performance standards for the discharge of ballast water. Potential treatment system customers should consult extensively with vendors to ensure that thorough system verification work has been conducted, and that the system is appropriate for the type of vessel of interest, under normal ballasting conditions.

A second, more rigorous assessment approach takes a closer look at the performance rates of those systems with available land-based and shipboard data (Table VI-3). The assessment presents the available data in fraction form, with the number of tests that demonstrated potential compliance with California's standards in the numerator, and the total number of tests in the denominator. This more detailed presentation provides the opportunity to discriminate between systems that have demonstrated higher rates of potential compliance versus those that may need to undergo additional testing or development to consistently meet California's performance standards.

Table VI-3. Detailed analysis of system performance at land-based (Land) and shipboard (Ship) testing scales. Data presented as number of tests that have demonstrated potential to meet standard/total number tests conducted. References for each system are listed in Table VI-1.

	>50		**10 - 50**		**<10 (bacteria)**		***E. coli***		**Enterococci**		***Vibrio***	
	Land	**Ship**	**Land**	**Ship**	**Land**	**Ship**	**Land**	**Ship**	**Land**	**Ship**	**Land**	**Ship**
Alfa Laval	8/10	1/4	3/10	1/4	0/8	2/2	10/10	4*/4	10/10	4*/4	10*/10	4*/4
Auramarine	4/6	--	0/7	--	0/2	--	1*/1	--	1/1	--	1*/1	
Ecochlor	8/15	1/1[1]	9/11	1/1[1]	8/11	1/1[1]	10/10	1/1[1]	11/11	--	(1/1 lab)	Unk
ETI			0/3	--	0/3	--	--	--	--	--	--	--
Hamann[2]	*16/19*	*4/5*	*17/18*	*0/5*	*1/13*	*3/4*	*12/12*	*4*/4*	*12/12*	*4*/4*	*1*/1*	--
Hamworthy	5/5	--	3/5	--	2/5	--	5*/5	--	5*/5	--	(2/3 lab)	
Hi Tech	--	0/2	--	Unk	5/6	--	6/6	--	--	--	--	--
Hyde	1/10	3/3	0/10	1/3	5/10	3/3	10*/10	3*/3	10*/10	3*/3	--	3*/3
MARENCO	3/4	--	0/1	--	2/3	--	--	--	--	--	--	--
MSI	0/5	--	0/5	--	3/5	--	5/5	--	5/5	--	5*/5	--
Mitsui	0/4	0/1	Unk	Unk	Unk	Unk	Unk	--	Unk	--	Unk	--
NEI	1/5	1/2	0/1	Unk	0/2	0/2	0/1	2*/2	0/1	Unk	--	2*/2
Nutech	0/3	2/3	0/2	0/3	3/3	2/2	--	3*/3	--	3*/3	--	3*/3
OceanSaver	2/14	1/3	5/14	0/2,Unk	5/5	--	14*/14	3*/3	9*/14	3*/3	14*/14	3*/3
OptiMarin	8/12	0/8	6/12	2/8	2/12	--	12*/12	8*/8	12*/12	8*/8	12*/12	8*/8
Qingdao	4/13	3/3	8/13	3/3	9/13	3/3	13*/13	3*/3	13*/13	3*/3	13*/13	3*/3
RBT	3/3	0/2	0/3	0/2	--	--	3/3	2*/2	--	2/2	3*/3	2*/2
RWO	2/2	--	1/2	--	--	--	2/2	--	2/2	--	2/2	--
Severn Trent	3/5[1]	--	2/5[1]	--	4/4[1]	--	--	--	--	--	--	--
Siemens	0/3	--	0/3	--	0/3	--	3/3	--	3/3	--	3*/3	--
Techcross	8/11	3/3	9/11	3/3	4/4	Unk	10*/10	3*/3	11*/11	2*/2	11*/11	3*/3

* Concentration at intake was zero, non-detectable or unknown.
[1] Vendor has added a filter since system testing was conducted.
[2] The Hamann system was removed from the market (effective 1/31/10).

The data presented in Table VI-3 are highly variable. Some systems reliably meet the standards during land-based testing, but fail to do so during shipboard testing. The reverse is also true. Others have demonstrated the potential to meet the standards in 100% of tests, but have only undergone one or two tests. As described earlier, much of the performance data for human health indicator species was collected when the initial pre-treatment concentration of microbes, particularly *Vibrio cholerae,* was zero, non-detectable or unknown. The IMO G8 Guidelines do not require testing organizations to "spike" testing water with microbes due to safety concerns. Testing can proceed in the absence of natural populations of these species. However, the conclusions drawn from these tests may be of questionable value because they do not demonstrate how effectively a system may eliminate such microbes under detectable concentration conditions. Conversely, data from laboratory tests that spike water with microbes before treatment provide valuable insight to the efficacy of systems to kill bacteria, *E. coli*, intestinal enterococci, and/or *Vibrio cholerae*.

In order to determine if systems are available to meet California standards on a consistent basis, Commission staff reviewed the data (Table VI-3) for systems that have conducted three or more tests per standard (land-based or shipboard) and have demonstrated the potential to meet each of the CA standards at least 50% of the time. Two treatment systems – Qingdao Headway Tech. and Techcross - meet these more rigorous criteria. Qingdao demonstrated the potential to meet California's standards in all shipboard tests (see Table VI-3), and Techcross demonstrated the potential to meet California's standards more than 70% of the time for all land-based tests. One additional system – Ecochlor – met the standard over 50% of the time for all organism classes during land-based testing, but was only tested once for *Vibrio cholerae* in the laboratory. Though this does not meet the more rigorous criteria of three tests or more, the laboratory test did involve evaluating system efficacy under spiked concentrations of *Vibrio* above levels present in the pre-treatment tests of other systems. As noted earlier, such laboratory testing provides as much, if not more insight into a system's ability to kill *Vibrio* as does data from land-based or shipboard tests. Thus, the

Commission believes Ecochlor system also shows potential to meet California's standards under this more rigorous assessment.

Overall, this review of system performance indicates that progress is being made in the development of treatment systems to meet California's performance standards for the discharge of ballast water. Eight systems have demonstrated the potential (in at least one test) to meet California's performance standards (Table VI-1). A more stringent review indicates that two systems have demonstrated the potential to meet California's standards greater than 70% of the time over multiple tests. A third system meets all but the *Vibrio* standard greater than 50% of the time over multiple tests. However, that system did met the *Vibrio* standard in a single laboratory test using spiked concentrations of the bacteria above the pre-treatment levels present in land-based or shipboard tests of nearly all other systems. Thus, this third system also shows potential to meet California's standard using the more stringent assessment approach. No system has yet met California's standards 100% of the time for both land-based and shipboard testing. As noted repeatedly throughout this document, evaluations in this report do not constitute endorsement, approval, or guarantee that a ballast water treatment system will meet California's standards for all vessels and all scenarios. The Commission does not have the authority to approve treatment systems.

Commission staff have consulted with the vendors of systems that have demonstrated the potential to comply with California's standards, and at this time, two vendors (Ecochlor and Qingdao Headway Tech.), are willing to self-certify that their systems will meet California's standards. California does not require this certification for operation in California waters, but this certification may help assuage some concerns by vessel owners/operators about the availability of systems for use. Ultimately, however, vessel owners/operators must closely scrutinize the available data to ensure that systems will meet California's standards on a regular basis given the configuration of the vessel, piping/water flow requirements, normal transit routes and water quality conditions.

Availability

Many factors play into system availability including industry demand (i.e. how many ships need to buy systems) and commercial availability (i.e. are there enough systems being sold to meet industry demand). Of the eight systems that demonstrated the potential to meet California's standards, all eight are commercially available at this time (see Lloyd's Register 2010). As noted in the efficacy section, the Hamann Evonik Degussa system was pulled from the market in 2010 due to toxicity concerns. It is more difficult to gauge how many vessels with a ballast water capacity greater than 5000 metric tons will be built that will need to purchase systems for the implementation of the standards in 2012. As shown in Figure VI-1, the majority the vessels calling on California ports have a total ballast water capacity of greater than 5000 MT.

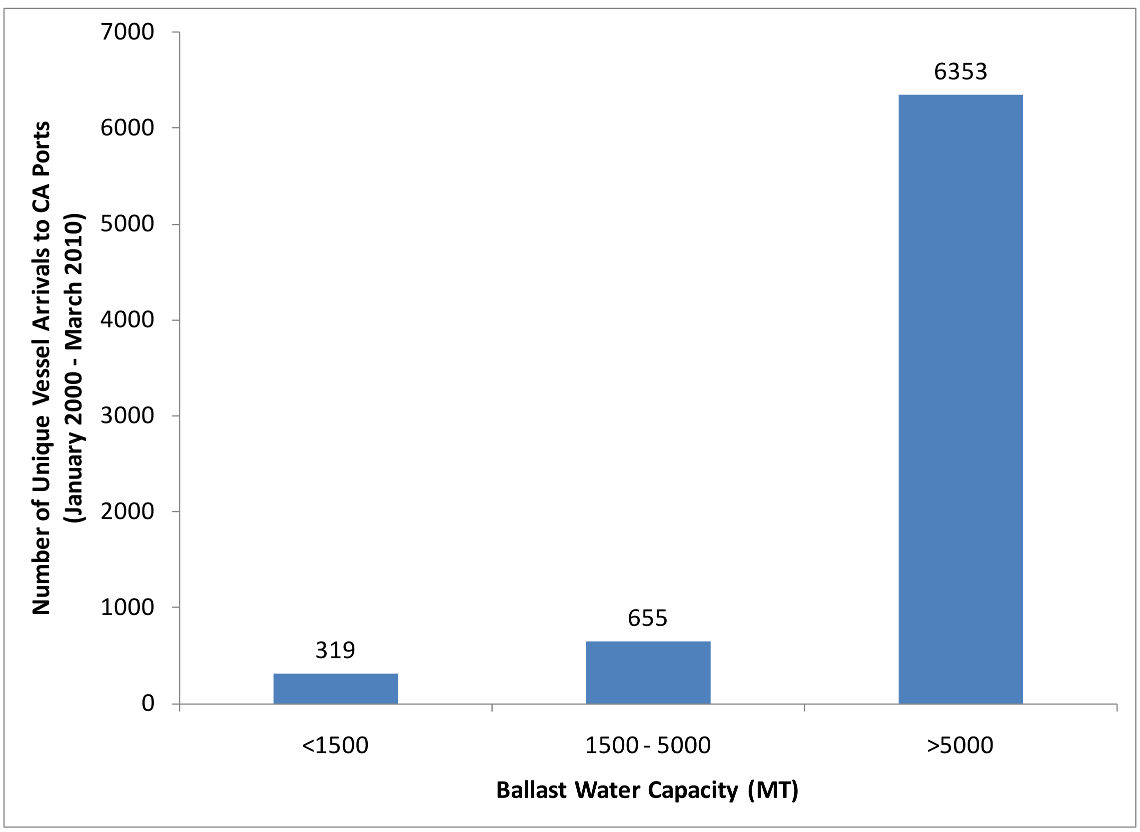


Figure VI-1. Number of unique vessels that arrived to California ports between January, 2000 and March, 2010 as a function of ballast water capacity (MT).

Between January 2000 and March 2010, 6353 unique vessels with a ballast water capacity greater than 5000 MT arrived at California ports (Figure VI-1). Presuming a

20-year vessel replacement cycle (Reynolds, K., pers. comm. 2010), approximately 5% (=318) of these 6353 vessels may be replaced by new vessels and be required to meet the performance standards in 2012. As only 20% of vessels, on average, discharge ballast in California waters (Falkner et al. 2007), an even smaller number of vessels (~ 64) will likely require treatment system usage. Distributed among the eight treatment systems that have demonstrated the potential to comply with California's performance standards and are commercially available, that equates to about eight systems per treatment vendor. That number would certainly fall within treatment system manufacturing capabilities. For example, Alfa Laval sold over thirty treatment systems in the last year (Marinelink 2010). However, caution should be made in interpreting these statistics, as the number of vessels in production and visiting California waters may vary based on economic conditions, and not all treatment systems are equally appropriate for all vessels.

System support is as important as commercial availability. Following installation, system developers will need to have personnel and infrastructure in place to troubleshoot and fix problems that arise during system operation. Maritime trade is a global industry, and vessel operators will need to have global support for onboard machinery. The Lloyd's Register (2010) report does not address the issue of after-purchase support of systems. The initial influx of systems into the marketplace will no doubt challenge developers to provide adequate service. Larger companies entrenched in the maritime logistics or equipment industries may already be prepared to respond to technological challenges and emergencies as they arise, but smaller ballast water treatment vendors may face an initial period to ramp-up service and access to replacement parts. Vendors claim that service will be available worldwide. Only time will tell, however, how well existing support networks can deal with this influx of new machinery, and if system support services will be adequate as California's performance standards are implemented for vessels with a ballast water capacity greater than 5000 MT in 2012.

While commercial availability and industry demand are two important components of this assessment of availability, the specific purpose of this report is to assess the availability of ballast water treatment systems for newly built vessels with a ballast water capacity greater than 5000 metric tons. The 2009 technology assessment report (see Dobroski et al. 2009a) did not specifically address the capacity of systems to treat large volumes of water – as will be necessary for this upcoming largest size class of vessels.

Systems must be able to treat all ballast on a vessel prior to discharge. For systems that treat on uptake and/or discharge - which includes all of the systems that have demonstrated the potential to meet California's standards (Table VI-4) – the total volumetric capacity of the vessel is not the determining factor. Instead, the treatment system must be able to keep pace with the flow rate of the vessel's ballast water pumps. Commission staff analyzed data on the number of ballast water pumps and the maximum pump rates for the fleet of vessels that call on California ports. It is difficult to pinpoint an average system treatment rate necessary for these vessels because, depending on a vessel's piping configuration, a vessel may need one system per pump or one system to treat water coming in or out from all pumps. Figures VI-2 and VI-3 illustrate the range of ballast water pump rates on vessels with a ballast water capacity of greater than 5000 MT that operate in California waters. The figures include both vessels that have discharged and have not discharged ballast in California waters, because all vessels have the potential to discharge ballast at some point either due to cargo operations or safety concerns. Figure VI-2 shows the maximum single pump rate per vessel, and Figure VI-3 shows the maximum combined pump rate per vessel.

Table VI-4. System Capacity and Timing of Treatment for Systems that Have Demonstrated Potential to Meet California's Performance Standards

System Manufacturer	Timing of Treatment	Maximum System Capacity
Alfa Laval	Uptake and Discharge	2500 m^3/h
Ecochlor**	Uptake	Unlimited (>13000 m^3/h)
Hamworthy Greenship	Uptake	1000 m3/h per pump
Hyde Marine	Uptake and Discharge	6000 m^3/h
OceanSaver	Uptake	Unlimited (>6000 m^3/h)
OptiMarin	Uptake and Discharge	3000 m^3/h
Qingdao Headway Tech.**	Uptake and Discharge	4500 m^3/h
Techcross**	Uptake and Discharge	Unlimited (>5000 m3/h)

**Demonstrated potential to meet California's standards under more rigorous evaluation criteria: Showed potential more than 50% of the time in 3 or more tests.

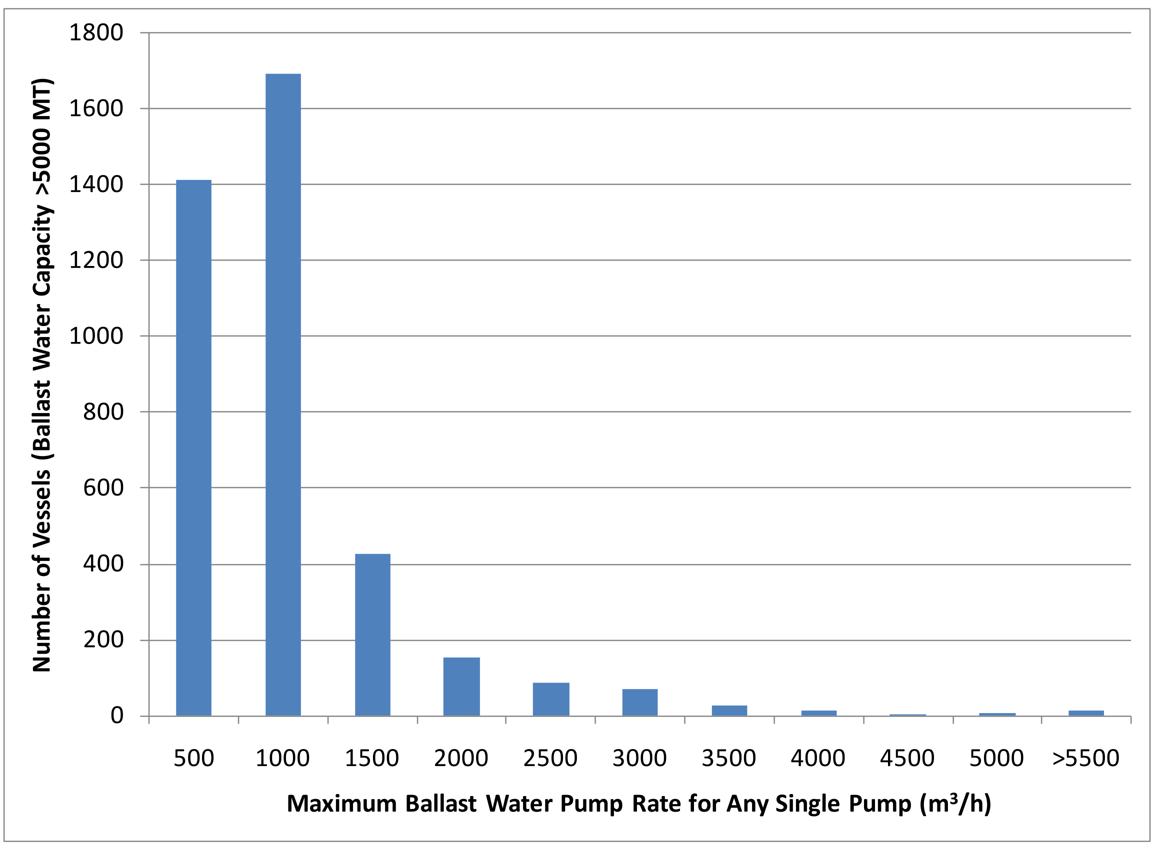


Figure VI-2. Histogram of number of vessels with a total ballast water capacity greater than 5000 MT that have visited California ports and their maximum ballast water pump rate for any single pump (m^3/h).

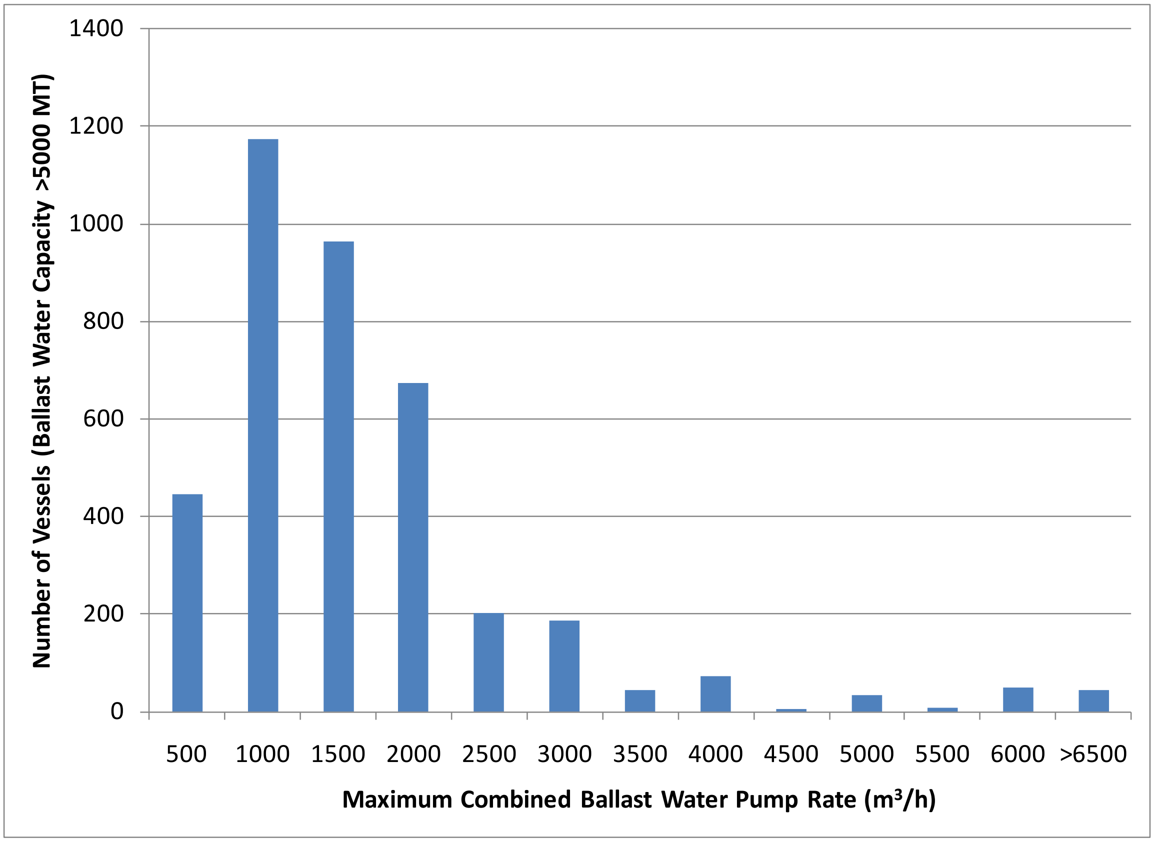


Figure VI-3. Histogram of number of vessels with a total ballast water capacity greater than 5000 MT that have visited California ports and their maximum combined ballast water pump rates (m^3/h).

Taking into account both single and combined pump rates, the majority of vessels operating in California waters will need treatment systems that operate at rates between 250 and 3000 m^3/h. A closer look at vessel pump rates reveals that treatment systems with a maximum rate of 2000 m^3/h will accommodate over 80% of those vessels with a ballast water capacity of greater than 5000 MT that operate in California waters. Based on vendor supplied data (Table VI-4), seven of the treatment systems that have demonstrated the potential to meet California's performance standards are commercially available and are able to treat ballast water at a rate of 2000 m^3/h. All three of the systems that show potential for meeting the standards under the more rigorous consistency criteria can accommodate much higher pump rates of 4500 m^3/h or more. Many systems are modular, and vendors note that systems can be combined to accommodate a wide variety of flow rates. Therefore vessel owners and operators should consult with treatment vendors to determine if systems are available to treat the appropriate flow rates given the piping and tank configurations of each vessel.

For systems that do not treat on uptake and/or discharge, total ballast water capacity, and not ballast pump flow rate, is the determining factor for system size. Of the 46 systems reviewed in this report, only six treat ballast in-tank during the voyage (see Lloyd's Register (2010) for additional information on timing of treatment), and none of these systems have demonstrated the potential to meet California standards. At this time there is insufficient information available to evaluate whether or not these systems will be able to accommodate the range of ballast water capacities of vessels operating in California waters. As these systems undergo additional testing, Commission staff will gather information in order to assess the ability of these systems to treat the largest size class of vessels operating in California waters.

Environmental Regulation and Impact Assessment

An effective ballast water treatment system must consistently comply with both performance standards for the discharge of ballast water and applicable environmental safety and water quality laws, regulations and permits. The discharge of treated ballast should not impair water quality so it impacts the beneficial uses of the State's receiving waters (e.g. recreation, fisheries, fish/wildlife habitat). The IMO, federal government and individual states have developed specific limits for discharge constituents and/or whole effluent toxicity evaluation procedures in order to protect the beneficial uses of waterways from harmful contaminants. Commission staff has drawn on the environmental review of ballast water treatment systems and active substance constituents from all levels of government (international, federal, state) in the assessment of environmental risk from the 46 treatment systems reviewed here.

International

As discussed in Section III (Regulatory Overview), the IMO has established an approval process through Guideline G9 for treatment technologies using active substances (i.e. chemicals) to ensure systems are safe for the environment, ship, and personnel. The

two-step process is comprised of an initial “Basic Approval” utilizing laboratory test results to demonstrate basic environmental safety, followed by “Final Approval” based upon evaluation of the environmental integrity of the full-scale system.
Guideline G9 of the Convention requires applicants to provide information identifying: 1) Chemical structure and description of the active substance and relevant chemical byproducts; 2) Results of testing for persistence (environmental half-life), bioaccumulation, and acute and chronic aquatic toxicity effects of the active substance on aquatic plants, invertebrates, fish, and mammals; and 3) An assessment report that addresses the quality of the tests results and a characterization of risk (MEPC 2008f). Systems that apply for Basic and Final Approval are reviewed by the IMO Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) – Ballast Water Working Group (BWWG) in accordance with the procedures detailed in Guideline G9. The Guideline does not address system efficacy, only environmental safety (MEPC 2008f).

Federal

Outside of the USCG’s Shipboard Technology Evaluation Program (STEP), ballast water treatment systems are not currently approved for use in compliance with federal ballast water management requirements. Consequently, there is no formal environmental impacts assessment process (like that of IMO) for ballast water treatment systems at the federal level. EPA, however, recognizes that ballast water treatment systems will be used both experimentally at the federal level and in compliance with state ballast water management requirements, and has therefore included provisions in the VGP for discharges from vessels employing ballast water treatment systems.

The effluent limits and best management practices described in the VGP are specific to those treatment systems that make use of biocides. Under the permit, all biocides that meet the definition of a “pesticide” under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA; 7 U.S. Code § 136 *et seq*.) must be registered for use with the EPA. Biocides generated onboard a vessel solely through the use of a “device” (as defined under FIFRA) do not require registration. Additionally, the permit sets a limit for

Total Residual Chlorine (TRC; instantaneous maximum = 100 µg/l) in ballast water discharge, and states that discharges of other biocides or residuals must not “exceed acute water quality criteria as listed in EPA’s 1986 Quality Criteria for Water [the Gold Book], or any subsequent revisions” (EPA 2008). Systems that use biocides or produce derivatives which lack applicable EPA Water Quality Criteria must conduct Whole Effluent Toxicity testing to determine chronic toxicity levels. Systems that do not meet the Water Quality Criteria or chronic toxicity limits may be required to cease discharging and must apply for coverage under an individual NPDES permit.

Vessels participating in the STEP must comply with the VGP and additionally conform to the environmental compliance requirements associated with STEP participation including: 1) Compliance with the National Environmental Policy Act process; 2) Due diligence by the applicant in providing requested biological and ecological information and obtaining necessary permits from regulatory agencies; and 3) A provision that systems found to have an adverse impact on the environment or present a risk to the vessel or human health will be withdrawn from the program (USCG 2006).

States

As discussed in Section III, several states established ballast water management programs and performance standards requirements through the Section 401 certification of the Vessel General Permit. This certification also provided states a mechanism to set water quality criteria for ballast water discharges. Chlorine was a toxicant of concern for many states, particularly those located on the Great Lakes. Several states chose to establish limits for Total Residual Chlorine (TRC) in ballast discharges that were substantially more stringent than the limit established by the VGP (= 100 µg/l). Massachusetts, for example, set a TRC limit of 10 µg/l in discharges from experimental treatment systems. Several states also established conditions requiring evaluation of acute and chronic impacts from treated discharges.

State of Washington

The State of Washington's evaluation of environmental impacts from the discharge of treated ballast water has proved an invaluable resource to Commission staff. The Washington State Department of Ecology developed a framework for "Establishing the Environmental Safety of Ballast Water Biocides" in 2003, and revised it in 2008 to be included as Appendix H in the *Laboratory Guidance and Whole Effluent Toxicity Test Review Criteria* manual (Washington State Department of Ecology 2008, available at http://www.ecy.wa.gov/pubs/9580.pdf). Thus far, three systems have completed toxicity testing in accordance with Washington requirements (Table VI-5).

The tests used in the Washington State framework for evaluating ballast water biocides include EPA-approved acute and sensitive life stage toxicity tests on invertebrate, fish and algal species. One ISO test on growth inhibition of a marine diatom is also required in order to be consistent with international testing requirements. If treated ballast water might be discharged more than once in the same location during a week or in sensitive marine areas in the state, then EPA chronic tests or Washington State tests using Pacific herring may also be required to determine the biocide environmental safety. The results of the toxicity testing are used to set system discharge conditions such as maximum concentration or minimum degradation time (Washington State Department of Ecology 2008).

California

California does not have a formal environmental impact evaluation process for the discharge of ballast water that has undergone treatment. Vessels that discharge in California waters must comply with the applicable provisions of the EPA's VGP including any California-specific conditions added by the State Water Resources Control Board through the Section 401 certification process. California's Section 401 certification requires that vessel discharges contain no hazardous wastes as defined in California law or hazardous substances as listed in the certification letter (see Water Board 2009). Discharges may not contain an oily sheen, noxious liquid substance residues, and detergents may not be used to disperse hydrocarbon sheens. For more information go to http://www.swrcb.ca.gov/water_issues/programs/index.shtml and review the section on vessel discharges under the clean beaches/ocean programs.

Environmental Assessment of Treatment Systems

Staff has compiled environmental assessment reports and water quality data reported to the IMO, as well as information made available to the State of Washington and Commission staff, to assess available treatment systems for potential environmental impacts to California waters. The IMO active substance approval documents, in particular, have proved to be a valuable resource to assess a treatment system's broad-scale environmental safety prior to comparison of specific system effluent constituents to the VGP and California water quality objectives.

Of the 46 treatment systems reviewed for this report, 28 use a biocide or chemical additive in the treatment process (Table VI-5), and will therefore require monitoring of discharges for chemical residuals. An assessment of the potential impacts from all possible chemicals and residuals associated with the use of these treatment technologies cannot be adequately addressed in this report and is the purview of the California Water Board and the EPA. Instead, Commission staff has focused this environmental assessment on total residual chlorine (TRC) concentrations in discharged ballast water because both the VGP and the Water Board (through the California Ocean Plan; see Water Board (2005)) have identified TRC as a particular concern due to its widespread toxicity to all organisms. Currently, California defers regulation of TRC in discharged ballast water to the EPA through the VGP. All vessels that discharge ballast in California waters must comply with the EPA VGP limit for TRC (= instantaneous maximum of 100 µg/l in discharged waters). Vendors and vessel owners/operators must consult with the Water Board and EPA to ensure that vessel discharges comply with all other applicable effluent requirements.

Table VI-5 lists the active substances and summarizes the status of environmental approvals/assessments for each of the technologies reviewed in this report. Where applicable, the available data has been analyzed to determine whether or not treated ballast would comply with the EPA water quality objective for TRC in ballast water discharge (= instantaneous maximum of 100 µg/l in discharged waters). Many systems have initiated toxicity testing of treated discharges and have applied to IMO for Basic and Final Approval. The IMO Basic Approval application, however, may include data from general literature review or laboratory analysis of system toxicity. Until such time that a system submits a full dossier of whole effluent toxicity data as required for IMO Final Approval, it will be difficult to anticipate the potential environmental impacts to California waters from the discharge of treated ballast from a fully functioning treatment system. Currently only twelve treatment systems have received Final Approval from IMO (Table V-1, VI-5).

The “pesticide” registration requirement under FIFRA is one mechanism to regulate and assess the impacts to U.S. federal waters from biocide use in treatment systems. The thorough chemical safety analysis and registration process required under FIFRA has been completed by two systems - Hamann Evonik Degussa (removed from the market in 2010) and Ecochlor (Albert, R., pers. comm. 2010). FIFRA, however, does not apply to chemicals that are generated onsite and used in place (e.g. generated and used by a vessel). Most treatment systems using biocides generate that chemical through onboard electrochemical processes, and thus will not be subject to FIFRA registration. This exception provides significant room for systems to operate in U.S. waters without any kind of federal biocide regulation except as provided by the VGP, and at this time, it is uncertain how EPA will enforce the permit’s provisions.

Table VI-5. Summary of environmental assessment and approval of treatment systems
Note: Table does not address whether or not toxicity testing was performed in accordance with the EPA Vessel General Permit.

Manufacturer	Active Substance	Toxicity Testing Conducted	Environmental Related Approvals	VGP TRC Compliant? (100 ug/l)	Source
21st Century Shipbuilding	superoxide, oxygen radical,hydroxyl radical, electron, ozone	X	IMO Basic	Y	117
Alfa Laval	free radicals	X	IMO Basic and Final	Y	86,135,137
Aquaworx ATC Gmbh	n/a (UV, cavitation bubble)	X	IMO Basic	Y	111
atg UV Technology	n/a (UV)				
ATLAS-DANMARK	hyplochlorous acid, ozone, hydrogen peroxide,chlorine dioxide, hydrogen, sodium hydroxide				125
Auramarine Ltd.	n/a (UV)	X			4
Brillyant Marine LLC					
Coldharbour Marine	n/a (deoxygenation)				
COSCO/Tsinghua Univ.	n/a (UV)	X	IMO Basic		105
DESMI Ocean Guard A/S	hydroxyl radical, ozone	X	IMO Basic		115
Ecochlor	chlorine dioxide	X	IMO Basic, Rec WA Cond.[1]	Y	97,124
EcologiQ	yeast	X			6
Electrichlor	sodium hypochlorite				
ETI	ozone	X			75
Ferrate Treatment Tech.	ferrate				
Hamann Evonik Degussa[2]	Peraclean Ocean (peracetic acid, hydrogen peroxide, acetic acid)	X	IMO Basic & Final, EPA Req., Rec. WA Conditional[1]		90,132
Hamworthy Greenship	free active chlorine, total residual chlorine	X	IMO Basic and Final	Y	93,100,109
Hi Tech Marine	n/a (heat)		New South Wales EPA		175
Hitachi/Mitsubishi	triiron tetraoxide, poly aluminum chloride, poly acrylamide sodium acrylate	X	IMO Basic and Final		88,108
Hyde Marine	n/a (UV)	X			
Hyundai Heavy Ind. (1) EcoBallast	n/a (UV)	X	IMO Basic and Final		107,114
Hyundai Heavy Ind. (2) HiBallast	chlorine, bromine, sodium hypochlorite, sodium hypobromite, hypochlorous acid, hypobromous acid,	X	IMO Basic	Detection limit of tests above EPA standard	119
JFE Eng. Corp./TG Group	sodium hypochlorite	X	IMO Basic and Final	Y	100,116

Blank cells indicate that data was not available

[1] WA Dept. of Ecology Water Quality Program has recommended Conditional Approval of the system to WA Dept. Fish and Wildlife. As of the writing of this report, approval has not been granted.

[2] The Hamann Evonik Degussa system was temporarily removed from the market in 2010 due to environmental concerns regarding the toxicity of Peraclean Ocean in freshwater and cold water (see de Lafontaine et al. 2008, 2009).

Table VI-5 (continued). Summary of environmental assessment and approval of treatment systems
Note: Table does not address whether or not toxicity testing was performed in accordance with the Vessel General Permit

Manufacturer	Active Substance	Toxicity Testing Conducted	Environmental Related Approvals	VGP TRC Compliant? (100 ug/l)	Source
Kwang San Co. Ltd.	Cl_2, hypochlorous acid, hypobromous acid, sodium hypochlorite, sodium hypobromite	X	IMO Basic	Detection limit of tests above EPA standard	120
MAHLE Ind. GmbH	n/a (UV)				
MARENCO	n/a (UV)				
Maritime Solutions Inc.	n/a (UV)				
Mexel Industries	yes, unknown				
MH Systems	n/a (deoxygenation)				
Mitsui Engineering	ozone	X	IMO Basic	N	84,104,114
NEI	n/a (deoxygenation)	X			11
NK Co. Ltd.	ozone, total residual oxidant	X	IMO Basic and Final	Y	98,106,114
ntorreiro	yes, unknown				
Nutech 03 Inc.	ozone	X		N	195
OceanSaver	free and total residual oxidant	X	IMO Basic and Final	Y	95,101,146
OptiMarin	n/a (UV)	X		Y	136
Panasia Co.	n/a (UV)	X	IMO Basic and Final	Y	91,94,110
Pinnacle Ozone Solutions	ozone				
Qingdao Headway Tech	hydroxyl radical, hypochlorous acid, hypochlorite, hydrogen peroxide	X	IMO Basic	Y	121,126,147
Resource Ballast Tech.	ozone, hydroxyl radicals, hypochlorite	X	IMO Basic and Final	N	87,112,124
RWO Marine Water Tech.	hydroxyl radicals, free active chlorine	X	IMO Basic and Final	N	89,103,114
Severn Trent DeNora	sodium hypochlorite, sodium bisulfite	X	IMO Basic, Rec. WA Conditional[1]	Y	49,122
Siemens	sodium hypochlorite, sodium hypobromite, oxygenated species, oxygen, hydrogen	X	IMO Basic	Y	78,113
Sunrui CFCC	hypochlorite, hypobromite, chloramines, bromamines	X	IMO Basic		118
Techcross Inc.	hypochlorite, hypobromite, ozone, hydroxyl radicals, hydrogen peroxide	X	IMO Basic and Final	Y	83,96,100
Wartsila	n/a (UV)				

Blank cells indicate that data was not available

[1] WA Dept. of Ecology Water Quality Program has recommended Conditional Approval of the system to WA Dept. Fish and Wildlife. As of the writing of this report, approval has not been granted.

A system's availability for use in California waters is dependent on its ability to meet all of the EPA's and California's environmental laws, regulations and permits for vessel discharges - not simply the performance standards. While it is the purview of the EPA and the Water Board to review and regulate the effluent from treatment systems used on vessels, Commission staff is working to educate technology vendors, particularly those from foreign countries, about the EPA's water quality objectives. Staff also encourages vendors to consult with the Water Board to ensure that systems meet California's Section 401 provisions in the VGP.

As a first step towards assessing system environmental impacts, staff has attempted to compile data on TRC in treated effluent because of its broad-scale toxicity, and because so many systems use chlorine and related byproducts in the treatment process. Of the 46 systems reviewed, 21 have data available for TRC in the treated effluent. Based on the available data, 14 appear to meet the EPA VGP objective (California defers to the EPA VGP for regulation of TRC in vessel discharges) of 100 µg/L or less of TRC (Table VI-5). Of the eight systems that demonstrated the potential to meet California's performance standards for the discharge of ballast water and that are commercially available, seven have data demonstrating TRC compliance with the EPA VGP objective. The only system without TRC data, Hyde, uses a filtration/UV system that should not generate any chlorine residuals. Clearly, not all treatment systems will meet California's and EPA's stringent water quality standards. However, it is difficult to assess at this time whether systems are simply unable to meet the standards or whether additional water quality data must be gathered from operation of full-scale systems under real world scenarios. Commission staff will continue to work with the Water Board, vessel owners/operators and technology vendors to ensure that systems are tested with California and federal water quality objectives in mind and that the information is made available to interested parties.

Economic Impacts

An assessment of the economic impacts associated with the implementation of performance standards and the use of treatment technologies requires consideration not only of costs connected with the purchase, installation and operation of treatment systems, but also the costs of NIS introductions if performance standards are not met. As discussed in the Introduction (Section II), the U.S. has suffered major economic losses as a result of attempts to control and eradicate NIS (aquatic and terrestrial; Carlton 2001, Lovell and Stone 2005, Pimentel et al. 2005). NIS can also cause direct economic losses by reducing yield (i.e. aquaculture), reducing the value of commodities, increasing health care costs, or by reducing tourism-based revenues. For example, evidence strongly indicates that a toxogenic strain of *Vibrio cholera* was transported via ships from South America to the U.S. Gulf coast in 1991, resulting in the closure of Mobile Bay (Alabama) shellfish beds. Economic damages for the short-term localized closure are estimated at over $700,000 (Lovell and Drake 2009). Prince Edward Island oyster operations in Canada lose approximately $1.5 million annually due to mortality caused by the nonindigenous seaweed *Codium fragile* (Colautti et al. 2006). The rate of new introductions is increasing (Cohen and Carlton 1998, Ruiz and Carlton 2003) which suggests that economic impacts will likely increase as well.

California had the largest ocean-based economy in the U.S. in 2004, ranking number one for employment, wages and gross state product (NOEP 2010a). California's natural resources contribute significantly to the coastal economy. For example, in 2007 total landings of fish were over 380 million pounds, valued at more than $120 million (NOEP 2010b). Squid, the top revenue-generating species in 2007, brought in almost $30 million (NOEP 2010b). Millions of people visit California's coasts and estuaries each year, spending money on recreational activities that are directly related to the health of the ecosystem. Annually, over 150 million visits are made to California's beaches: approximately 20 million for recreational fishing, over 65 million for wildlife viewing, and over 5 million for snorkeling or scuba diving (Pendleton 2009). Direct expenditures for recreational beach activities alone likely exceed $3 billion each year (Kildow and Pendleton 2006). In total, the tourism and recreation industries accounted for almost $12 billion of California's gross state product in 2004 (NOEP 2007). NIS pose a threat to these and other components of California's ocean economy including fish hatcheries and aquaculture, recreational boating, and marine transportation.

The use of ballast water treatment technologies to combat NIS introductions will involve economic investment on the part of ship owners. This investment reflects not only initial capital costs for the equipment and installation, but also the continuing operating costs for replacement parts, equipment service and shipboard energy usage. Cost estimates are strongly linked to vessel-specific characteristics including ballast water capacity, ballast pump rates and available space. Additionally, the retrofit of vessels already in operation (existing vessels) with ballast water treatment technologies may cost significantly more than installation costs for newly built vessels due to: 1) The necessity to rework existing installations (plumbing, electric circuitry); 2) Non-optimal arrangement of equipment that may require equipment be broken into pieces and mounted individually; 3) Relocation of displaced equipment; and 4) Time associated with lay-up (Reynolds, K., pers. comm. 2007). Nonetheless, the use of these treatment technologies will help minimize or prevent future introductions of NIS and relieve some of the future economic impacts associated with new introductions.

Many treatment technology vendors are hesitant to release costs because system prices still represent research and development costs and do not reflect the presumably lower costs that would apply once systems are in mass production. In the 2010 Lloyd's Register report, only 22 of 41 technologies profiled provided estimates of system capital expenditures (equipment and installation) and half (20) provided estimates of system operating expenditures (parts, service, and energy usage; Table VI-6). Commission staff has also acquired some data on capital and operating costs. Capital expenditure costs are dependent on system size. A 200 cubic meters per hour (m^3/h) capacity system may require an initial capital expenditure between $20,000 and $630,000 with an average cost of $291,000 (Lloyd's Register 2007, Lloyd's Register 2010, Commission data from technology vendors 2007-2008) – down $96,500 from 2009 (see Dobroski et al. 2009a). A 2000 m^3/h capacity system ranges from $50,000 to $2,000,000 with an average cost of $892,500 per system (Lloyd's Register 2007, Lloyd's Register 2010, Commission data from technology vendors 2007-2008). The average cost of the large capacity systems has not changed since Dobroski et al.

(2009a). Operating costs range from negligible, assuming waste heat is utilized, to $1.50 per m^3 with an average of $0.07 per m^3 (Lloyd's Register 2007, Lloyd's Register 2010, Commission data from technology vendors 2007-2008) – down $0.06 per m^3 since 2009 (see Dobroski et al. 2009a).

Treatment systems will likely increase the cost of a new vessel by 1-2%. For example, a new 8200 TEU (twenty-foot equivalent unit) container ship built by Hyundai Samho Heavy Industries costs approximately $120 million per vessel (Pacific Maritime 2010). Installation of the most expensive treatment system currently available at $2.0 million (as indicated in Table VI-6) would increase the cost of that vessel by 1.7%. Many treatment technology developers claim that their systems will last the life of the vessel, so the capital costs for treatment systems should be a one-time investment per vessel.

While the economic investment by the shipping industry in ballast water treatment technologies will be significant, when compared to the major costs to control and/or eradicate NIS, the costs to treat ballast water may be negligible. Treating ballast water with treatment technologies will help to prevent further introductions and lower future costs for control and eradication. Additional studies will be necessary to obtain actual economic impacts associated with treating ballast water.

Table VI-6. Summary of capital and operating cost data for select treatment systems. Unless otherwise noted, source of data is Lloyd's Register (2010).

Manufacturer	Capital Expenditure *(Equipment & Installation)*			Operating Expenditure *($ per m3, unless otherwise noted)*
	200 m^3/h *($ in thousands)*	**2000 m^3/h** *($ in thousands)*	**Other** *($ in thousands)*	
21st Century Shipbuilding				
Alfa Laval				0.015[1]
Aquaworx ATC				
atg UV Technology				
ATLAS-DANMARK	180	850		
Auramarine Ltd.				0.040
Brillyant Marine LLC	300	2000		
Coldharbour Marine				
COSCO/Tsinghua Univ.				
DESMI Ocean Guard				
Ecochlor	500	800		0.080
EcologiQ			<50[1]	1 - 1.50[1]
Electrichlor	350			.019
ETI		500		cost of power
Ferrate Treatment Tech.				
~~Hamann Evonik Degussa~~				~~0.2~~
Hamworthy Greenship				
Hi Tech Marine	150	1600	16.5 – 300[1] *(equipment only)*	nil[2]
Hitachi/Mitsubishi		400		
Hyde Marine	250	1200	174 – 503[1]	<.020
Hyundai Heavy Industries (1) – Ecoballast				
Hyundai Heavy Industries (2) – HiBallast				
JFE Eng. Corp./TG Corp.				0.053
Kwang San Co. Ltd.				
MAHLE				
MARENCO	145	175		0.0006 - 0.001
Maritime Solutions Inc.				
Mexel Industries	20	50		
MH Systems	500	1500		0.06
Mitsui Engineering			100[1] *(installation only)*	0.15[3]
NEI	249	670		0.13
NK Co. Ltd.	250	1000		0.007
ntorreiro				
Nutech 03 Inc.	250	450		0.32
OceanSaver	288	1600		0.06[3]

[1] Source: Communications with technology vendors (2007-2008).
[2] Assumes waste heat utilized
[3] Source: Lloyd's Register (2007)

Table VI-6 (continued). Summary of capital and operating cost data for select treatment systems. Unless otherwise noted, source of data is Lloyd's Register (2010).

Manufacturer	Capital Expenditure *(Equipment & Installation)*			Operating Expenditure
	200 m³/h *($ in thousands)*	**2000 m³/h** *($ in thousands)*	**Other** *($ in thousands)*	*($ per m3, unless otherwise noted)*
OptiMarin	290	1280		
Panasia Co. Ltd.				
Pinnacle Ozone Solutions	200	500		0.013
Qingdao Headway Tech.				0.0018
Resource Ballast Tech.	275	700		
RWO Marine Water Tech.				
Severn Trent DeNora	630	975		0.020
Siemens	500	1000		0.0085 - 0.010
Sunrui CFCC				
Techcross Inc.	200	600		0.003
Wartsila				

[1] Source: Communications with technology vendors (2007-2008).
[2] Assumes waste heat utilized
[3] Source: Lloyd's Register (2007)

VII. DISCUSSION AND CONCLUSIONS

Ballast water treatment is an emerging and quickly expanding industry. New technologies continue to be developed and existing ones refined in search of the most effective methods to reduce and/or eliminate the spread of nonindigenous species via ballast water release. While hurdles remain for the full implementation of all of California's performance standards, significant progress has been made in the development of treatment systems since the previous technology assessment reports (see Dobroski et al. 2007, 2009a). Both the quantity and the quality of the recently received data on system performance attest to this fact.

While treatment system performance data has improved in recent years, it is important to note that systems have undergone a relatively small number of tests, under a limited range of environmental conditions. This leads to inherent uncertainty regarding treatment system performance across the spectrum of potential variables, including ship type and source water properties (e.g. temperature, turbidity, salinity). This uncertainty is likely to persist over the next several years. Commission staff believe it is unreasonable to expect that sample sizes and available data will increase adequately in the near future to demonstrate, with a high level of confidence, that treatment systems will consistently meet California's performance standards under every potential situation and under all circumstances. However, continuing to wait for such information will only serve to delay progress. Commission staff believe that, given the data currently available, multiple treatment systems have shown they can meet California's performance standards with acceptable consistency. Due to the inherent uncertainty regarding treatment system performance and evaluation, the utilization of adaptive management approach will be essential at all stages of implementation to move forward.

Like the ballast water treatment industry, the fields of treatment technology assessment and compliance verification are still evolving. Challenges remain in assessing system compliance with the standards for total bacteria and viruses standards. While there are currently widely-accepted methods for assessing viability for a subgroup of total bacteria, Commission staff believes that there are no acceptable methods for verification of compliance with the virus standard and that the Commission should proceed with assessment of technologies for the remaining six standards.

Based on the available information and using best assessment techniques, at least eight treatment systems have demonstrated the **potential** to comply with the Commission's performance standards (Table VII-1). Efficacy data for these systems indicate that at least one test met or exceeded California's performance standard for every testable organism/size category during either land-based or shipboard testing. Systems that met California's *Vibrio* standard in laboratory tests that involved spiked concentrations of the microbe above levels generally found in land- or ship-based testing were considered indicative of a system's performance at the land or shipboard scales. Three of the eight systems show the **potential** to meet California's performance standards under more rigorous evaluation criteria. These three passed more than 50% of the time over multiple tests (3 or more) at either the land or shipboard scale (Table VII-1). Additional systems are close to demonstrating the potential for meeting

California’s standards, and Commission staff are awaiting data from these tests of system performance.

Current federal law will continue to require ballast water exchange as the primary management method. Thus, in order to comply with both California and federal law, many vessels that must discharge in California will need to first exchange ballast water according to federal requirements for distance from shore and depth, and utilize a ballast water treatment system to reduce organisms to levels at or below California’s standards. Though seemingly duplicative, the execution of exchange along with or before treatment will likely serve to improve the efficacy of systems. The concentrations of organisms in the open ocean (where exchange will occur) will be lower than concentrations in nearshore areas. Since the shipboard and land-based data utilized for this report tested treatment systems with comparatively organism-rich water from nearshore areas, it is expected that system performance will be improved if open ocean exchange is conducted before treatment. Open ocean waters also generally exhibit lower levels of turbidity, organic matter, and human pathogens/pathogen indicators, which should also serve to improve system performance and reduce organism levels at discharge.

All eight of the systems that have demonstrated the potential to comply with California’ standards (see Table VII-1) are currently commercially available. Seven should be able to treat at ballast water pump rates over 2000 m^3/hr, which would accommodate over 80% of the vessels that operate in California with ballast water capacity over 5000 MT. The manufacturers of six systems attest that their products will operate at much higher pump rates. Of the three systems that show potential for meeting the standards under more rigorous consistency criteria, all can accommodate much higher pump rates of 4500 m^3/hr or more.

Table VII-1. Summary of assessment for ballast water treatment systems with potential to meet California's performance standards. **Denotes systems which demonstrated potential to meet standards more than 50% of the time over 3 or more tests. See tables V-1, VI-1, VI-3, VI-4, VI-5, VI-6, and Section VI text for more information.

System Manufacturer	Max System Capacity (Pump Rate)	General Approvals *(Non-California)*	Environmental Approvals	VGP Total Residual Chlorine Compliant	Costs		
					Initial *($ in Thousands)*		Operating *($ per m³)*
					200 m³/hr	2000 m³/hr	
Alfa Laval	2500 m³/hr	Type Approval (Norway)	IMO Basic & Final	Yes			0.015
Ecochlor**	>13,000 m³/hr	USCG STEP[1], WA Conditional[1]	IMO Basic, USCG STEP[1], WA Conditional[1]	Yes	500	800	0.080
Hamworthy Greenship	1000 m³/hr (per pump)		IMO Basic & Final	Yes			
Hyde Marine	6000 m³/hr	WA Conditional[1], Type Approval (UK), USCG STEP[1]	(UV System) USCG STEP[1], WA Conditional[1]	N/A	250[2]	1200[2]	<0.020
OceanSaver	>6000 m³/hr	Type Approval (Norway)	IMO Basic & Final	Yes	288	1600	0.06
OptiMarin	3000 m³/hr	Type Approval (Norway)	(UV System)	Yes	290	1280	
Quingdao Headway Tech**	4500 m³/hr		IMO Basic	Yes			0.0018
Techcross**	>5000 m³/hr	Type Approval (Korea)	IMO Basic & Final	Yes	200	600	0.003

[1] USCG STEP and WA Conditional approvals require that systems demonstrate levels of efficacy and environmental acceptability. Acceptance into STEP constitutes an experimental use approval that applies to the combination of one vessel and one treatment system. STEP requires compliance with the EPA Vessel General Permit, the National Environmental Policy Act, and requires vessels to obtain other applicable permits. STEP is not a Type Approval process. Washington State Conditional Approval requires data from specific laboratory and effluent toxicity tests. See text for more detail.
[2] Additional initial costs for the Hyde Marine system not noted in table are $174-503 thousand.

NOTE: These systems demonstrate the potential to meet California's performance standards, however, this does not constitute an approval or endorsement of any system. The California State Lands Commission does not have authority to approve systems.

The IMO approval pathway for systems utilizing active substances has been a resource for information about the potential environmental impacts from the discharge of treated ballast water. Overall, the number of systems that have received IMO Final Approval remains small at this time, however, and thus environmental impact analysis of whole effluent toxicity remains hampered by a lack of data. The data available on total residual chlorine concentration in treated ballast effluent makes it clear that not all systems will meet water quality standards set forth in the EPA Vessel General Permit. However, information gaps related to system impacts to receiving waters still exist. Commission staff continues to work with the Water Board to track the implementation of the Vessel General Permit in California and assess the acceptability of discharges under this new regulatory program. Ultimately, treatment vendors and vessel operators will need to consult with the EPA and the Water Board to assess the potential for water quality impacts and treatment system compliance with water quality requirements in federal and California waters.

Most of the eight treatment systems that demonstrate the potential to meet California's standards have received one or more approvals from other regulatory entities, which involve the demonstration of specific levels of efficacy and/or minimization of environmental impact. Four have received both IMO Basic and Final approval for the use of active substances. Two additional systems have received USCG STEP and Washington State Conditional approvals, which require certain levels of performance efficacy, and/or environmental toxicity testing. Available data indicate that seven systems meet the EPA VGP total residual chlorine limit, save one UV-based system which should not produce residuals (test data was not available). Though systems must ultimately meet all requirements of the US EPA and the California Water Board, in addition to California's performance standards, in order to operate in California waters, the available environmental data reviewed for this report is promising. While STEP, IMO and/or Washington Conditional approvals do not constitute authorization for use in California (California does not require these approvals nor will California provide approvals), approvals from other regulatory entities may allow operation of such systems on routes outside of California.

VIII. RECOMMENDATIONS

1. **Move forward with January 1, 2012 implementation date of California's performance standards for new vessels with a ballast water capacity greater than 5000 MT.**

   Based on the available information, the Commission recommends that the implementation of performance standards for new vessels with a ballast water capacity greater than 5000 MT proceed on January 1, 2012. This review indicates that systems are available to meet California's performance standards, and those systems will be available for use on vessels with a ballast water capacity greater than 5000 MT. Commission staff is developing verification procedures to assess vessel compliance with the performance standards, and is working closely with the shipping industry and treatment vendors to ensure a smooth transition to the new standards. The Commission intends to proceed with the implementation of the standards as set forth in statute and in regulation. Staff will conduct another assessment of available treatment technologies by July 1, 2012 in anticipation of the 2014 implementation date for existing vessels (those built before 2010) with a ballast water capacity of between 1500 MT and 5000 MT.

2. **Support Commission staff involvement with the development and implementation of performance standards at the federal and international levels.**

   Commercial shipping is an international industry; any single ship may operate throughout several regions of the world. Ideally, performance standards that align both at the federal and international levels are preferable to a patchwork of standards adopted by individual states. Commission staff have been working with the federal government, including the U.S. Congress, USCG and EPA, on the development of federal performance standards and treatment technology performance verification protocols. Staff participates on both the EPA ETV program Ballast Water Technical Panel and Stakeholder Advisory Panel. These panels are working with ETV program staff and the USCG to finalize the technology verification protocols for ballast water treatment systems. Additionally, due to California's role as a world leader in the implementation of ballast water management regulations, Staff has recently been invited to participate in meetings hosted by the European Union to discuss the future implementation of the IMO Convention and rules for ballast water management in European waters. Staff expects to be asked to provide information and guidance about the Commission's Marine Invasive Species Program during conferences and outreach events held throughout California, the U.S. and internationally.

The development of U.S. Federal and international policies and regulations related to performance standards frequently take place in locations outside of California (esp. Washington D.C.) and occasionally, at international venues. With ongoing prohibitions on out-of-state and out-of-country travel, Commission staff can often only participate in such discussions when it is possible to do so via teleconference. Often teleconferencing is not an option, and the development of federal or international policies simply move forward without input from California. When presentations over the telephone are possible, sound quality is poor, presentation via power point is problematic, and audience question and answer sessions are difficult. Engagement in discussion or dialogue in-person at meetings and conference is extremely effective. The Legislature is encouraged to support Commission Staff participation in such important meetings and conferences, particularly in instances where travel expenses are covered by third parties.

3. Maintain accessibility to Marine Invasive Species Program funds to address immediate research needs related to the development of methods to assess compliance with California's performance standards.

Additional research is needed to develop new techniques and refine existing methods to assess treatment system performance and verify vessel compliance with California's performance standards. Scientific methods do not currently exist to assess the viability and quantity of all living bacteria and viruses in ballast water samples. The development of these techniques is necessary for the full implementation and verification of California's performance standards. Sampling methods must balance the need for statistical confidence with practical, rapid, and relatively easy techniques for shipboard inspection. Research must be conducted to determine the most effective way of achieving adequate sampling confidence that are practicable for regulators and do not unduly burden vessel operators.

As performance standards are implemented, the need for practical and rapid onboard methods to assess compliance will quickly become critical. It is anticipated that vessels with operating treatment systems will begin arriving to the state as early as next year (2011). Though the Marine Invasive Species Program is funded through a programmatic fee and does not draw from the general fund, it has been subject to the same cuts that have applied to many California agencies. The legislature should ensure that MISP funds dedicated to priority research needs are not compromised, particularly given the current budget climate.

IX. LOOKING FORWARD

Ballast water treatment remains a burgeoning industry that will undergo significant development as the IMO, proposed federal, and California's performance standards are progressively implemented and as new vessel types are built. Staff is currently engaged with numerous activities to ensure the comprehensive implementation and enforcement of California's performance standards for the discharge of ballast water:

Staff is developing draft protocols for use by the Commission's marine safety personnel to verify vessel compliance with the performance standards. Commission staff has consulted with scientists and industry experts in order to select the best available methods for organism enumeration and viability assessment taking into account ease of use, cost effectiveness, accuracy and precision, acceptance by the scientific community, and ability to withstand legal scrutiny. The draft compliance verification protocols describe administrative inspection procedures, including review of relevant reporting forms and ballast water logs, and methods for on-site sampling of ballast water discharges. The performance standards compliance protocols will be tested on vessels over the next several months in conjunction with regular vessel inspections conducted by the Commission's marine safety personnel. This process will be challenging, as few vessels that operate in California waters have installed ballast water treatment systems or sampling ports for collection of treated discharge samples. Commission staff will seek out every possible sampling opportunity in order to refine the draft protocols in preparation for the arrival of the first vessels that must meet California's performance standards. These vessels will likely arrive in California waters in 2011.

To augment the administrative component of the ballast water inspections, Commission staff has developed two ballast water treatment technology reporting forms. These forms will require information on ballast water treatment system installation and use in California waters. This information will be valuable to the Commission's marine safety personnel as they inspect ballast water treatment systems onboard vessels. The data will also be used by Commission staff to evaluate the implementation of the performance standards in California waters. Assembly Bill 248 (Chapter 317, Statutes of 2009) provided Commission staff with the authority to develop these forms. Staff met with an advisory panel to discuss the contents of the forms before implementing the forms via the California rulemaking process. The 45-day public comment period for the rulemaking closed in March, 2010. Based on comments, staff is in the process of revising the forms which will then require an additional comment period before going to the Commission for approval. Staff expects the final forms to be approved and adopted in at the end of 2010.

Research Needs

In addition to the aforementioned activities being conducted by Commission staff to implement California's performance standards, staff is also working with scientists and industry experts to identify and address gaps in our understanding of ballast water treatment methods and system evaluation, particularly at the shipboard level. Eight systems evaluated in this report have demonstrated the potential to meet California's performance standards, but many systems still require further development and evaluation, and many have not yet been tested on vessels. The proposed USCG ballast water treatment system approval process will involve shipboard evaluation of treatment systems, and therefore vessel owners and operators must continue to make their vessels available for the shipboard testing of experimental treatment systems. A greater understanding of how treatment systems function on vessels will be particularly important as existing vessels, those built before 2010, will be retrofitted with treatment systems beginning in 2014 to comply with California's performance standards. Those technologies must be installable under limited space conditions, and must be able to integrate with the existing engineering of ships (piping, electrical, computer, etc.). Funding from state, federal and international organizations will be necessary to advance this important shipboard work.

X. LITERATURE CITED

1. Albert, R. (personal communication, 30 March 2010 and 31 March 2010)

2. Anchor Environmental. 2009. Ship based test RBT reactor phytoplankton results. CK 96/0407094/23. 10 December 2009.

3. Anchor Environmental. 2010. Efficacy testing of the RBT reactor. CK 96/0407094/23.15 April 2010.

4. AuraMarine. 2010. California Performance Information Crystal Ballast™.

5. Balasubramanian, S., J. Ortego, K.A. Rusch, and D. Boldor. 2008. Efficiency of *Artemia* cysts removal as a model invasive spore using a continuous microwave system with heat recovery. Environmental Science and Technology, 42: 9363-9369.

6. Bilkovski, R. (personal communication, 22 August 2008)

7. Bluewater Network. 2006. Treating ballast water from cruise ships at the Port of San Francisco: Options and Feasibility. 62 pp.

8. Boldor, D., S. Balasubramanian, S Purohit, and K.A. Rusch. 2008. Design and implementation of a continuous microwave heating system for ballast water treatment. Environmental Science and Technology, 42(11): 4121-4127.

9. BLG (IMO Sub-Committee on Bulk Liquids and Gases). 2008. Report to the Maritime Safety Committee and the Marine Environment Protection Committee. Annex 1 Draft MEPC Resolution – Guidelines for Ballast Water Sampling. BLG 12/17. 20 February 2008.

10. California Department of Fish and Game. 2008. Quagga and Zebra Mussels. Website: http://www.dfg.ca.gov/invasives/quaggamussel/. Accessed: 11 September 2008.

11. Candy, G. (personal communication, 14 August 2008)

12. CAPA (California Association of Port Authorities). 2000. Feasibility of onshore ballast water treatment at California ports. A study conducted on behalf of the California Association of Port Authorities (CAPA) pursuant to a Small Grant Assistance Agreement with the U.S. Environmental Protection Agency. September 2000. Prepared by URS Corporation/Dame and Moore.

13. Carlton, J.T. 1999. The scale and ecological consequences of biological invasions in the world's oceans. *In* Invasive Species and Biodiversity

Management. O. Sandulund, P. Schei, and A. Viken (Eds.) Kluwer Academic Publishers. Dordrecht, Netherlands. 195-212 pp.

14. Carlton, J.T. 2001. Introduced species in U.S. coastal waters: environmental impacts and management priorities. Pew Oceans Commission, Arlington, Virginia, 28 pp.

15. Carlton, J.T. 2008. The zebra mussel *Dreissena polymorpha* found in North America in 1986 and 1987. Journal of Great Lakes Research, 34:770-773.

16. Choi, K-H, W. Kimmerer, G. Smith, G.M. Ruiz, and K. Lion. 2005. Post-exchange zooplankton in ballast water of ships entering the San Francisco Estuary Journal of Plankton Research, 27:707-714.

17. Cohen, A.N. 1998. Ships' ballast water and the introduction of exotic organisms into the San Francisco Estuary: Current status of the problem and options for management. San Francisco Estuary Institute.

18. Cohen, A.N. and J.T. Carlton. 1995. Nonindigenous aquatic species in a United States estuary: A case study of the biological invasions of the San Francisco Bay and Delta, U.S. Fish and Wildlife Service.

19. Cohen, A.N. and J.T. Carlton. 1998. Accelerating invasion rate in a highly invaded estuary. Science, 279:555-558.

20. Colautti, R.I., Bailey, S.A., van Overdijk, C.D.A., Amundsen, K., and MacIsaac, H.J. 2006. Characterized and projected costs of nonindigenous species in Canada. Biological Invasions, 8:25-59.

21. Culley, A.I., and C.A. Suttle. 2007. Viral community structure. Chapter 36 (pp. 445-453) *In* Hurst, C.J. (ed.), Manual of Environmental Microbiology, Third Edition. ASM Press, Washington, D.C.

22. Daly, L.J., D. Reinhart, V. Sharma, L. Walters, A. Randall, and B. Hardman. 2005. Final Report. Laboratory-scale investigation of ballast water treatment using Ferrate. NOAA Award # NA04OAR4170147

23. de Lafontaine, Y., S-P Despatie, and C. Wiley. 2008. Effectiveness and potential toxicological impact of the PERACLEAN® Ocean ballast water treatment technology. Ecotoxicology and Environmental Safety, 71(2):355-369.

24. de Lafontaine, Y., S-P Despatie, É. Veilleux, and C. Wiley. 2009. Onboard ship evaluation of the effectiveness and the potential environmental effects of PERACLEAN® Ocean for ballast water treatment in very cold conditions. Environmental Toxicology, 24(1):49-65.

25. Dobbs, F. (personal communication, 5 November 2008)

26. Dobroski, N., L. Takata, C. Scianni, and M. Falkner. 2007. Assessment of the Efficacy, Availability, and Environmental Impacts of Ballast Water Treatment Systems for Use in California Waters. Produced for the California State Legislature.

27. Dobroski, N., C. Scianni, D. Gehringer, and M. Falkner. 2009a. 2009 Assessment of the Efficacy, Availability, and Environmental Impacts of Ballast Water Treatment Systems for Use in California Waters. Produced for the California State Legislature.

28. Dobroski, N., C. Scianni, L. Takata, and M. Falkner. 2009b. October 2009 Update: Ballast Water Treatment Technologies for Use in California Waters. Prepared by the Californai State Lands Commission, Marine Invasive Species Program.

29. Dogterom, J., G.J. Jansen, and H.J. Wopereis. 2005. Study report. Greenship's Ballast Water Management System. Technologische werkplaats. Noordelijke Hogeschool Leeuwarden.

30. Echardt, J. and A. Kornmueller. 2009a. The advanced EctoSys elecvtrolysis as an integral part of a ballast water treatment system. Water Science and Technology, 60(9): 2227-2234.

31. Echardt, J. and A. Kornmueller. 2009b. The advanced EctoSys electrolysis as an integral part of a ballast water treatment system. Proceedings of the IWA 5th Conference on Oxidation Technologies for Water and Wastewater Treatment, Mar 30 – Apr 1, 2009, Berlin.

32. Ecowise Environmental. 2003. Technical Report: HTM-AquaTherm® Disinfection Unit Study – Revised February 2003. Prepared by Danielle Baker. Reviewed by Dr. Therese Flapper. For Aerocycle Wastewater Solutions.

33. Ellis, S. (personal communication, 14 January 2010)

34. EPA (U.S. Environmental Protection Agency). 1986. Ambient water quality criteria for bacteria – 1986. EPA440/5-84-002. January 1986.

35. EPA (U.S. Environmental Protection Agency). 2008. National Pollutant Discharge Elimination System (NPDES) Proposed Vessel General Permit for Discharges Incidental to the Normal Operation of Commercial Vessels and Large Recreational Vessels (VGP).

36. Everett, R. (personal communication, 13 August 2007).

37. Everett, R. (personal communication, 11 March 2010).

38. Faimali, M., F. Garaventa, E. Chelossi, V. Piazza, O.D. Saracino, F. Rubino, G.L. Mariottini, and L. Pane. 2006. A new photodegradable molecule as a low impact ballast water biocide: efficacy screening on marine organisms from different trophic levels. Marine Biology, 149:7-16.

39. Falkner, M., L. Takata, and S. Gilmore. 2006. California State Lands Commission Report on Performance Standards for Ballast Water Discharges in California. Produced for the California State Legislature.

40. Falkner, M., L. Takata, S. Gilmore, and N. Dobroski. 2007. 2007 Biennial Report on the California Marine Invasive Species Program. Produced for the California State Legislature.

41. Felbeck, H. 2009. Tests of the effects of “TriMix” on bacteria and invertebrates were run using *E. coli*, Enterococcus sp., sea urchin larvae, brine shrimp.

42. Feyrer, F., H.B. Matern, and P.B. Moyle. 2003. Dietary shifts in a stressed fish assemblage: Consequences of a bivalve invasion in the San Francisco estuary. Environmental Biology of Fishes, 67:277-288.

43. Fofonoff, P.W., G.M. Ruiz, B. Steves, and J.T. Carlton. 2003. In ships or on ships? Mechanisms of transfer and invasion for nonnative species to the coasts of North America. *In*: Ruiz, G.M. and J.T. Carlton (eds.) Invasive Species: Vectors and Management Strategies. Island Press, Washington D.C. p 152-182.

44. Fuchs, R. and I. de Wilde. 2004. Peraclean Ocean® - A potentially environmentally friendly and effective treatment option for ballast water. *In*: Matheickal, J.T. and S. Raaymakers (eds.) 2004. 2nd International Ballast Water Treatment R&D Symposium, IMO London, 21-23 July 2003: Proceedings. GloBallast Monograph Series No. 15. IMO London.

45. Giovannoni, S.J., R.A. Foster, M.S. Rappé, and S. Epstein. 2007. New cultivation strategies bring more microbial plankton species into the laboratory. Oceanography, 20(2):62-69.

46. Gregg, M.D. and G.M. Hallegraeff. 2007. Efficacy of three commercially available ballast water biocides against vegetative microalgae, dinoflagellate cysts and bacteria. Harmful Algae, 6:567-584.

47. Hallegraeff, G.M. 1998. Transport of toxic dinoflagellates via ships' ballast water: bioeconomic risk assessment and efficacy of possible ballast water management strategies Marine Ecology Progress Series, 168:297-309.

48. Heida, M.R. and G.J. Jansen. Undated. Ballast Water Treatment: Killing studies of IMO monitoring micro-organisms. Research Institutes: Technologische werkplaats and Moordelijke Hogeschool Leeuwarden. 25 pp.

49. Herwig, R.P., J.R. Cordell, B.C. Nielsen, N.C. Ferm, D.J. Lawrence, J.C. Perrins, and A.C.E. Rhodes. 2006a. Final Report. Efficacy Testing of the Severn Trent De Nora Balpure® System. School of Aquatic and Fishery Sciences, University of Washington, Seattle, Washington. March 13, 2006.

50. Herwig, R.P., J.R. Cordell, J.C. Perrins, P.A. Dinnel, R.W. Gensemer, W.A. Stubblefield, G.M. Ruiz, J.A. Kopp, M.L. House, and W.J. Cooper. 2006b. Ozone treatment of ballast water on the oil tanker *S/T Tonsina*: chemistry, biology, and toxicity. Marine Ecology Progress Series, 324: 37-55.

51. Hi Tech Marine. 1997. Ballast water trial on M.V. Sandra Marie. 9th May 1997 Sydney to Hobart.

52. Husain, M., H. Felbeck, D. Altshuller, and C. Quirmbach. 2004. Ballast water treatment by de-oxygenation with elevated CO_2 for a shipboard installation – a potentially affordable solution. *In*: Matheickal, J.T. and S. Raaymakers (eds.) 2004. 2nd International Ballast Water Treatment R&D Symposium, IMO London, 21-23 July 2003: Proceedings. GloBallast Monograph Series No. 15. IMO London.

53. IMO (International Maritime Organization). 2005. Ballast Water Management Convention International Convention for the Control and Management of Ships' Ballast Water and Sediments. International Maritime Organization, London, p 138.

54. IMO (International Maritime Organization). 2007. Resolution A. 1005(25). Application of the international convention for the control and management of ships’ ballast water and sediments, 2004. Adopted on 29 November 2007 (Agenda item 11).

55. IMO (International Maritime Organization). 2010. Summary of Status of Conventions as at 31 May 2010. Accessed: June 14, 2010. Website: http://www.imo.org

56. Japan Association of Marine Safety. 2007. Special Pipe Ballast Water Management System. Report of 1st on-board test (revised).

57. Jelmert, A. 1999. Testing the effectiveness of an integrated Hydro cyclone/UV treatment system for ballast water treatment. Accessed: 11/9/07, Website: www.optimarin.com/test1999Austevoll.htm

58. Kikuchi, T. and Y. Fukuto. Development of the Special Pipe Hybrid System, one of the most promising ballast water management systems.

59. Kikuchi, T., K. Yoshida, S. Kino, and Y. Fukuyo. 2004. Progress report on the ‘Special Pipe System’ as a potential mechanical treatment for ballast water. *In*: Matheickal, J.T. and S. Raaymakers (eds.) 2004. 2nd International Ballast Water Treatment R&D Symposium, IMO London, 21-23 July 2003: Proceedings. GloBallast Monograph Series No. 15. IMO London.

60. Kildow, J. and Pendleton, L. 2006. The non-market value of beach recreation in California. Shore and Beach, 74: 34-37.

61. King, D.M. and M.N. Tamburri. 2009. Verifying compliance with U.S. ballast water discharge regulations. *Submitted to* Ocean Development and International Law.

62. KORDI (Korean Ocean Research and Development Institution). 2008. Preliminary Report for the Type Approval Test Used by Electro-Clean Ballast Water Management System. Project No. PI49300. 3 March 2008.

63. KORDI (Korean Ocean Research and Development Institution). 2009. Heterotrophic bacteria test results performed by KORDI during the land-based tests for the IMO final approval.

64. Lawrence, D.J., J.C. Perrins, N.C. Ferm, J.R. Cordell, and R.P. Herwig. 2006a. Phase 1 Test: Preliminary Report. Efficacy testing of the MARENCO ballast water treatment system.

65. Lawrence, D.J., J.C. Perrins, N.C. Ferm, J.R. Cordell, and R.P. Herwig. 2006b. Phase 2 Test: Preliminary Report. Efficacy testing of the MARENCO ballast water treatment system.

66. Lloyd’s Register. 2007. Ballast water treatment technology. Current status. June 2007.

67. Lloyd’s Register. 2010. Ballast water treatment technology. Current status. February 2010.

68. Lovell, S.J. and S.F. Stone. 2005. The Economic Impacts of Aquatic Invasive Species. Report No. Working Paper #05-02, US Environmental Protection Agency.

69. Lovell, S.J., and Drake, L.A. 2009. Tiny stowaways: Analyzing the economic benefits of a U.S. Envrionmental Protection Agency permit regulating ballast water discharges. Environmental Management, v. 42, p. 546-555.

70. Mackey, T.P. and D.A. Wright. 2002. A filtration and UV based ballast water treatment technology: Including a review of initial testing and lessons learned aboard three cruise ships and two floating test platforms. Paper presented at ENSUS 2002. Marine Science and Technology for Environmental Sustainability. University of Newcastle-upon-Tyne, School of Marine Science and Technology. Dec. 16-18, 2002.

71. MacIsaac, H.J., T.C. Robbins, and M.A. Lewis. 2002. Modeling ships' ballast water as invasion threats to the Great Lakes. Canadian Journal of Fisheries and Aquatic Sciences, 59:1245-1256.

72. Maddox, T.L. 2000. Final Report. Ballast water treatment and management with ozone and sonics. National Sea Grant NA96RG0478.

73. Maddox, T.L. 2004a. Phase II Final Report. Ballast water treatment and management with filtration, ozone, and sonics. National Sea Grant NA03OAR4170008.

74. Maddox, T.L. 2004b. Phase III Final Report. Field test demonstration of improved methods of ballast water treatment and monitoring utilizing filtration, ozone, and sonics. National Sea Grant NA04OAR4170150.

75. Maddox, T.L. 2005. Phase IV Final Report. Full scale, land based field test demonstration of improved methods of ballast water treatment and monitoring utilizing ozone and sonic energy. National Sea Grant NA05OAR4171070.

76. Maranda, L., R.G. Campbell, D.C. Smith, and C.A. Oviatt. 2005. Final Report. Summer field test of the Ecopod aboard the M/V Atlantic Compass. Graduate School of Oceanography. University of Rhode Island. Submitted October 31, 2005.

77. Marinelink. 2010. Alfa Laval's PureBallast for Australian Navy. Accessed: 6 May 2010. Website: http://marinelink.com/News/Article/Alfa-Laval-s-PureBallast-for-Australian-Navy/333787.aspx. Originally published: 29 March 2010.

78. Maritime Environmental Resource Center. 2009a. Land-based Evaluations of the Siemens Water Technologies SiCURE™ Ballast Water Management System. 6 November 2009. UMCES Technical Report Series: Ref. No. [UCMES] CBL 09-13.

79. Maritime Environmental Resource Center. 2009b. Land-Based Evaluations of the Maritime Solutions, Inc. Ballast Water Treatment System. 20 November 2009. UMCES Technical Report Series: Ref. No. [UMCES] CBL 09-138.

80. McMullin, J., V. Loete, R. Larson, S. Sylvester, and D. Drew. 2008. Port of Milwaukee Onshore Ballast Water Treatment. 17 pp.

81. MEPC (Marine Environment Protection Committee). 2003. Comments on draft regulation E-2. Concentrations of organisms delivered in ships' ballast water in the absence of any treatment: Establishing a baseline for consideration of treatment efficacy. MEPC 49/2/1. 23 May, 2003.

82. MEPC (Marine Environment Protection Committee). 2005a. Harmful aquatic organisms in ballast water: Information to be considered by the Review Group. Submitted by Sweden. MEPC 53/2/6. 15 April 2005.

83. MEPC (Marine Environment Protection Committee). 2005b. Application for basic approval of active substances used by Electro-Clean (electrolytic disinfection) ballast water management system. Submitted by Republic of Korea. MEPC 54/2/3. 16 December 2005.

84. MEPC (Marine Environment Protection Committee). 2006a. Basic Approval of Active Substances used by Special Pipe Ballast Water Management System (combined with Ozone treatment). Submitted by Japan. 55/2. 12 April 2006.

85. MEPC (Marine Environment Protection Committee). 2006b. Information (Update of MEPC 53/2/11 Annex 1) provided by Elga Berkefeld GMBH, Lückenweg, 5, 29227 Celle, Germany and its subsidiary RWO Marine Water Technology, Leerkämpe 3, 29259, Bremen, Germany. MEPC 55/2/17, Annex 1. 7 July, 2006.

86. MEPC (Marine Environment Protection Committee). 2006c. Application for Final Approval of Ballast Water Management System Using Active Substances. Submitted by Norway. 56/2/1. 15 December 2006.

87. MEPC (Marine Environment Protection Committee). 2007a. Basic Approval of Active Substances used by Resource Ballast Technologies Systems (Cavitation combined with Ozone and Sodium Hypochlorite treatment). Submitted by South Africa. 56/2/3. 6 April 2007.

88. MEPC (Marine Environment Protection Committee). 2007b. Application for Basic Approval of Active Substances used by Hitachi Ballast Water Purification System (ClearBallast). Submitted by Japan. 57/2/2. 7 September 2007.

89. MEPC (Marine Environment Protection Committee). 2007c. Application for Final Approval of a ballast water management system using Active Substances. Submitted by Germany. 57/2/3. 7 September 2007.

90. MEPC (Marine Environment Protection Committee). 2007d. Application for Final Approval of a ballast water management system using Active Substances. Submitted by Germany. 57/2/5. 7 September 2007.

91. MEPC (Marine Environment Protection Committee). 2007e. Basic Approval of Active Substance used by GloEn-Patrol™ Ballast Water Management System. Submitted by the Republic of Korea. 57/2/4. 7 September 2007.

92. MEPC (Marine Environment Protection Committee). 2007f. Report of the fourth meeting of the GESAMP-Ballast Water Working Group (GESAMP-BWWG). Note by the Secretariat. 57/2. 19 December 2007.

93. MEPC (Marine Environment Protection Committee). 2007g. Application for Basic Approval of a combined ballast water management system consisting of sediment removal and an electrolytic process using seawater to produce Active Substances (Greenship Ltd). Submitted by the Netherlands. 57/2/7. 20 December 2007.

94. MEPC (Marine Environment Protection Committee). 2008a. Report of the fifth meeting of the GESAMP-Ballast Water Working Group (GESMP-BWWG). Note by the Secretariat. 57/2/10. 25 January 2008.

95. MEPC (Marine Environment Protection Committee). 2008b. Application for Final Approval of the OceanSaver® Ballast Water Management System (OS BWMS). Submitted by Norway. 58/2/1. 19 March 2008.

96. MEPC (Marine Environment Protection Committee). 2008c. Application for Final Approval of the Electro-Clean System (ECS). Submitted by the Republic of Korea. 58/2. 20 March 2008.

97. MEPC (Marine Environment Protection Committee). 2008d. Application for Basic Approval of the Ecochlor® Ballast Water Treatment System. Submitted by Germany. 58/2/2. 20 March 2008.

98. MEPC (Marine Environment Protection Committee). 2008e. Application for Final Approval of the NK-O3 BlueBallast System (Ozone). Submitted by the Republic of Korea. 58/2/3. 21 March 2008.

99. MEPC (Marine Environment Protection Committee). 2008f. Procedure for approval of ballast water management systems that make use of active substances (G9). MEPC 57/21. Annex 1. Resolution MEPC.169(57). Adopted on 4 April 2008.

100. MEPC (Marine Environment Protection Committee). 2008g. Report of the sixth meeting of the GESAMP-Ballast Water Working Group. Note by the Secretariat. MEPC 58/2/7. 14 July 2008.

101. MEPC (Marine Environment Protection Committee). 2008h. Report of the seventh meeting of the GESAMP-Ballast Water Working Group. Note by the Secretariat. 58/2/8. 28 July 2008.

102. MEPC (Marine Environment Protection Committee). 2008i. Guidelines for approval of ballast water management systems (G8). MEPC 58/23. Annex 4. Resolution MEPC.174(58). Adopted on 10 October 2008.

103. MEPC (Marine Environment Protection Committee). 2008j. Application for Final Approval of the RWO Ballast Water Management System (CleanBallast). Submitted by Germany. 59/2. 28 November 2008.

104. MEPC (Marine Environment Protection Committee). 2008k. Application for Final Approval of the Special Pipe Hybrid Ballast Water Management System (combined with Ozone treatment). Submitted by Japan. 59/2/1. 4 December 2008.

105. MEPC (Marine Environment Protection Committee). 2008l. Application for Basic Approval of the Blue Ocean Shield Ballast Water Management System. Submitted by China. 59/2/2. 5 December 2008.

106. MEPC (Marine Environment Protection Committee). 2008m. Application for Final Approval of the NK-O3 BlueBallast System (Ozone). Submitted by the Republic of Korea. 59/2/3. 8 December 2008.

107. MEPC (Marine Environment Protection Committee). 2008n. Application for Basic Approval of the HHI Ballast Water Management System (EcoBallast). Submitted by the Republic of Korea. 59/2/4. 9 December 2008.

108. MEPC (Marine Environment Protection Committee). 2008o. Application for Final Approval of the Hitachi Ballast Water Purification System (ClearBallast). Submitted by Japan. 59/2/5. 11 December 2008.

109. MEPC (Marine Environment Protection Committee). 2008p. Application for Final Approval of the Greenship Sedinox Ballast Water Management System. Submitted by the Netherlands. 59/2/6. 12 December 2008.

110. MEPC (Marine Environment Protection Committee). 2008q. Application for Final Approval of the GloEn-Patrol™ Ballast Water Treatment System. Submitted by the Republic of Korea. 59/2/7. 16 December 2008.

111. MEPC (Marine Environment Protection Committee). 2008r. Application for Basic Approval of the AquaTriComb™ Ballast Water Treatment System. Submitted by Germany. 59/2/8. 16 December 2008.

112. MEPC (Marine Environment Protection Committee). 2008s. Application for Final Approval of the Resource Ballast Technologies System (Cavitation combined with Ozone and Sodium Hypochlorite treatment). Submitted by South Africa. 59/2/10. 19 December 2008.

113. MEPC (Marine Environment Protection Committee). 2008t. Application for Basic Approval of the Siemens SiCURE™ Ballast Water Management System. Submitted by Germany. 59/2/11. 19 December 2008.

114. MEPC (Marine Environment Protection Committee). 2009a. Report of the eighth meeting of the GESAMP-Ballast Water Working Group. Note by the Secretariat. 59/2/16, Annex 4. 8 April 2009.

115. MEPC (Marine Environment Protection Committee). 2009b. Application for Basic Approval of the DESMI Ocean Guard Ballast Water Management System. Submitted by Denmark. 60/2/4. 19 August 2009.

116. MEPC (Marine Environment Protection Committee). 2009c. Application for Final Approval of the JFE Ballast Water Management System (JFE-BWMS) that makes use of "TG Ballastcleaner® and TG Environmentalguard®." Submitted by Japan. 60/2/2. 20 August 2009.

117. MEPC (Marine Environment Protection Committee). 2009d. Application for Basic Approval of Blue Ocean Guardian (BOG) Ballast Water Management System. Submitted by the Republic of Korea. 60/2/5. 24 August 2009.

118. MEPC (Marine Environment Protection Committee). 2009e. Application for Basic Approval of the Sunrui ballast water management system. Submitted by China. 60/2/3. 24 August 2009.

119. MEPC (Marine Environment Protection Committee). 2009f. Application for Basic Approval of the Hyundai Heavy Industries Co., Ltd. (HHI) Ballast Water Management System (HiBallast). Submitted by the Republic of Korea. 60/2/6. 24 August 2009.

120. MEPC (Marine Environment Protection Committee). 2009g. Application for Basic Approval of Kwang San Co., Ltd. (KS) Ballast Water Management System "En-Ballast." Submitted by Korea. 60/2/7. 25 August 2009.

121. MEPC (Marine Environment Protection Committee). 2009h. Application for Basic Approval of the OceanGuard™ Ballast Water Management System. Submitted by Norway. 60/2/8. 26 August 2009.

122. MEPC (Marine Environment Protection Committee). 2009i. Application for Basic Approval of the Severn Trent DeNora BalPure® Ballast Water Management System. Submitted by Germany. 60/2/9. 28 August 2009.

123. MEPC (Marine Environment Protection Committee). 2009j. Draft MEPC resolution on the installation of ballast water management systems on new ships

in accordance with the application dates contained in the BWM Convention. Note by the Secretariat. 60/2/10. 23 September 2009.

124. MEPC (Marine Environment Protection Committee). 2009k. Report of the tenth meeting of the GESMP-Ballast Water Working Group. Note by the Secretariat. 60/2/11. 30 October 2009.

125. MEPC (Marine Environment Protection Committee). 2009l. Report of the eleventh meeting of the GESMP-Ballast Water Working Group. Note by the Secretariat. 60/2/12, Annex 4. 1 December 2009.

126. MEPC (Marine Environment Protection Committee). 2010. Report of the twelfth meeting of the GESAMP – Ballast Water Working Group. Note by the Secretariat. 60/2/16. 8 February 2010.

127. Michigan DEQ (Department of Environmental Quality). 2006. Ballast water control general permit. Port operations and ballast water discharge. Permit No. MIG140000. Issued 11 October 2006.

128. Moore, B. (personal communication, 11 March 2010)

129. Moore, S. (personal communication, 12 September 2005)

130. MPCA (Minnesota Pollution Control Agency). 2008. Ballast Water Discharge General Permit: FAQs for Vessel Owners and Operators. Water Quality/Surface Water #8.03. October 2008.

131. National Research Council. 1996. Stemming the Tide: Controlling Introductions of Nonindigenous Species by Ships' Ballast Water, Vol. National Academy Press, Washington, D.C.

132. NIOZ (Royal Netherlands Institute for Sea Research). 2008. Final report of the land-based testing of the SEDNA®-System, for Type Approval according to Regulation-D2 and the relevant IMO Guidelines (April – July 2007). Final report of the shipboard testing of the SEDNA®-System, for Type Approval according to Regulation-D2 and the relevant IMO Guidelines (June - December 2007). BSH/M5101.

133. NIOZ (Royal Netherlands Institute for Sea Research). 2009a. Final report of the land-based testing of the Ecochlor®-System, for type approval according to regulation-D2 and the relevant IMO Guideline (April – July 2008).

134. NIOZ (Royal Netherlands Institute for Sea Research). 2009b. Final report of the land-based testing of the Hyde-Guardian™-System, for Type Approval according to the Regulation D-2 and the relevant IMO Guideline (April – July 2008).

135. NIVA (Norwegian Institute for Water Research). 2006. Full scale toxicity testing of the PureBallast System – preliminary Report.

136. NIVA (Norwegian Institute for Water Research). 2008a. Land based testing of the OptiMarin ballast water management system of OptiMarin AS – Treatment effect studies. Final Report. Report SNO 5659-2008.

137. NIVA (Norwegian Institute for Water Research). 2008b. Land based testing of the PureBallast Treatment System of AlfaWall AB – approved test cycles. Report SNO 5667-2008.

138. NIVA (Norwegian Institute for Water Research). 2008c. Shipboard testing of the PureBallast Treatment System of AlfaWall AB. Report SNO 5617-2008.

139. NIVA (Norwegian Institute for Water Research). 2008d. Land based testing of the OceanSaver ballast water management system of MetaFil AS – Final Report (report no: -272249). 28 January 2008.

140. NIVA (Norwegian Institute for Water Research). 2009a. Shipboard testing of the OptiMarin Ballast System of OptiMarin AS. Report SNO 5828-2009.

141. NIVA (Norwegian Institute for Water Research). 2009b. Additional shipboard testing of the PureBallast treatment System of AlfaLaval/Wallenius Water AB. Report SNO 5850-2009.

142. NIVA (Norwegian Institute for Water Research). 2010. Land based testing of the OceanGuard™ Ballast Water Management System of Qingdao Headway. Report SNO 5938-2010.

143. NOEP (National Ocean Economic Program). 2007. Ocean economy data. Accessed 9 November 2007. Website: http://noep.mbari.org/Market/ocean/oceanEcon.asp

144. NOEP (National Ocean Economics Program). 2010a. Ocean economy data. Accessed: 24 March 2010. Website: http://noep.mbari.org/Market/ocean/oceanEcon.asp

145. NOEP (National Ocean Economics Program). 2010b. Natural Resources - Commercial fish species search. Accessed: 24 March 2010. Website: http://noep.mbari.org/LMR/fishSearch.asp

146. OceanSaver. 2008. FRO and TRO – Neutralisation Study. November 2008. Project Team: J.J. Dale and E. Fraas, Mentum AS.

147. Ocean University of China. 2010. Monitoring (Inspection Report). Shipboard Testing of OceanGuard™ Ballast Water Management System. OUC (Testing) No. HDJC2010-002.

148. Oviatt, C., P. Hargraves, R. Kelly, M. Kirs, L. Maranda, B. Moran, D. Outram, D. Smith, B. Sullivan, and K. Whitman. 2002. Toxicity of chlorine dioxide to ballast water flora and fauna in bench scale assays. Final Report to Ecochlor Inc. (Charles Goodsill, VP).

149. Pacific Maritime. 2010. ZIM takes new vessels. Volume 28, Number 2, pg 10.

150. Parsons, M.G. 1998. Flow-through ballast water exchange. SNAME Transactions, 106:485-493.

151. Parsons, M.G. 2003. Considerations in the design of the primary treatment for ballast systems. Marine Technology, 40:49-60.

152. Parsons, M.G. and R.W. Harkins. 2002. Full-Scale Particle Removal Performance of Three Types of Mechanical Separation Devices for the Primary Treatment of Ballast Water. Marine Technology, 39:211-222.

153. Pendleton, L. 2009. The economic value of coastal and estuary recreation. *In The Economic and Market Value of Coasts and Estuaries* : *What's at Stake?* pp. 140-175.

154. Perrins, J.C., J.R. Cordell, N.C. Ferm, J.L. Grocock, and R.P. Herwig. 2006. Mesocosm experiments for evaluating the biological efficacy of ozone treatment of marine ballast water. Marine Pollution Bulletin, 52: 1756-1767.

155. Pimentel, D., R. Zuniga, and D. Morrison. 2005. Update on the environmental and economic costs associated with alien-invasive species in the United States. Ecological Economics, 52:273-288.

156. Pleus, A. (personal communication, 7 April 2010)

157. Reid, D.F., T.H. Johengen, H. MacIssac, F. Dobbs, M. Doblin, L. Drake, G. Ruiz, and P. Jenkins. 2007. Identifying, verifying and establishing options for best management practices for NOBOB vessels. Prepared for: The Great Lakes Protection Fund, the U.S. Coast Guard, and the National Oceanic and Atmospheric Administration. 173 pp.

158. Reynolds, K. (personal communication, 2 August 2007)

159. Reynolds, K. (personal communication, 7 May 2010)

160. Rigby, G.R., G.M. Hallegraeff, and C. Sutton. 1999. Novel ballast water heating technique offers cost-effective treatment to reduce the risk of global transport of harmful marine organisms. Marine Ecology Progress Series, 191:289-293.

161. Rigby, G., G.M. Hallegraeff, and A. Taylor. 2004. Ballast water heating offers a superior treatment option. Journal of Marine Environmental Engineering, 7:217-230.

162. Ruiz, G.M. and J.T. Carlton. 2003. Invasion vectors: A conceptual framework for management. *In*: Ruiz, G.M and J.T. Carlton (eds.) Invasive Species: Vectors and management strategies. Island Press, Washington D.C., p 459-504.

163. 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, 408:49-50.

164. Ruiz, G.M. and D.F. Reid. 2007. Current State of Understanding about the Effectiveness of Ballast Water Exchange (BWE) in Reducing Aquatic Nonindigenous Species (ANS) Introductions to the Great Lakes Basin and Chesapeake Bay, USA: Synthesis and Analysis of Existing Information. NOAA Technical Memorandum GLERL-142.

165. Saaros, H. (personal communication, 14 March 2010 and 11 May 2010)

166. SGS Institut Fresenius, 2009, Report on the sample received on 1st April 2009. Test Report 1367519_V 1.0. Prepared for Evonik Degussa GmbH.

167. Siefert, E. and K. Siers. 2007. Landbased test report – Test cycle summary. Institut fur Umwelttechnik.

168. Sommer, T., C. Armor, R. Baxter, R. Breuer, L. Brown, M. Chotkowski, S. Culberson, F. Feyrer, M. Gingras, B. Herbold, W. Kimmerer, A. Mueller-Solger, M. Nobriga, and K. Souza. 2007. The collapse of pelagic fishes in the upper San Francisco estuary. Fisheries, 32(6): 270-277.

169. Spellman, M. (personal communication, 14 August 2008)

170. Tamburri, M.N., B.J. Little, G.M. Ruiz, J.S. Lee, and P.D. McNulty. 2004. Evaluations of Venturi Oxygen Stripping™ as a ballast water treatment to prevent aquatic invasions and ship corrosion. *In*: Matheickal, J.T. and S. Raaymakers (eds.) 2004. 2nd International Ballast Water Treatment R&D Symposium, IMO London, 21-23 July 2003: Proceedings. GloBallast Monograph Series No. 15. IMO London.

171. Tamburri, M.N. and G.M. Ruiz. 2005. Evaluations of a ballast water treatment to stop invasive species and tank corrosion. 2005 SNAME Maritime Technology Conference & Expo and Ship Production Symposium, Houston, TX.

172. Tamburri, M., G.E. Smith, and T.L. Mullady. 2006. Quantitative shipboard evaluations of Venturi Oxygen Stripping as a ballast water treatment. 3rd International Conference on Ballast Water Management. Singapore, 25-26 September, 2006.

173. Tang, Z., M. Butkus, and Y.F. Xie. 2006. Crumb rubber filtration: a potential technology for ballast water treatment. Marine Environmental Research, 61:410-423.

174. Tang, Z., M. Butkus, and Y.F. Xie. 2009. Enhanced performance of crumb rubber filtration for ballast water treatment. Chemosphere, 74:1396-1399.

175. Thornton, G. (personal communication, 26 January 2010)

176. UNIFOB AS. 2008. Quality Assurance Project Plan (QAPP) for shipboard tests of ballast water management systems.

177. USCG (United States Coast Guard). 2001. Report to Congress on the voluntary national guidelines for ballast water management. Washington D.C.

178. USCG (United States Coast Guard). 2004. Navigation and Inspection Circular No. 01-04. Shipboard Technology Evaluation Program (STEP): Experimental Ballast Water Treatment Systems. January 2004.

179. USCG (United States Coast Guard). 2006. 2006 Shipboard Technology Evaluation Program. General Guidance for the Applicant. March 2006.

180. USCG (United States Coast Guard). 2008. Environmental Standards Update. Fall 2008.

181. USCG (United States Coast Guard). 2010. Shipboard Technology Evaluation Program. Accessed: 9 June 2010. Website: http://www.uscg.mil/hq/cg5/cg522/cg5224/step.asp.

182. Veldhuis, M.J.W., F. Fuhr, J.P. Boon, and C.C. Ten Hallers-Tjabbers. 2006. Treatment of ballast water: how to test a system with a modular concept? Environmental Technology, 27:909-921.

183. Viitasalo, S., J. Sassi, J. Rytkonen, and E. Leppakoski. 2005. Ozone, ultraviolet light, ultrasound and hydrogen peroxide as ballast water treatments - experiments with mesozooplankton in low-saline brackish water. Journal of Marine Environmental Engineering, 8:33-55.

184. Washington State Department of Ecology. 2008. Laboratory guidance and whole effluent toxicity test review criteria. Publication No. WQ-R-95-80. Revised December 2008. Prepared by Randall Marshall.

185. Water Board (State Water Resources Control Board). 2002. Evaluation of Ballast Water Treatment Technology for Control of Nonindigenous Aquatic Organisms, p 70.

186. Water Board (State Water Resources Control Board). 2005. California Ocean Plan. Water Quality Control Plan. Ocean Waters of California.

187. Water Board (State Water Resources Control Board). 2009. Modification to California's Water Quality Certification for the U.S. Environmental Protection Agency's Vessel General Permit. Website: http://www.epa.gov/npdes/pubs/401_california.pdf

188. Weigle, S.M., L.D. Smith, J.T. Carlton, and J. Pederson. 2005. Assessing the risk of introducing exotic species via the live marine species trade. Conservation Biology, 19(1): 213-223.

189. Welschmeyer, N., C. Scianni, and S. Smith. 2007. Ballast water management: Evaluation of the MARENCO ballast water treatment system. Moss Landing Marine Laboratories.

190. Wonham, M.J., W.C. Walton, G.M. Ruiz, A.M. Frese, and B.S. Galil. 2001. Going to the source: Role of the invasion pathway in determining potential invaders. Marine Ecology Progress Series, 215:1-12.

191. Woodfield, R. 2006. Invasive seaweed threatens California's coastline – an update. Ballast Exchange: Newsletter of the West Coast Ballast Outreach Project, 6;10-11.

192. Wright, D.A. 2009. Shipboard trials of Hyde 'Guardian' system in Caribbean Sea and Western Pacific Ocean, April 5th – October 7th, 2008. Final report to Hyde Marine and Lamor Corp. April 2009.

193. Wright, D.A., R. Dawson, C.E. Orano-Dawson, and S.M. Moesel. 2007. A test of the efficacy of a ballast water treatment system aboard the vessel *Coral Princess*. Marine Technology, 44(1): 57-67.

194. Wright, D.A., R. Dawson, C.E.F. Orano-Dawnson, G.R. Morgan, and J. Coogan. 2006. The development of ultraviolet irradiation as a method for the treatment of ballast water in ships. Journal of Marine Science and Environment, C4:3-12.

195. Wright, D.A., C. Mitchelmore, J. Bearr, R. Dawson, C.E. Orano-Dawson, and M. Olson. 2008. Shipboard Testing of Nutech-O3 ozonation system as a method for Ballast Water Treatment. A Final Report to Nutech-O3. June, 2008.

196. Zhang, F. and M. Dickman. 1999. Mid-ocean exchange of container vessel ballast water. 1: Seasonal factors affecting the transport of harmful diatoms and dinoflagellates. Marine Ecology Progress Series, 176:243-251.

XI. APPENDICES

APPENDIX A

Ballast Water Treatment System
Efficacy Matrix

Forty-six ballast water treatment systems were reviewed by Commission staff for compliance with the California performance standards. Twenty-seven systems had data on system efficacy available for review. Staff included data from shipboard, dockside and laboratory studies of system performance. In an effort to standardize results, staff evaluated any data on zooplankton abundance as representative of the largest size class of organisms (greater than 50 µm in size), and phytoplankton abundance was evaluated on par with organisms in the 10 – 50 µm size class. Results presented as percent reduction in organism abundance or as concentration of pigments or biological compounds associated with organism presence were noted, but these metrics were not comparable to the performance standards.

In the following tables, systems with at least one test (averaged across replicates) in compliance with the performance standard are scored as meeting California standards. Efficacy data with no tests demonstrating potential compliance with the standards are scored as not meeting California standards. Systems that presented data for a given organism size class but presented the results in metrics not comparable to the standards are classified as “Unknown.” For example, a system that presented results of system efficacy as percent reduction of zooplankton abundance could not be compared against the California standards, and thus ability of the system to comply with the standards is unknown. Open cells indicate lack of data for a given organism size class. Compliance with the bacteria standard was assessed using the concentration of culturable heterotrophic bacteria in discharged ballast water. Due to the lack of available methods to both quantify and assess the viability of all viruses, systems cannot be assessed for compliance with the viral standard at this time. The source(s) of the data for each system can be found in the Literature Cited section of the main report.

Appendix A1 Organisms > 50 µm

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls	# Organisms/cubic meter	Methods	Reference
21 Century Shipbuilding	Laboratory	2	1	Unk	Unk	0 - 10	Unk	117
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Alfa Laval	Laboratory	1	0	-	-	Unk (% Reduction)	Visual Assesment	82
	Land-Based	10	8	6	Y	0 - 26	Microscope/mobility	137
	Shipboard	4	1	12	Y	0 - 3	Microscope/mobility	138
Aquaworx ATC Gmbh	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
atg UV Technology	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
ATLAS-DANMARK	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Auramarine Ltd.	Laboratory	-	-	-	-	-	-	-
	Land-Based	5	3	Y	Y	0 - 19.3	Unk	4,165
	Shipboard	-	-	-		-	-	-
Brillyant Marine LLC	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Coldharbour Marine	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
COSCO/Tsinghua Univ.	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
DESMI Ocean Guard A/S	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Ecochlor	Laboratory[1]	2	2	2	Y	0 - $3.5x10^{5}$	Visual, Neutral Red Stain	148
	Land-Based	15	8	-	Y	0 - 81	Visual Assess, Neutral Red	133
	Shipboard[1]	1	1	3	Y	0-5	Visual Assessment	76
EcologiQ	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Electrichlor	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
ETI	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Ferrate Treatment Tech.	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-

Unk = Unknown, [1] = Filter added to system since testing conducted

Appendix A1 Organisms > 50 µm

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls	# Organisms/cubic meter	Methods	Reference
Hamann AG Evonik Degussa	Laboratory	2	2	Y	Y	0	Visual Assesment	44,182
	Land-Based	19	16	Y	Y	0-0.7	Visual Asses., Neutral Red	132
	Shipboard	5	4	3	Y	0-1.1	Visual Asses., Neutral Red	132
Hamworthy Greenship	Laboratory	-	-	-	-	-	-	-
	Land-Based	5	5	Y	Y	0	Visual Assessment	167
	Shipboard	-	-	-	-	-	-	-
Hi Tech Marine	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	2	0	-	-	Unk (% mortality)	-	51
Hitachi	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Hyde Marine	Laboratory	1	0	Y	Y	-	Visual Assessment	70
	Land-Based	10	1	Y	Y	0 - 7.3	Visual, Neutral Red Stain	134
	Shipboard	3	3	9	Y	0	Visual, Neutral Red Stain	192
Hyundai Heavy Industries (1)	Laboratory	2	2	9	Y	0	Unk	107
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Hyundai Heavy Industries (2)	Laboratory	2	2	9	Y	0	Unk	119
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
JFE Engineering Corp	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Kwang San Co. Ltd.	Laboratory	2	0	Unk	Y	160-180	Unk	120
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
MAHLE	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
MARENCO	Laboratory	-	-	-	-	-	-	-
	Land-Based	4	3	3	Y	0 - 1.57	Visual Assessment	64,65,189
	Shipboard	-	-	-	-	-	-	-
Maritime Solutions Inc.	Laboratory	-	-	-	-	-	-	-
	Land-Based	5	0	5	Y	6 - 2170	Microscope/Mobility	79
	Shipboard	-	-	-	-	-	-	-
Mexel Industries	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-

Unk = Unknown

Appendix A1 Organisms > 50 µm

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls	# Organisms/cubic meter	Methods	Reference
MH Systems	Laboratory	11	10	Y	Y	Unk (No Units)	Visual Assessment	41,52
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Mitsui Engineering	Laboratory	-	-	-	-	-	-	-
	Land-Based	4	0	3-5	Y	BD, 2 $x10^5$ - $1.4x10^6$	Visual Assessment	58,59
	Shipboard	1	0	-	Y	8	Visual Assessment	56
NEI	Laboratory	-	-	-	-	-	-	-
	Land-Based	5	1	Y	Y	0, Unk (% Survival)	Visual Assessment	170,171
	Shipboard	2	1	Y	Y	0 - 7	Visual Assessment	172
NK-O3	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
ntorreiro	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Nutech O3 Inc.	Laboratory	3	0	4	Y	$1.2x10^2$ - $1.2x10^4$	Visual Assessment	154
	Land-Based	3	0	Y	Y	Unk (% Live)	Visual Assessment	50
	Shipboard	3	2	12	Y	0 - 150	Visual Assessment	195
OceanSaver	Laboratory	-	-	-	-	-	-	-
	Land-Based	14	2	3	Y	0-135	Visual Assessment	139
	Shipboard	3	1	3	Y	0 - 9720	Visual Assessment	176
OptiMarin	Laboratory	1	0	-	Y	> 0	Visual Assessment	57
	Land-Based	12	8	3	Y	0-144	Microscope/Mobility	136
	Shipboard	8	0	9	Y	1.4 - ~5500	Visual Assessment	140
Panasia Co.	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Pinnacle Ozone Solutions	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Qingdau Headway Tech	Laboratory	-	-	-	-	-	-	-
	Land-Based	13	4	3	Y	0 - 15.3	Microscope/Mobility	142
	Shipboard	3	3	Y	Y	0	Microscope/Mobility	147
Resource Ballast Tech	Laboratory	-	-	-	-	-	-	-
	Land-Based	3	3	Unk	Y	0	Microscope/Mobility	3
	Shipboard	2	0	3	Y	0.6 - 1.1	Microscope/Mobility	3
RWO Marine Water Tech	Laboratory	1	1	-	-	0	Visual Assessment	85
	Land-Based	2	2	N	Y	0	"Standard Operating Proc."	30,31
	Shipboard	-	-	-	-	-	-	-

Unk = Unknown, BD = Below Detection Limits

Appendix A1 Organisms > 50 µm

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls	# Organisms/cubic meter	Methods	Reference
Severn Trent[1]	Laboratory	-	-	-	-	-	-	-
	Land-Based	5	3	3-4	Y	0 - ~4x10^5	Visual Assessment	49
	Shipboard	-	-	-	-	-	-	-
Siemens	Laboratory	-	-	-	-	-	-	-
	Land-Based	3	0	5	Y	15-57	Microscope/Mobility	78
	Shipboard	-	-	-	-	-	-	-
Sunrui CFCC	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Techcross Inc.	Laboratory	-	-	-	-	-	-	-
	Land-Based	11	8	3	Y	0-6	Visual Assessment	62
	Shipboard	3	3	3	Y	0	Visual Assessment	62
Wartsila	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-

[1] System has added a filter since testing was conducted.

Appendix A2 Organisms 10 - 50 µm

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls	# Organisms/ml	Methods	Reference
21 Century Shipbuilding	Laboratory	2	0	Unk	Unk	1	Unk	117
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Alfa Laval	Laboratory	1	0	-	-	Unk (% Reduction)	Visual Assesment	82
	Land-Based	10	3	6	Y	0-92.5	Microscope/stain (CDFA_AM), MPN	137
	Shipboard	4	1	12	Y	0-1.7	Microscope/stain (CDFA_AM), MPN	138
Aquaworx ATC Gmbh	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
atg UV Tech	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
ATLAS-DANMARK	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Auramarine Ltd.	Laboratory	-	-	-	-	-	-	-
	Land-Based	7	0	Y	Y	<0.1 - >240	MPN, plate counts	4,165
	Shipboard	-	-	-		-	-	-
Brillyant Marine LLC	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Coldharbour Marine	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
COSCO/Tsinghua Univ.	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
DESMI Ocean Guard A/S	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Ecochlor	Laboratory[1]	2	0	2	Y	<0.1 - >60, Unk ([Chl a])	Visual Assessment, MPN, [Chl a]	148
	Land-Based	11	9	N	Y	0.0 - 3.7	Visual, Sytox, flow cytometer, PAM fluorometer	133
	Shipboard[1]	1	1	3	Y	0-81	Visual Assessment, [Chl a]	76
EcologiQ	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Electrichlor	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
ETI	Laboratory	-	-	-	-	-	-	-
	Land-Based	3	0	2-3	Y	1 - 1.5	Grow out (+, -), Flow cam	73,74,75
	Shipboard	-	-	-	-	-	-	-
Ferrate Treatment Tech.	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-

Unk = Unkown, MPN = Most Probable Number, 1 = Filter added to system since testing conducted

Appendix A2 Organisms 10 - 50 µm								
Manufacturer	**Location**	**# Tests**	**# Tests Met Std**	**Replicates**	**Controls**	**# Organisms/ml**	**Methods**	**Reference**
Hamann Evonik Degussa	Laboratory	3	3	Y	Y	0 (100% Mortality)	Visual Assessment, Sytox Green	44,46,182
	Land-Based	18	17	3	Y	0 - <0.01	Flow Cytometer, Sytox stain	132
	Shipboard	5	0	3	Y	<0.1	Flow Cytometer, Sytox stain, PAM fluorometry	132
Hamworthy Greenship	Laboratory	-	-	-	-	-	-	-
	Land-Based	5	3	Y	Y	0 - 7	Total Counts	167
	Shipboard	-	-	-	-	-	-	-
Hi Tech Marine	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	2	Unk	Unk	Unk	Unk (% Mortality)	Unk	51
Hitachi	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Hyde Marine	Laboratory	1	0	Y	Y	26 - 210	Visual Assessment, Coulter, MPN	70
	Land-Based	10	0	Y	Y	0.0 - 10.9	SYTOX Green, FCM, [Chl a]	134
	Shipboard	3	1	9	Y	0.002 - 0.10	Visual, [Chl a], Grow out, neutral red	192
Hyundai Heavy Industries (1)	Laboratory	2	2	9	Y	0	Unk	107
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Hyundai Heavy Industries (2)	Laboratory	2	2	9	Y	0	Unk	MEPC 60/2/6
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
JFE Engineering Corp	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Kwang San Co. Ltd.	Laboratory	2	0	Unk	Y	1	Unk	120
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
MAHLE	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
MARENCO	Laboratory	-	-	-	-	-	-	-
	Land-Based	1	0	3	Y	0.05 - 0.186	MPN, [Chl a], ^{14}C, PAM	64,65,189
	Shipboard	-	-	-	-	-	-	-
Maritime Solutions Inc.	Laboratory	-	-	-	-	-	-	-
	Land-Based	5	0	5	Y	0.6-12	CDFA-AM, Chl a	79
	Shipboard	-	-	-	-	-	-	-
Mexel Industries	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-

Unk = Unkown, MPN = Most Probable Number

Appendix A2 Organisms 10 - 50 µm								
Manufacturer	**Location**	**# Tests**	**# Tests Met Std**	**Replicates**	**Controls**	**# Organisms/ml**	**Methods**	**Reference**
MH Systems	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Mitsui Engineering	Laboratory	-	-	-	-	-	-	-
	Land-Based	4	Unk	3-5	Y	BD, 206.6 - 387.4, Unk	Visual Assessment (20 - 50um)	58,59
	Shipboard	1	Unk	Unk	Y	BD	Visual Assessment	56
NEI	Laboratory	-	-	-	-	-	-	-
	Land-Based	1	0	Y	Y	Unk	[Chl a]	170,171
	Shipboard	4	Unk	Y	Y	443 - 593	Total Counts (Preserved), [Chl a], Regrowth	172
NK-O3	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
ntorreiro	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Nutech O3 Inc.	Laboratory	3	0	4	Y	Unk	[Chl a]	154
	Land-Based	2	0	Y	Y	22 - 190	Total Counts (Preserved)	50
	Shipboard	3	0	5	Y	0.016 - 4	[Chl a], Grow Out, Counts	195
OceanSaver	Laboratory	-	-	-	-	-	-	-
	Land-Based	14	5	3	Y	0-8.7	dilution, microscopy (CFDA stain), plate counts	139
	Shipboard	2	0,Unk	3	Y	0-2.8	Microscope (CFDA stain), Photosynethic rates	176
OptiMarin	Laboratory	1	0	-	Y	26 - 210	MPN, Coulter	57
	Land-Based	12	6	3	Y	0-92	Microscope/stain, MPN, agar plates	136
	Shipboard	8	2	9	Y	0 - 3.9	Serial Dilution, Counts, Grow out	140
Panasia Co.	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Pinnacle Ozone Solutions	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Qingdau Headway Tech	Laboratory	-	-	-	-	-	-	-
	Land-Based	13	8	3	Y	0-35	Serial dilution, CFDA-AM	142
	Shipboard	3	3	Y	Y	0.0007 - 0.003	Microscope/stain (CDFA), MPN	147
Resource Ballast Tech	Laboratory	-	-	-	-	-	-	-
	Land-Based	3	0	Unk	Y	0.32 - 2.7	FDA stain, Flow CAM	3
	Shipboard	2	0	3	Y	0.5 - 1.4	FDA stain, Flow CAM	2,3
RWO Marine Water Tech	Laboratory	1	1	Unk	Unk	0	Visual Assessment	85
	Land-Based	2	1	N	Y	0 - 1	"Standard Operating Proc."	30,31
	Shipboard	-	-	-	-	-	-	-

Unk = Unknown, BD = Below Detection Limits, MPN = Most Probably Number

Appendix A2 Organisms 10 - 50 µm

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls	# Organisms/ml	Methods	Reference
Severn Trent[1]	Laboratory	-	-	-	-	-	-	-
	Land-Based	5	2	3-4	Y	0.002 - 10, BD ([Chl a])	MPN, [Chl a]	49
	Shipboard	-	-	-	-	-	-	-
Siemens	Laboratory	-	-	-	-	-	-	-
	Land-Based	3	0	5	Y	0.5-6.8	CFDA PAM, Chl a	78
	Shipboard	-	-	-	-	-	-	-
Sunrui CFCC	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Techcross Inc.	Laboratory	-	-	-	-	-	-	-
	Land-Based	11	9	3	Y	0-4	Light micro., epifluor. and fluorometer (FDA stain)	62
	Shipboard	3	3	3	Y	0	Light micro., epifluor. and fluorometer (FDA stain)	62
Wartsila	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-

Unk = Unknown, BD = Below Detection Limits, MPN = Most Probably Number, 1 = Filter added to system since testing conducted

Appendix A3 *E. coli*

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls used	# CFU/100 ml	Methods	Reference
21 Century Shipbuilding	Laboratory	2	2	Unk	Unk	0	Unk	117
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Alfa Laval	Laboratory	1	0	-	-	Unk (% Reduction)	-	82
	Land-Based	12	12	6	Y	0 - 800	Membrane filtration	137
	Shipboard	4	4*	9	Y	0*	Membrane filtration	138
Aquaworx ATC Gmbh	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
atg UV Technology	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
ATLAS-DANMARK	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Auramarine Ltd.	Laboratory	-	-	-	-	-	-	-
	Land-Based	1	1	Y	Y	<1	Unk	4,165
	Shipboard	-	-	-		-	-	-
Brillyant Marine LLC	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Coldharbour Marine	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
COSCO/Tsinghua Univ.	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
DESMI Ocean Guard A/S	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Ecochlor	Laboratory	-	-	-	-	-	-	-
	Land-Based	10	10	N	Y	<0.1	NEN-EN-ISO 9308-1	133
	Shipboard[1]	1	1	3	Y	0 - ~21	Idexx Labs Colilert	76
EcologiQ	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Electrichlor	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
ETI	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Ferrate Treatment Tech.	Laboratory	1	0	-	-	300	Idexx Labs QuantiTray MPN	22
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-

Unk = Unkow n, MPN = Most Probable Number, 1 = Filter added to treatment system since testing conducted, * = Initial concentration at intake w as 0, unk or non-detectable

Appendix A3 *E. coli*								
Manufacturer	**Location**	**# Tests**	**# Tests Met Std**	**Replicates**	**Controls used**	**# CFU/100 ml**	**Methods**	**Reference**
Hamann Evonik Degussa	Laboratory	1	1	Y	-	0	Plate Counts	46
	Land-Based	12	12	3	Y	<0.1/ml	Membrane filtration	132
	Shipboard	4	4*	3	Y	<0.1/ml	Membrane filtration	132
Hamworthy Greenship	Laboratory	1	1	-	Y	>1000 - 3000	Plate Counts	29
	Land-Based	5	5	Y	Y	0 - 1	Unk	167
	Shipboard	-	-	-	-	-	-	-
Hi Tech Marine	Laboratory	-	-	-	-	-	-	-
	Land-Based	6	6	Y	Y	0	APHA 9222	32
	Shipboard	-	-	-	-	-	-	-
Hitachi	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Hyde Marine	Laboratory	-	-	-	-	-	-	-
	Land-Based	10	10*	N	Y	<10	NEN EN ISO 9308-1	134
	Shipboard	3	3*	9	Y	0	Idexx Labs Colisure	192
Hyundai Heavy Industries (1)	Laboratory	2	2	9	Y	0	Unk	107
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Hyundai Heavy Industries (2)	Laboratory	2	2	9	Y	0	Unk	119
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
JFE Engineering Corp	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Kwang San Co. Ltd.	Laboratory	2	2	Unk	Y	0	Unk	120
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
MAHLE	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
MARENCO	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Maritime Solutions Inc.	Laboratory	-	-	-	-	-	-	-
	Land-Based	5	5	5	Y	0	IDEXX kit, Membrane Filtration	79
	Shipboard	-	-	-	-	-	-	-
Mexel Industries	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-

Unk = Unknown, * = Initial concentration at intake was 0, unk or non-detectable

Appendix A3 *E. coli*

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls used	# CFU/100 ml	Methods	Reference
MH Systems	Laboratory	7	0, Unk	Unk	Y	BD-420	IDEXX Colilert 18	41
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Mitsui Engineering	Laboratory	-	-	-	-	-	-	-
	Land-Based	2	0	3	Y	BD, Unk	Plate Counts	58
	Shipboard	-	-	-	-	-	-	-
NEI	Laboratory	-	-	-	-	-	-	-
	Land-Based	1	0	Y	Y	10 - 160	Idexx Labs MPN Kit	170,171
	Shipboard	2	2*	Y	Y	<100	Idexx Labs MPN Kit	172
NK-O3	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
ntorreiro	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Nutech O3 Inc.	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	3	3*	11-12	Y	0*	IDEXX Labs MPN Kit	195
OceanSaver	Laboratory	-	-	-	-	-	-	-
	Land-Based	14	14*	3	Y	0-123	Membrane Filtration	139
	Shipboard	3	3*	3	Y	0*	Membrane Filtration	176
OptiMarin	Laboratory	-	-	-	-	-	-	-
	Land-Based	12	12*	3	Y	0-2	Membrane Filtration	136
	Shipboard	8	8*	9	Y	0	Membrane Filtration	140
Panasia Co.	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Pinnacle Ozone Solutions	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Qingdau Headway Tech	Laboratory	-	-	-	-	-	-	-
	Land-Based	13	13*	3	Y	<1	Plate Counts	142
	Shipboard	3	3*	Y	Y	0	Membrane Filtration	147
Resource Ballast Tech	Laboratory	-	-	-	-	-	-	-
	Land-Based	3	3	Unk	Y	0	Unk	3
	Shipboard	2	2*	3	Y	0	"Standard methods"	3
RWO Marine Water Tech	Laboratory	-	-	-	-	-	-	-
	Land-Based	2	2	N	Y	<15 - 32	EN ISO 9303-3	30,31
	Shipboard	-	-	-	-	-	-	-

Unk = Unknown, MPN = Most Probable Number, BD = Below Detection Limits, * = Initial concentration at intake was 0, unk or non-detectable

Appendix A3 *E. coli*

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls used	# CFU/100 ml	Methods	Reference
Severn Trent	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Siemens	Laboratory	-	-	-	-	-	-	-
	Land-Based	3	3	5	Y	0.10 - 0.20	Membrane Filtration	78
	Shipboard	-	-	-	-	-	-	-
Sunrui CFCC	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Techcross Inc.	Laboratory	-	-	-	-	-	-	-
	Land-Based	10	10*	3	Y	0	Plate counts	62
	Shipboard	3	3*	3	Y	0	Plate Counts	62
Wartsila	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-

Unk = Unknown, * = Initial concentration at intake was 0, unk or non-detectable

Appendix A4 Intestinal Enterococci

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls	# CFU/100 ml	Methods	Reference
21 Century Shipbuilding	Laboratory	2	2	Unk	Unk	0	Unk	117
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Alfa Laval	Laboratory	-	-	-	-	-	-	-
	Land-Based	10	10	6	Y	0 - 4	Membrane filtration	137
	Shipboard	4	4*	10	Y	0	Membrane filtration	138
Aquaworx ATC Gmbh	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
atg UV Technology	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
ATLAS-DANMARK	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Auramarine Ltd.	Laboratory	-	-	-	-	-	-	-
	Land-Based	1	1	Y	Y	<1	Unk	4,165
	Shipboard	-	-	-		-	-	-
Brillyant Marine LLC	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Coldharbour Marine	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
COSCO/Tsinghua Univ.	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
DESMI Ocean Guard A/S	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Ecochlor	Laboratory	-	-	-	-	-	-	-
	Land-Based	11	11	N	Y	<1	NEN-EN ISO 7899-2	133
	Shipboard	-	-	-		-	-	-
EcologiQ	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Electrichlor	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
ETI	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Ferrate Treatment Tech.	Laboratory	1	0	Unk	Unk	80	Idexx Labs QuantiTray MPN	22
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-

Unk = Unknown, * = Initial concentration at intake was 0, unk or non-detectable.

Appendix A4 Intestinal Enterococci

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls	# CFU/100 ml	Methods	Reference
Hamann Evonik Degussa	Laboratory	-	-	-	-	-	-	-
	Land-Based	12	12	3	Y	<0.1/ml	Membrane filtration	132
	Shipboard	4	4*	3	Y	<0.1/ml	Membrane filtration	132
Hamworthy Greenship	Laboratory	-	-	-	-	-	-	-
	Land-Based	5	5*	Y	Y	0	Unk	167
	Shipboard	-	-	-	-	-	-	-
Hi Tech Marine	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Hitachi	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Hyde Marine	Laboratory	-	-	-	-	-	-	-
	Land-Based	10	10*	N	Y	<100	NEN EN ISO 7899-2	134
	Shipboard	3	3*	9	Y	0-3.4	Idexx Labs Enterolert	192
Hyundai Heavy Industries (1)	Laboratory	2	2*	9	Y	0	Unk	107
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Hyundai Heavy Industries (2)	Laboratory	2	2	9	Y	0	Unk	119
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
JFE Engineering Corp	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Kwang San Co. Ltd.	Laboratory	2	2	Unk	Y	0	Unk	120
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
MAHLE	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
MARENCO	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Maritime Solutions Inc.	Laboratory	-	-	-	-	-	-	-
	Land-Based	5	5	5	Y	0	IDEXX kit, Membrane Filtration	79
	Shipboard	-	-	-	-	-	-	-
Mexel Industries	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-

Unk = Unknown, * = Initial concentration at intake was 0, unk or non-detectable.

Appendix A4 Intestinal Enterococci

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls	# CFU/100 ml	Methods	Reference
MH Systems	Laboratory	3	0	Unk	Y	90-350	IDEXX Enterolert	41
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Mitsui Engineering	Laboratory	-	-	-	-	-	-	-
	Land-Based	2	0	3	Y	BD, Unk	Plate counts	58
	Shipboard	-	-	-	-	-	-	-
NEI	Laboratory	-	-	-	-	-	-	-
	Land-Based	1	0	Y	Y	36	Idexx Labs MPN Kit	170,171
	Shipboard	2	Unk	Y	Y	Unk	Idexx Labs MPN Kit	172
NK-O3	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
ntorreiro	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Nutech O3 Inc.	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	3	3*	11-12	Y	0*	Idexx Labs Enterolert	195
OceanSaver	Laboratory	-	-	-	-	-	-	-
	Land-Based	14	9*	3	Y	0-133	Membrane Filtration	139
	Shipboard	3	3*	3	Y	0*-9	Membrane Filtration	176
OptiMarin	Laboratory	-	-	-	-	-	-	-
	Land-Based	12	12*	3	Y	0	Membrane Filtration	136
	Shipboard	8	8*	9	Y	0	Membrane Filtration	140
Panasia Co.	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Pinnacle Ozone Solutions	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Qingdau Headway Tech	Laboratory	-	-	-	-	-	-	-
	Land-Based	13	13*	3	Y	0.3 - <1	Membrane Filtration	142
	Shipboard	3	3*	Y	Y	0.3 - 1	Membrane Filtration	147
Resource Ballast Tech	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	2	2	3	Y	5.0 - 9.3	"Standad methods"	3
RWO Marine Water Tech	Laboratory	-	-	-	-	-	-	-
	Land-Based	2	2	N	Y	neg	Membrane Filtration	30,31
	Shipboard	-	-	-	-	-	-	-

Unk = Unknown, BD = Below Detection Limits, * = Initial concentration at intake was 0, unk or non-detectable

Appendix A4 Intestinal Enterococci

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls	# CFU/100 ml	Methods	Reference
Severn Trent	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Siemens	Laboratory	-	-	-	-	-	-	-
	Land-Based	3	3	5	Y	1.00 - 2.22	IDEXX kit	78
	Shipboard	-	-	-	-	-	-	-
Sunrui CFCC	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Techcross Inc.	Laboratory	-	-	-	-	-	-	-
	Land-Based	11	11*	3	Y	0-5	Plate counts	62
	Shipboard	2	2*	3	Y	0	Plate counts	62
Wartsila	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-

Unk = Unknown, BD = Below Detection Limits, * = Initial concentration at intake was 0, unk or non-detectable

Appendix A5 *Vibrio cholerae*								
Manufacturer	**Location**	**# Tests**	**# Tests Met Std**	**Replicates**	**Controls**	**# Organisms/100 ml**	**Methods**	**Reference**
21 Century Shipbuilding	Laboratory	2	2	Unk	Unk	0	Unk	117
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Alfa Laval	Laboratory	-	-	-	-	-	-	-
	Land-Based	10	10*	3	Y	<1*	Supplemented Agar Plates	137
	Shipboard	4	4*	9	Y	<1*	Supplemented Agar Plates	138
Aquaworx ATC Gmbh	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
atg UV Technology	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
ATLAS-DANMARK	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Auramarine Ltd.	Laboratory	-	-	-	-	-	-	-
	Land-Based	1	1*	Y	Y	<1	Unk	4,165
	Shipboard	-	-	-		-	-	-
Brillyant Marine LLC	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Coldharbour Marine	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
COSCO/Tsinghua Univ.	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
DESMI Ocean Guard A/S	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Ecochlor	Laboratory[1]	1	1	2	Y	0 (% cover)	Plate Counts	148
	Land-Based	-	-	-	-	-	-	-
	Shipboard[1]	1	0	3	Y	BD - ~1000	Unk	76
EcologiQ	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Electrichlor	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
ETI	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Ferrate Treatment Tech.	Laboratory	1	0	Unk	Unk	108	Indexx Labs QuantiTray MPN	22
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-

Unk = Unknown, * = Initial concentration at intake was 0, unk or non-detectable, 1 = Filter added to system since testing conducted

Appendix A5 ***Vibrio cholerae***

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls	# Organisms/100 ml	Methods	Reference
Hamann Evonik Degussa	Laboratory	-	-	-	-	-	-	-
	Land-Based	1	1*	N	N	0*	culture, molecular methods	166
	Shipboard	-	-	-	-	-	-	-
Hamworthy Greenship	Laboratory	3	2	Unk	N	0-1	TSB broth, incubation	48
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Hi Tech Marine	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Hitachi	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Hyde Marine	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	3	3*	9	Y	0*	PCR	192
Hyundai Heavy Industries (1)	Laboratory	2	Unk	9	Y	BD	Unk	107
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Hyundai Heavy Industries (2)	Laboratory	2	2*	9	Y	0	Unk	119
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
JFE Engineering Corp	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Kwang San Co. Ltd.	Laboratory	2	2*	Unk	Y	0	Unk	120
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
MAHLE	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
MARENCO	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Maritime Solutions Inc.	Laboratory	-	-	-	-	-	-	-
	Land-Based	5	5*	5	Y	0*	DFA	79
	Shipboard	-	-	-	-	-	-	-
Mexel Industries	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-

Unk = Unknown, BD = Below Detection, * = Initial concentration at intake was 0, unk or non-detectable

Appendix A5 *Vibrio cholerae*

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls	# Organisms/100 ml	Methods	Reference
MH Systems	Laboratory	1	Unk	3	N	Unk (% Reduction)	Plate Counts	52
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Mitsui Engineering	Laboratory	-	-	-	-	-	-	-
	Land-Based	2	0	3	Y	BD, Unk	Plate Counts	58
	Shipboard	-	-	-	-	-	-	-
NEI	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	2	2*	Y	Y	0	DFA	172
NK-O3	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
ntorreiro	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Nutech O3 Inc.	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	3	3*	11-12	Y	0*	Unknown	195
OceanSaver	Laboratory	-	-	-	-	-	-	-
	Land-Based	14	14*	3	Y	<1*	Plate counts (TCBS agar)	139
	Shipboard	3	3*	3	Y	0*	Plate counts (TCBS agar)	176
OptiMarin	Laboratory	-	-	-	-	-	-	-
	Land-Based	12	12*	3	Y	<1	Supplemented Agar Plates	136
	Shipboard	8	8*	9	Y	<1	Filtration, Plate count, PCR	140
Panasia Co.	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Pinnacle Ozone Solutions	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Qingdau Headway Tech	Laboratory	-	-	-	-	-	-	-
	Land-Based	13	13*	3	Y	<1	Membrane Filtration	142
	Shipboard	3	3*	Y	Y	0	Membrane Filtration	147
Resource Ballast Tech	Laboratory	-	-	-	-	-	-	-
	Land-Based	3	3*	Unk	Y	0	Unk	3
	Shipboard	2	2*	3	Y	0	Unk	3
RWO Marine Water Tech	Laboratory	-	-	-	-	-	-	-
	Land-Based	2	2	N	Y	neg	APHA Std. Method	31,31
	Shipboard	-	-	-	-	-	-	-

Unk = Unknown, BD = Below Detection Limits, DFA = Direction Fluorescent Antibody, * = Initial concentration at intake was 0, unk or non-detectable

Appendix A5 *Vibrio cholerae*

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls	# Organisms/100 ml	Methods	Reference
Severn Trent	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Siemens	Laboratory	-	-	-	-	-	-	-
	Land-Based	3	3*	5	Y	0	DFA	78
	Shipboard	-	-	-	-	-	-	-
Sunrui CFCC	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Techcross Inc.	Laboratory	-	-	-	-	-	-	-
	Land-Based	11	11*	3	Y	0*	Plate counts (TCBS agar)	62
	Shipboard	3	3*	3	Y	0*	Plate counts (TCBS agar)	62
Wartsila	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-

Unk = Unknown, BD = Below Detection Limits, DFA = Direction Fluorescent Antibody, * = Initial concentration at intake was 0, unk or non-detectable

Appendix A6 Organims < 10 µm (Bacteria)

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls	# Organisms/100 ml	Methods	Reference
21 Century Shipbuilding	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Alfa Laval	Laboratory	1	0	-	-	Unk (% Reduction)	Visual Assesment	82
	Land-Based	8	0	6	Y	820/ml - $4x10^8$/ml	Agar Plate Counts	137
	Shipboard	2	2	9	Y	480 - 800	Plate Counts, Difco marine agar	141
Aquaworx ATC Gmbh	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
ATG Willand	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
ATLAS-DANMARK	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Auramarine Ltd.	Laboratory	-	-	-	-	-	-	-
	Land-Based	1	0	Y	Y	80/ml - 1200/ml	Unk	4,165
	Shipboard	-	-	-		-	-	-
Brillyant Marine LLC	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Coldharbour Marine	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
COSCO/Tsinghua Univ.	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
DESMI Ocean Guard A/S	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Ecochlor	Laboratory[1]	2	2	2	Y	0,Unk (% of control, % Plate cover)	Plate Counts, ^{3}H-leucine	148
	Land-Based	11	8	N	Y	<10 - 1700	plate, NEN-EN-ISO 6222:1999	133
	Shipboard[1]	1	1	3	Y	BD	Plate Counts, ^{3}H-leucine	76
EcologiQ	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Electrichlor	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
ETI	Laboratory	1	0	3	Y	-	Plate Counts, BacLight	72
	Land-Based	3	0	2-3	Y	$5x10^7$ - $1x10^9$	Grow out (+, -), FCM/PicoGreen	73,74,75
	Shipboard	-	-	-	-	-	-	-
Ferrate Treatment Tech.	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-

Unk = Unknown, BD = Below Detection Limits, FCM = Flow Cytometer, 1 = Filter added to system since testing conducted

Appendix A6 Organims < 10 µm (Bacteria)								
Manufacturer	**Location**	**# Tests**	**# Tests Met Std**	**Replicates**	**Controls**	**# Organisms/100 ml**	**Methods**	**Reference**
Hamann Evonik Degussa	Laboratory	2	0	Y	Y	$3.8x10^7$ - $4.6x10^7$	Plate Counts, PicoGreen	182
	Land-Based	13	1	3	Y	<10/ml - 4.6×10^7	PicoGreen, Agar Plate	132
	Shipboard	4	3	3	Y	5-15/ml	heterotrophic bacteria, plate	132
Hamworthy Greenship	Laboratory	-	-	-	-	-	-	-
	Land-Based	5	2	Y	Y	0 - 6000	Unk	167
	Shipboard	-	-	-	-	-	-	-
Hi Tech Marine	Laboratory	-	-	-	-	-	-	-
	Land-Based	6	5	Y	Y	1 - $1.9x10^6$	APHA 9215B, pour plate method	32
	Shipboard	-	-	-	-	-	-	-
Hitachi	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Hyde Marine	Laboratory	1	0	Y	Y	~5000 - 7000	Plate Counts	70
	Land-Based	10	5	Y	Y	<1000 - >100000	Plate Counts, AODC	134
	Shipboard	3	3	9	Y	1 - 148	Plate Counts	192
Hyundai Heavy Industries (1)	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Hyundai Heavy Industries (2)	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
JFE Engineering Corp	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Kwang San Co. Ltd.	Laboratory	2	2	Unk	Y	0	Unk	120
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
MAHLE	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
MARENCO	Laboratory		-	-	-	-	-	-
	Land-Based	3	2	3	Y	0 - $\sim5x10^8$	Plate Counts, Membrane Filtration	64,65,189
	Shipboard	-	-	-	-	-	-	-
Maritime Solutions Inc.	Laboratory	-	-	-	-	-	-	-
	Land-Based	5	3	5	Y	116.88-7860	Plate Counts	79
	Shipboard	-	-	-	-	-	-	-
Mexel Industries	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Unk = Unknown, AODC = Acridine Orange Direct Counts, FCM = Flow Cytometer								

Appendix A6 Organims < 10 µm (Bacteria)								
Manufacturer	**Location**	**# Tests**	**# Tests Met Std**	**Replicates**	**Controls**	**# Organisms/100 ml**	**Methods**	**Reference**
MH Systems	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Mitsui Engineering	Laboratory	-	-	-	-	-	-	-
	Land-Based	2	0	3	Y	BD, Unk	Plate Counts	58
	Shipboard	1	0	-	Y	BD	Plate Counts	56
NEI	Laboratory	-	-	-	-	-	-	-
	Land-Based	2	0	Y	Y	> $1x10^8$	FCM	170,171
	Shipboard	2	0	Y	Y	$7.3x10^7$ - $7.9x10^7$	FCM	172
NK-O3	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
ntorreiro	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Nutech O3 Inc.	Laboratory	3	3	4	Y	$\leq 10^1$ - 10^8	Plate Counts, Membrane Filtration	154
	Land-Based	3	3	Y	Y	$3x10^{-1}$ - $3x10^2$	Plate Counts, Membrane Filtration	50
	Shipboard	2	2	9-12	Y	0	Plate Counts, Filtration	195
OceanSaver	Laboratory	-	-	-	-	-	-	-
	Land-Based	5	5	3	Y	0 - $8.2x10^5$/ml	Plate Counts	139
	Shipboard	-	-	-	-	-	-	-
OptiMarin	Laboratory	2	0	Unk	Y	~ $5x10^3$ - ~$7x10^3$	Plate Counts	57
	Land-Based	12	2	3	Y	9-220/ml	Agar Plate Counts	136
	Shipboard	-	-	-	-	-	-	-
Panasia Co.	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Pinnacle Ozone Solutions	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Qingdau Headway Tech	Laboratory	-	-	-	-	-	-	-
	Land-Based	13	9	3	Y	30 - 19000	Plate Counts	142
	Shipboard	3	3	Y	Y	243 - 590	Plate Counts	147
Resource Ballast Tech	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
RWO Marine Water Tech	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-

Unk = Unknown, FCM = Flow Cytometer, BD = Below Detection Limits

Appendix A6 Organims < 10 µm (Bacteria)

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls	# Organisms/100 ml	Methods	Reference
Severn Trent[1]	Laboratory	-	-	-	-	-	-	-
	Land-Based	4	4	3-4	Y	$<1 - 10^{10}$	Plate Counts, Membrane Filtration	49
	Shipboard	-	-	-	-	-	-	-
Siemens	Laboratory	-	-	-	-	-	-	-
	Land-Based	3	0	5	Y	169100 - 1515200	Plate Counts	78
	Shipboard	-	-	-	-	-	-	-
Sunrui CFCC	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Techcross Inc.	Laboratory	-	-	-	-	-	-	-
	Land-Based	4	4	3	Y	0 - 500	plate counts, DAFI stain	63
	Shipboard	3	Unk	3	Y	Unk	Fluorescent microscopy (DAFI)	62
Wartsila	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-

Unk = Unknown, 1 = Filter added to system since testing conducted.

APPENDIX B

California State Lands Commission
Advisory Panel Members

Ryan Albert	U.S. Environmental Protection Agency
Marian Ashe (2007 only)	California Department of Fish and Game
John Berge	Pacific Merchant Shipping Association
Dave Bolland	Association of California Water Agencies
Brad Chapman (2007,2009)	Chevron Shipping Company
Andrew Cohen	San Francisco Estuary Institute
Tim Eichenberg (2007 only)	The Ocean Conservancy
Richard Everett	United States Coast Guard
Naomi Feger	San Francisco Bay Regional Water Quality Control Board
Andrea Fox	California Farm Bureau Federation
Dominic Gregorio	State Water Resources Control Board
Marc Holmes	The Bay Institute
Rian Hooff	Oregon Department of Environmental Quality
Bill Jennings	The DeltaKeeper
Edward Lemieux	Naval Research Laboratory
Karen McDowell	San Francisco Estuary Project
Steve Morin	Chevron Shipping Company LLC
Allen Pleus	Washington Department of Fish & Wildlife
Darrin Polhemus	State Water Resources Control Board
Kevin Reynolds	The Glosten Associates
Greg Ruiz	Smithsonian Environmental Research Center
Spencer Schilling	Herbert Engineering Corp.
Sharon Shiba	California Department of Fish and Game, OSPR
Jon Stewart	International Maritime Technology Consultants Inc.
Lisa Swanson	Matson Navigation
Mark Sytsma	Portland State University
Drew Talley (2007, 2009)	San Francisco Bay National Estuarine Research Reserve
Kim Ward (2007, 2009)	State Water Resources Control Board
Nick Welschmeyer	Moss Landing Marine Laboratory

California State Lands Commission
2010 Treatment Technology Assessment Report
Technical Advisory Panel
April 15, 2010
Meeting Notes

Attendees

Sharon Shiba, California Department of Fish and Game

Steve Morin, Chevron Shipping

Maurya Falkner, California State Lands Commission

Jackie Mackay, California State Lands Commission

Nicole Dobroski, California State Lands Commission

Lynn Takata, California State Lands Commission

Gary Gregory, California State Lands Commission

Kevin Mercier, California State Lands Commission

Cameron Baker, Herbert Engineering

Tom Burke, California State Lands Commission

Rian Hooff, Oregon Department of Environmental Quality

Lisa Swanson, Matson Navigation

Nick Welschmeyer, Moss Landing Marine Laboratories

John Berge, Pacific Merchant Shipping Association

Ryan Albert, U.S. Environmental Protection Agency

Purpose of Meeting

California Public Resources Code requires that the California State Lands Commission produce a report for the state legislature reviewing the efficacy, availability and environmental impacts of ballast water treatment systems 18 months before the implementation dates for California's performance standards for ballast water discharge. The purpose of this meeting is to review and discuss a draft report evaluating treatment systems for new build vessels with a ballast water capacity over 5000 metric tons (MT), before the implementation date on January 1, 2012.

Report Timeline

This draft report was provided to this Technical Advisory Panel (Panel) during the week of April 5th. Today's meeting will focus on discussion of major content issues for that draft. To maximize discussion time, the TAG is requested to submit editorial type comments via email by April 23, rather than discuss them at this meeting. Following this meeting, the goal will be to complete a revised draft in early May that will be provided to Commission executive staff for review. A draft final version will be posted for public comment on the Commission website two weeks before the Commission meeting (currently scheduled for June 28th). Public comments may be submitted in writing before the Commission meeting or comments may be submitted in person during the public comment portion at the meeting. The final, Commission-approved report is due to the California State Legislature by July 1, 2010.

Highlights of the Draft Report

The format of this report is based on the previous 2009 assessment report that evaluated treatment systems for new build vessels with ballast water capacity less than 5000 MT. Revisions/updates for the 2010 draft include:

- New information on related State and Federal programs
- This report covers 46 systems – ranging from chemical to UV filtration systems (majority).
- **Efficacy:** The quality and quantity of testing data from treatment vendors has improved, including better 3rd party testing data and more large scale land-based facility testing. Though most testing has been done to meet International Maritime Organization (IMO) standards and requirements, the data also addresses California's standards.
- Robust and widely accepted test procedures still do not exist for viral standards, so the systems were not evaluated against California's viral standard.
- Nine systems appear to have the potential to comply with California's standards, though California will not be approving systems. Commission staff reviewed the available data, and if at least one replicate met CA standards, the system was considered to have the "potential" to comply. Ultimately, it is up to vessel

owners/operators working with vendors to select systems that are appropriate for their vessels' routes and water conditions.

- Of the 9 systems, 8 are commercially available. The one that is not is the Hamann system, which was pulled from production due to potential toxicity problems. It is not clear if they will continue to pursue the system.
- **Availability:** The ability of systems to handle large ballast water capacities was considered a potentially new issue with the current class of vessels, and was investigated by staff. However, since most systems treat on uptake and/or discharge, the ballast water uptake/discharge rates of ballast pumps were found to be a more important factor than total ballast water capacity in determining the availability of systems. Systems must be able to keep pace with ballasting rates. Data on pump rates of vessels visiting California was reviewed, and in general, most systems are designed to keep up with observed pump rates.
- **Environmental Impacts:** Current requirements are the purview of the U.S. Environmental Protection Agency's (EPA) Vessel General Permit and California additions through the Clean Water Act Section 401 Certification process. These issues are the purview of the California State Water Resources Control Board (Water Board) rather than the Commission, but staff did evaluate systems against the chlorine discharge standard, since several systems use it as an active substance. Most systems that use chlorine can comply with chlorine standard, but not all. Currently the systems that may not comply did not provide adequate or appropriate data. For example, the detection limits of the tests measuring chlorine residuals was not sensitive enough to determine compliance with EPA standards. Commission staff is encouraging vendors to consult with Water Board to make sure they meet these and other water quality requirements.
- **Economics:** Costs have not changed significantly from the 2009 report. There has been a slight drop in price for smaller capacity systems (200 cubic meters per hour), and it is likely that research and development costs will decrease as vessels begin purchasing and installing them. The average cost of larger capacity systems has not changed since the last report.

- The MISP plans on taking an adaptive management approach for implementing performance standards
- No specific recommendations to the State Legislature are included in this report.

Update on Related Marine Invasive Species Program (MISP) Activities

In 2010 the performance standards went into effect for new build vessels with a ballast water capacity less than 5000 MT. Since these are new vessels, they probably won't call to California ports until 2011. Commission staff is currently completing a rulemaking for reporting forms that will be required of vessels using treatment systems in California waters. These are expected to be approved by the Office of Administrative Law in early August. These forms will be required as systems are used and standards are implemented in California.

MISP staff provided comments on U.S. Coast Guard (USCG) proposed rule for performance standards, and are working with the EPA on Environmental Technology Verification (ETV) protocols for land-based ballast water treatment system testing. Staff are also consulting with federal, state, and international entities on the implementation of performance standards, and compliance verification.

Major Panel Comments & Discussion (Paraphrased and Edited)

Berge: Since much of the data provided by vendors is based on the IMO G8 testing protocols, how can it be used to gauge a system's potential to meet California's much more stringent standard?

- o **Dobroski:** Vendors are providing data, rather than saying simply "yes" or "no" to meeting the IMO standard. Commission staff used this data to see if it also meets California's standards. While there are issues around volumes necessary to test at certain levels of statistical significance, those volumes are unwieldy and impractical. No one is providing data on that level, nor is testing occurring at that level.

Berge: The industry is concerned about this, because it isn't clear if these systems can meet California's standards if testing protocols required are ultimately different from IMO's.

- **Falkner:** In discussions with folks from land-based testing facilities, it appears that results from systems they have tested are very accurate, you are probably getting good numbers with their data. The bigger issue is how to translate shore-based testing to the efficacy of a system on a ship, and how compliance verification will be completed. Though that problem applies to IMO, the USCG, as well as California.
- **Dobroski:** The majority of systems that appear to meet CA standards are going through the robust, go-to land-based facilities/testing organizations such as NIOZ (Royal Netherlands Institute for Sea Research) or NIVA (Norwegian Institute for Water Research).
- **Welschmeyer**: The IMO G8 testing protocols are probably not appropriate to evaluate California's standards.
- **Dobroski**: Some systems have met standards in only one replicate, but some have made it for many replicates. Our goal is to demonstrate potential compliance – really it depends on the vessel type, its route, etc. to select a truly appropriate system.

Berge: Comments to the USCG proposed rule by University of Maryland scientists (Tamburri, Wright) attest that no system has been proven to meet standards better than IMO. When the industry approaches vendors, they now say they are not confident they can meet anything more stringent than IMO. This report is providing the information that systems can meet California's performance standards. There appears to be a disconnect there.

- **Falkner**: Perhaps we need to chat again with vendors and see if they still believe they can meet CA standards (they have claimed in the past that they could).

- **Dobroski**: Oceansaver has told us that they can meet California's standards. It is possible that vendors may not being totally honest, as they want governments to go ahead with implementing standards laws.
- **Falkner**: Depending on what kind of feedback we get from vendors, perhaps we need to reevaluate our report. We don't want to impose a law that no one can meet.

Berge: Is it possible to give CSLC more flexibility/control without going through the legislature which is too slow? As it stands we have to guess two years in advance on what will happen with advancing technologies. It would be better if it can be dealt with more nimbly by the Commission.

- **Gregory:** There is probably not support for that amongst the Commission. The report does need to address the current and real situation, and we'll have to decide what a recommendation from this report might say.
- **Berge:** The intention would not be to change the standard in statute, but to have more flexibility with implementation extensions. This issue has only recently come about – vendors are now realizing they must be more honest to shipping companies about the capabilities of their systems, or they eventually have no one buying their systems.
- **Baker:** There doesn't appear to be a system that can meet the standards 100% of the time. Vendors will probably say this too. They probably won't say that their system will meet a standard unless it passes tests 99% of the time. If the data from the 2009 CSLC report indicates that two systems passed one test (replicate) out of five, are we saying that this will meet CA's standard? Most people will not agree.
- **Falkner:** At this point we say such systems have the "potential". A huge problem in the past has been limited data. Since then data has gotten much better, so perhaps we should verify from vendors how confident they are that they can meet CA standards, and how often and under what circumstances they think their systems can do it.

- **Gregory:** From a legal perspective, 75% compliance isn't good enough. If I was a ship owner, I wouldn't like that either. Short of a legislative change, we (CSLC) don't have the authority to say at 75% compliance you're okay. You're either in compliance or not. From a practical perspective, if no one can comply, we may have to look into changing the standards.
- **Falkner:** From the perspective of this report, it is important to know at what level systems can comply, and what situations are better or worse.
- **Berge:** The fact is that shipping lines will install systems that meet IMO standards and show promise to meet CA standards too. I don't think looking into this issue will stop progress.

Welschmeyer: Is the topic of concern that the CSLC report is too optimistic? Is there something wrong with being too optimistic? I agree that testing to non-detect is not possible to do well at the moment, but is there something misleading or detrimental about the report's claims? Aren't we doing a disservice to the currently rapid and wonderful progress of treatment technologies if we are not optimistic?

- **Berge:** In discussions with Washington, DC folks on the debate surrounding what's achievable consistently, it has come up that you as a ship owner/operator can be held legally accountable, even if you're hearing different stories about a system's capabilities from vendors, the USCG and CSLC (and others). From a public policy perspective, if you are to be held legally liable, you need a higher level of assurance than "probably."
- **Gregory:** We should call it as straight as possible, and not be overly optimistic. If ship owners can't find a vendor that will say they can meet CA's standard, and we say they can, it's a problem.
- **Hooff:** The crux of the issue is what measuring stick is used to evaluate systems. The report started during a time when there was a lack of data available. So, the measure of at least one replicate may have been appropriate back then, but it may be that that stick needs to be revised now that more data is available. Perhaps as data gets better, the reports need to step up evaluation criteria. This report isn't being misleading, because it's using the same

measuring stick as in the past, but perhaps it's time to use a different one. Regardless, these reports provide an excellent service to managers like me and ship owners as well, with all the information included.

- **Berge:** Agrees that the information is great, but the conclusion is very optimistic, and conclusions are what policymakers/legislators focus on, not all the details.
- **Swanson:** Matson engineers are not putting systems on ships unless they have better assurances (certifications or vendor assurance). It is a big problem that California is not approving systems. If you look only at the conclusions or tables in this report (as policy makers do) there will be misunderstandings.
- **Welschmeyer:** I appreciate that honesty is needed but at same time it's heartening to see now that vendors are having a chance to meet someone's standards somewhere. There's an optimism also amongst labs testing for standards. It's going to get more difficult that California has standards that are impossible to measure with statistical certainty, but does that mean that the state and the vendors should throw up their arms and give up efforts to protect the environment at the levels that we want to? We're on our way to doing something that is environmentally wise and constructive.
- **Berge:** To be fair, though, someone will be found liable, and the only party bearing that burden is the shipping industry.
- **Berge:** Aren't systems that are meeting the IMO standards really designed to meet zero?
- **Falkner:** Yes, and in discussions with folks at NIOZ, systems are either going way beyond IMO or completely crashing and burning. There's very few that are barely meeting IMO.

Baker: Optimism is good, but I am having difficulty with the conclusion that we are there [ready to meet the CA standard]. In my opinion, we are not.

- **Falkner:** A big difficulty is that we have to put a report out 18 months in advance of an implementation date, so we have to pontificate a bit, which is hard.
- **Berge:** Could we state something in the conclusions like there are indications for compliance potential, however it's questionable that systems can meet the

standards consistently under a regulatory regime? It's one thing to say that promising systems are out there, but consistency is difficult.

- **Falkner:** But no system is going to work 100% of the time, that's not realistic. Even when a system doesn't work, the CSLC policy has always been to try to work with industry to meet the intent/letter of the law.
- **Berge:** However, there's a concern for the industry over citizen lawsuits

Swanson: How does the viral standard play out? It's not testable, but the standard remains as is. That will be a problem if we have to install systems now that may have to meet a viral system later. Again, lack of certification by California is a problem.

- **Gregory:** There are lots of things on ships that, if operated according to established rules, are accepted by regulatory entities.
- **Swanson:** It doesn't seem like this program is going that way. You're not certifying. It's up to ships to self-certify, yet we've got a standard we can't test for. It's all on the shipping industry, there's nothing that puts responsibility on the vendor.
- **Gregory:** Disagrees. It's dependent on the contract established by the vendor and ships. MSDs are like that, oily water separators are that way, etc…
- **Berge:** Perhaps it should be written into the report that a contract must be established between vendor and ship owner.
- **Shiba:** If something is not testable, then is it considered non-detectable, and so meets the standard? At the time that viruses become testable, perhaps then you change the law and allow the Commission to make a determination about grandfathering.
- **Gregory:** Recall that performance standards were meant to be technology pushing, if it can't be developed it must be go to the legislature for addressing.
- **Berge:** Those caveats should be added to the conclusion.
- **Morin:** I understand the concept of contracts like MSDs, but the issue is that those have been around for decades. If I ask for an indemnity clause from a vendor, and they say no, then what do we do?
- **Gregory:** Then there's no system that can be considered available.

- **Falkner:** This isn’t the first “new technology” issue for ships. How was this done in the past?
- **Gregory:** What about air emissions? The manufacturer is certifying that the engine will meet standards if operated properly, and vessels get fined if they don’t meet them. It’s the same thing – engines are not certified by a regulatory agency. A ship owner would be crazy to buy a system that the manufacturer won’t certify for meeting a requirement. The regulatory scheme here is the same. The indemnification issue is up to shipping companies.
- **Berge:** If we get to the point that vendors will certify and provide indemnification, we’d be comfortable.

Berge: On availability, did you look at service and repair worldwide?

- **Dobroski:** That section (included in the last report) was removed from this report. The 9 systems mentioned here claim that they will be available worldwide for service. We can put that information back in the report.

Hooff: Are the max pump rates in Figure 6.2-6.3 for all vessels?   What if you just break out the only the 20% that discharge?

- **Dobroski:** Pump rates were analyzed for all vessels visiting California with a ballast water capacity over 5000 MT, but not broken down by dischargers vs. nondischargers.
- **Falkner:** About 75% of vessels operating in CA don’t discharge, but vessels are not consistent on when they do or don’t. They can go years without discharging, then suddenly do. That’s why we used all ships.
- **Hooff:** Suggest adding that clarifying language.
- **Falkner:** Given time constraints, we might be able to look at vessel activity history, and refine the data.

Berge: Are there any vessels under 5000 MT that have installed systems?

- **Dobroski:** Not that we're aware of, but vendors have said they've gotten inquiries. But vessels that visit California are only a small percentage of all vessels out there.

Welschmeyer: The report contained all elements of the issue very nicely. Is a very complex problem – I've come to appreciate all the content included, and have found many ideas I would have never thought of on my own. It is very spot on, including the optimism. I generally feel that all vendors/developers are doing such a much better job than before.

Draft Tables: 2010 Assessment of the Efficacy, Availability and Environmental Impacts of Ballast Water Treatment Systems for Use in California Waters. Prepared for the California State Legislature. California State Lands Commission.

References are not complete. Please contact Commission staff for proper citations.

Table 1. System Capacity and Timing of Treatment for Systems that Have Demonstrated Potential to Meet California's Performance Standards

System Manufacturer	**Timing of Treatment**	**Maximum System Capacity**
Alfa Laval	Uptake and Discharge	2500 m^3/h
Ecochlor	Uptake	Unlimited (>13000 m^3/h)
Hamworthy Greenship	Uptake	1000 m3/h per pump
Hyde Marine	Uptake and Discharge	6000 m^3/h
OceanSaver	Uptake	Unlimited (>6000 m^3/h)
OptiMarin	Uptake and Discharge	3000 m^3/h
Qingdao Headway Tech	Uptake and Discharge	4500 m^3/h
Techcross	Uptake and Discharge	Unlimited (>5000 m3/h)

Table 2. Summary of systems with available results for assessment of efficacy

Systems with at least one land-based or shipboard test (averaged across replicates) in compliance with the performance standards are denoted by a "Y.". Non-compliance is denoted by an "N," and those systems with data in metrics not directly comparable to the performance standards were designated as "unknown." A cell with hashing indicates that no data was available. Information about systems having only lab-scale data is provided in Appendix A.

Manufacturer	> 50 µm	10 - 50 µm	< 10 µm (bacteria)[1,2]	*E. coli*	Enterococci	*V. cholerae*	References[3]
21st Century Shipbuilding							Lab data only
Alfa Laval	Y	Y	Y	Y	Y	Y[4]	43,44,46
Aquaworx ATC GmbH							
atg UV Technology							
ATLAS-DANMARK							
Auramarine Ltd.	Y	N	N	Y[4]	Y	Y[4]	with Saaros, Aura
Brillyant Marine LLC							
Coldharbour Marine							
COSCO/Tsinghua Univ.							
DESMI Ocean Guard A/S							
Ecochlor	Y	Y	Y	Y	Y	Y[6]	35,41
EcologiQ							
Electrichlor							
ETI		N	N				31,32,33,34
Ferrate Treatment Tech.							Lab data only
Hamann Evonik Degussa[5]	Y	Y	Y	Y[4]	Y[4]	Y[4]	15,40,49,55
Hamworthy Greenship	Y	Y	Y	Y[4]	Y[4]	Y[6]	11,50
Hi Tech Marine	N	Unknown	Y				18, Hudson '99
Hitachi/Mitsubishi							
Hyde Marine	Y	Y	Y	Y[4]	Y[4]	Y[4]	30,58,59, NIOZ 20(
Hyundai Heavy Ind. (1)							Lab data only
Hyundai Heavy Ind. (2)							Lab data only
JFE Eng.Corp./TG Corp.							
Kwang San Co. Ltd.							Lab data only
MAHLE							

[1] Bacteria were assessed through examination of aerobic culturable heterotrophic bacteria (expressed as colony forming units).

[2] No methods exist to quantify and assess the viability of viruses at this time.

[3] Numbered references can be found in Literature Cited section

[4] Concentration at intake was zero, non-detectable or unknown.

[5] Hamann system has been temporarily removed from the market (effective 1/31/10)

[6] Vibrio testing conducted on live cultures in a lab

Table 2 (continued). Summary of systems with available results for assessment of efficacy

Systems with at least one land-based or shipboard test (averaged across replicates) in compliance with the performance standards are denoted by a “Y.”. Non-compliance is denoted by an “N,” and those systems with data in metrics not directly comparable to the performance standards were designated as “unknown.” A cell with hashing indicates that no data was available. Information about systems having only lab-scale data is provided in Appendix A.

Manufacturer	**> 50 µm**	**10 - 50 µm**	**< 10 µm (bacteria)[1,2]**	***E. coli***	**Enterococci**	***V. cholerae***	**References[3]**
MARENCO	Y	N	Y				27,28,57
Maritime Solutions Inc.	N	N	Y	Y	Y	Y[4]	MERC 2009b
Mexel Industries							
MH Systems							lab (appendix)
Mitsui Engineering	N	Unknown	Unknown	Unknown	Unknown	Unknown	21,23,24
NEI	Y	Unknown	N	Y[4]	Unknown	Y[4]	51,52,53
NK Co. Ltd.							
ntorreiro							
Nutech 03 Inc.	Y	N	Y	Y[4]	Y[4]	Y[4]	17,48,60
OceanSaver	Y	Y	Y	Y[4]	Y[4]	Y[4]	2,45,54
OptiMarin	Y	Y	Y	Y[4]	Y[4]	Y[4]	22,42,56, NIVA 200
Panasia Co. Ltd.							
Pinnacle Ozone Solutions							
Qingdao Headway Tech.	Y	Y	Y	Y[4]	Y[4]	Y[4]	VA, China Universi
Resource Ballast Tech.	Y	N		Y	Y	Y[4]	Anchor Report
RWO Marine Water Tech.	Y	Y		Y	Y	Y[4]	2,38, echardt 2009
Severn Trent DeNora[5]	Y	Y	Y				16
Siemens	N	N	N	Y	Y	Y[4]	MERC 2009a
Sunrui CFCC							
Techcross Inc.	Y	Y	Y	Y[4]	Y[4]	Y[4]	25,26,37
Wartsila							

[1] Bacteria were assessed through examination of aerobic culturable heterotrophic bacteria (expressed as colony forming units).

[2] No methods exist to quantify and assess the viability of viruses at this time.

[3] Numbered references can be found in Literature Cited section

[4] Concentration at intake was zero or non-detectable

[5] System has added a filter since this data was collected.

Table 3. Detailed Analysis of System Performance at Land-Based (Land) and Shipboard (Ship) Testing Scales. Data presented as number of tests that have demonstrated potential to meet standard/total number tests conducted.

	>50		10 - 50		<10		E. coli		Enterococci		Vibrio	
	Land	**Ship**	**Land**	**Ship**	**Land**	**Ship**	**Land**	**Ship**	**Land**	**Ship**	**Land**	**Ship**
Alfa Laval	8/10	1/4	3/10	1/4	0/8	2/2	10/10	4*/4	10/10	4*/4	10*/10	4*/4
Auramarine	4/6	--	0/7	--	0/2	--	1*/1	--	1/1	--	1*/1	
Ecochlor	8/15	1/1[1]	9/11	1/1[1]	8/11	1/1[1]	10/10	1/1[1]	11/11	--	(1/1 lab)	Unk
ETI			0/3	--	0/3	--	--	--	--	--	--	--
Hamann	16/19	4/5	17/18	0/5	1/13	3/4	12/12	4*/4	12/12	4*/4	1*/1	--
Hamworthy	5/5	--	3/5	--	2/5	--	5*/5	--	5*/5	--	(2/3 lab)	
Hi Tech	--	0/2	--	Unk	5/6	--	--	--	--	--	--	--
Hyde	1/10	3/3	0/10	1/3	5/10	3/3	10*/10	3*/3	10*/10	2*/3	--	3*/3
MARENCO	3/4	--	0/1	--	2/3	--	--	--	--	--	--	--
MSI	0/5	--	0/5	--	3/5	--	5/5	--	5/5	--	5*/5	--
Mitsui	0/4	0/1	Unk	Unk	Unk	Unk	Unk	--	Unk	--	Unk	--
NEI	1/5	1/2	0/1	Unk	0/2	0/2	0/1	2*/2	0/1	Unk	--	2*/2
Nutech	0/3	2/3	0/2	0/3	3/3	2/2	--	3*/3	--	3*/3	--	3*/3
OceanSaver	2/14	1/3	5/14	0/2,Unk	5/5	--	14*/14	3*/3	9*/14	3*/3	14*/14	3*/3
OptiMarin	8/12	0/8	6/12	2/8	2/12	--	12*/12	8*/8	12*/12	8*/8	12*/12	8*/8
Qingdao	4/13	3/3	8/13	3/3	9/13	3/3	13*/13	3*/3	13*/13	3*/3	13*/13	3*/3
RBT	3/3	0/2	0/3	0/2	--	--	3/3	2*/2	--	2/2	3*/3	2*/2
RWO	2/2	--	1/2	--	--	--	2/2	--	2/2	--	2/2	--
Severn Trent	3/5	--	2/5	--	4/4	--	--	--	--	--	--	--
Siemens	0/3	--	0/3	--	0/3	--	3/3	--	3/3	--	3*/3	--
Techcross	8/11	3/3	9/11	3/3	4/4	Unk	10*/10	3*/3	11*/11	2*/2	11*/11	3*/3

* Concentration at intake was zero, nondetectable or unknown
[1] System has added a filter since testing was conducted.

Table 4. Summary of environmental assessment and approval of treatment systems

Note: Table does not address whether or not toxicity testing was performed in accordance with the California Ocean Plan

Manufacturer	Active Substance	Toxicity Testing	Environmental Related Approvals	VGP TRC Compliant (100	Source
21st Century Shipbuilding	superoxide, oxygen radical,hydroxyl radical, electron, ozone	X	IMO Basic	Y	60/2/5
Alfa Laval	free radicals	X	IMO Basic and Final	Y	93, NIVA 20
Aquaworx ATC Gmbh	n/a (UV, cavitation bubble)	X	IMO Basic	Y	59/2/8
ATLAS-DANMARK	hyplochlorous acid, ozone, hydrogen peroxide,chlorine dioxide, hydrogen, sodium hydroxide				60/2/12
atg UV Technology	n/a (UV)				
Auramarine Ltd.	n/a (UV)	X			AuraMarine 20
Brillyant Marine LLC					
Coldharbour Marine	n/a (deoxygenation)				
COSCO	n/a (UV)	X	IMO Basic		59/2/2
DESMI Ocean Guard A/S	hydroxyl radical, ozone	X	IMO Basic	?	60/2/4
Ecochlor	chlorine dioxide	X	IMO Basic, Rec WA Cond.[1]	Y	84, 60/2/11
EcologiQ	yeast	X			3
Electrichlor	sodium hypochlorite				
ETI	ozone	X			62
Ferrate Treatment Tech.	ferrate				
Hamworthy Greenship	free active chlorine, total residual chlorine	X	IMO Basic and Final	Y	30,86, 59/2/6
Hamann Evonik Degussa[2]	Peraclean Ocean (peracetic acid, hydrogen peroxide, acetic acid)	X	IMO Basic & Final, EPA Reg., Rec. WA Conditional[1]		77,91
Hi Tech Marine	n/a (heat)		Queensland EPA		123
Hitachi/Mitsubishi	triiron tetraoxide, poly aluminum chloride, poly acrylamide sodium acrylate	X	IMO Basic		75
Hyde Marine	n/a (UV)	X			
Hyundai Heavy Ind. (1) Ecol	n/a (UV)	X	IMO Basic		59/2/4
Hyundai Heavy Ind. (2) HiBallast	chlorine, bromine, sodium hypochlorite, sodium hypobromite, hypochlorous acid, hypobromous acid,	X	IMO Basic	Detection limit of tests above EPA standard	60/2/6
JFE Eng. Corp./TG Group	sodium hypochlorite	X	IMO Basic and Final	Y	60/2/2
Kwang San Co. Ltd.	Cl_2, hypochlorous acid, hypobromous acid, sodium hypochlorite, sodium hypobromite,	X	IMO Basic	Detection limit of tests above EPA standard	60/2/7

Blank cells indicate that data was not available

[1] WA Dept. of Ecology Water Quality Program has recommended Conditional Approval of the system to WA Dept. Fish and Wildlife. As of the writing of this report, approval has not been granted.

[2] The Hamann Evonik Degussa system was temporarily removed from the market in 2010 due to environmental concerns regarding the toxicity of Peraclean Ocean in freshwater and cold water (source).

Table 4 (continued). Summary of environmental assessment and approval of treatment systems

Note: Table does not address whether or not toxicity testing was performed in accordance with the California Ocean Plan

Manufacturer	Active Substance	Toxicity Testing	Environmental Related Approvals	VGP TRC Compliant (100	Source
MAHLE Ind. GmbH	n/a (UV)				
MARENCO	n/a (UV)				
Maritime Solutions Inc.	n/a (UV)				
MH Systems	n/a (deoxygenation)				
Mitsui Engineering	ozone	X	IMO Basic	N	58/2/1, 59/2
NEI	n/a (deoxygenation)	X			10
NK Co. Ltd.	ozone, total residual oxidant	X	IMO Basic and Final	Y	59/2/3, 59/2
ntorreiro					
Nutech 03 Inc.	ozone	X		N	141
OceanSaver	free and total residual oxidant	X	IMO Basic and Final	Y	82,87,99
OptiMarin	n/a (UV)	X		Y	92
Panasia Co.	n/a (UV)	X	IMO Basic and Final	Y	78,81, 59/2/7
Pinnacle Ozone Solutions	ozone				
Qingdao Headway Tech	hydroxyl radical, hypochlorous acid, hypochlorite, hydrogen peroxide	X	IMO Basic	Y	0/2/16, Chin
Resource Ballast Tech.	ozone, hydroxyl radicals, hypochlorite	X	IMO Basic and Final	N	59/2/10, 60/
RWO Marine Water Tech.	hydroxyl radicals, free active chlorine	X	IMO Basic and Final	N	9, 59/2, 59/
Severn Trent DeNora	sodium hypochlorite, sodium bisulfite	X	IMO Basic, Rec. WA Conditi	Y	39,60/2/9
Siemens	sodium hypochlorite, sodium hypobromite, oxygenated species, oxygen, hydrogen	X	IMO Basic	Y	/11, MERC 2
Sunrui CFCC	hypochlorite, hypobromite, chloramines, bromamines	X	IMO Basic		60/2/3
Techcross Inc.	hypochlorite, hypobromite, ozone, hydroxyl radicals, hydrogen peroxide	X	IMO Basic and Final	Y	83,86
Wartsila	n/a (UV)				

Blank cells indicate that data was not available

[1] WA Dept. of Ecology Water Quality Program has recommended Conditional Approval of the system to WA Dept. Fish and Wildlife. As of the writing of this report, approval has not been granted.

Canada's Regulatory Regime for the Great Lakes

GL Collaboration
Montreal
May 18 / 2010

Chris Wiley

TC / DFO

Canada

Canada's Regulatory Regime Great Lakes

- Current Regulations 2006
- Iterative since 1989
- Harmonized with USCG under GLWQA
- All ships from outside EEZ entering Great Lakes must exchange / flush, treat to IMO D2, retain or pump ashore
- Current program based on bi national science DFO / NOAA
- Implements requirements of BW Convention – but doesn't include treatment dates etc.

Canada

Enforcement of Current Regulations

Ellis & MacIsaac (2009) Freshwater Biology

Study suggests that none of recent Great Lakes invaders tested could have invaded had we had mandatory BWE 25 years ago

- **100% of all ships from outside EEZ targeted in Montreal**
- **Joint TC, USCG, both Seaways**
- **Confirm salinity in all BW tanks - 30ppt**
- **Corrective action if non compliant 3% - retention**
- **No unmanaged BW entering GL from outside EEZ**
- **Joint report**
- **DFO random sampling / analysis – report to TC**
- **Regulations effective at reducing risk assuming 100% enforcement**
- **Exchange / Flushing - two actions – removal / osmotic shock**
- **Risk roughly equivalent to D2**

Canada has ratified the BW Convention

- **April 2010**
- **Regulations to be updated**
- **New legal regime CSA 2001**
- **Consistent with GOC direction on ratification of International Instruments**
- **Convention currently reflects input of science to support risk reduction – much Great Lakes driven**
- **Uniform Guidance for implementation.**
- **Canada chairs IMO Ballast Water Review Group – MEPC 61**

Science to understand implications of IMO discharge standards for Great Lakes

- Mesocosm Studies in Hamilton Harbour with high risk zooplankton indicate IMO standards will decrease invasions to the Great Lakes (Bailey et al. 2009. CJFAS)
- Dye Studies to measure spatial transport of discharged taxa - enclosed port: Goderich 2008 – in open port: Sarnia 2009
- Laker Study to examine role of Domestic fleet
- Risk Assessment of Ballast Water for all Coasts
- Current DFO report to TC suggests IMO standards appropriate to reduce risk sufficiently to protect Great Lakes
- Future Bi national Science protocols

Canada

Freshwater Specific Proposal to use Exchange plus Treatment to IMO Standard for Ships arriving from outside EEZ

- Currently only 2 of 9 vendors with final approval tested for fresh water
- Allows shipowner to use IMO approved treatment system
- Standardized Port State Control Regime
- Mitigates risk for pysical failure of technology
- Science suggests immediate 10 - 100 x decrease in risk over IMO standard
- TC, DFO to test (Germany)
- Mitigates toxicological and safety threat estimated for stand alone proposed higher standards (GESAMP)

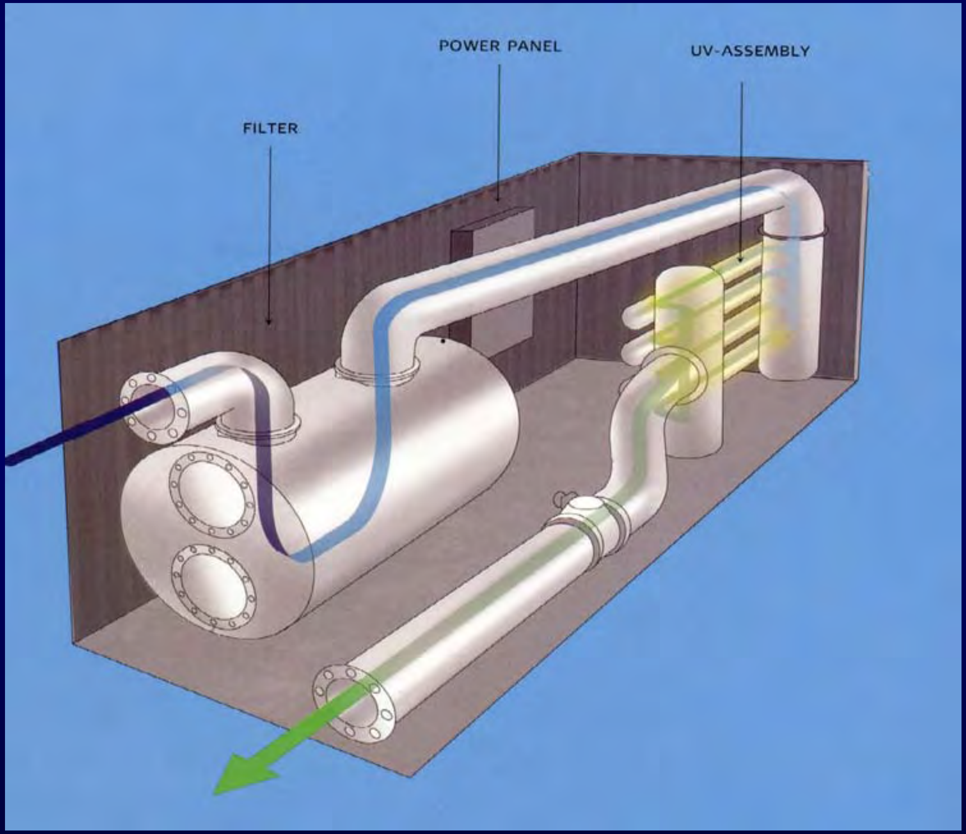
Canada

Ongoing / upcoming TC/ DFO research for 2010/11

- **Full Scale trials – Exchange plus BW Treatment**
- **Sampling for Efficacy of Regulations**
- **CAISN renewal - Sampling for Failure / Port State Control Int'l Consistency**
- **Flowcam, LOPC, Epi Fluorescent Microscope, DNA / RNA probes**
- **Risk Assessment of ballast discharge on all Coasts of Canada – East, West, St Lawrence, Great Lakes, Arctic**
- **Risk Assessment of ballast in comparison with other vectors in Great Lakes – likely 2012**
- **Role of Coastal Trade – sampling in Welland Canal**

Canada

IMO / Technology Update



Chris Wiley

Chair IMO Ballast Water Groups

IMO Update

- 24 Countries / 25% of Tonnage
- Canada ratified BW Convention first week of April 2010
- MEPC 61 – Review Group to indicate whether sufficient technologies available for next application date (2012 for new ships)

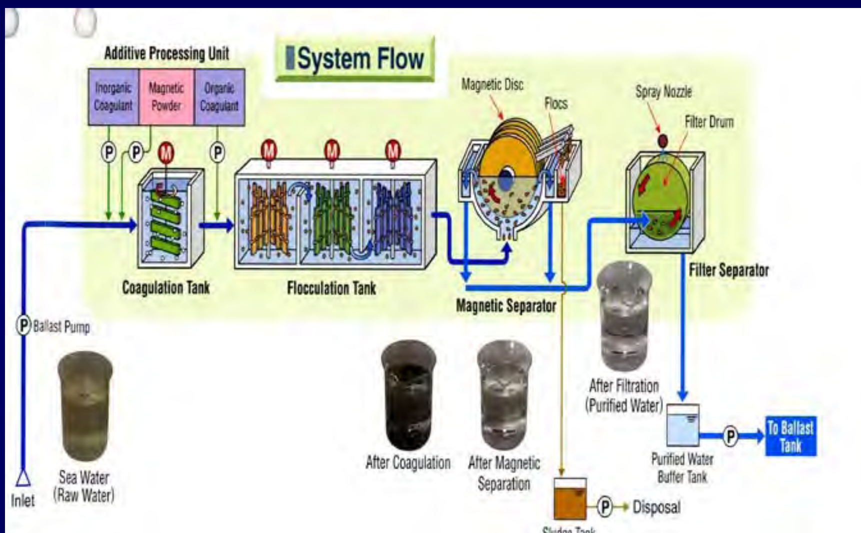
APPLICATION DATES

Date of build	BW Capacity (cubic m)	2009	2010	2011	2012	2013	2014	2015	2016
Before 2009	1500-5000	Comply with D1 Exchange or D2 Treatment					Comply with D2 Treatment		
	<1500 or >5000	Comply with D1 Exchange or D2 Treatment							D2
Ships shall comply, NOT later than the first intermediate or renewal survey, whichever occurs first, after the anniversary date in the year of compliance with the D-2 standard									
In or after 2009	<5000	Exchange or Treatment			Comply with D2 Treatment				
Resolution A 1005(25) postponed requirement for ships built in 2009 < 5000 cubic metres ballast capacity to second annual survey or at the latest by the end of 2011. MEPC 59, concluded there were sufficient technologies available and did not delay implementation further.									
2009 but before 2012	>5000	Comply with D1 Exchange or D2 Treatment							D2
In or after 2012	>5000				Comply with D2 Treatment				

BW Working Group BLG 14

- Guidance for Administrations on Type Approval according to G8 - issues important to Great Lakes re Type approval certificate to indicate test conditions – eg salinity, temp range etc.
- Framework for use of Basic Approval of one BW Management System for another using the same active substance - MEPC 61 - Periclean – Special Pipe
- Sampling – Indicative / Enforcement
- FSI - PSC in line with technology
- “Other” Alternative’s to D2 - NATO Navies Potable water
- Finalize Bio fouling Guidance

MEPC 60 – BW Approvals



- GESAMP 3 meetings 2009
- 9 Type Approvals to date
- 5 with G9 Approval
- 25 BWMS in the current approval process
- Lloyds update Feb 2010
- MEPC 61 – Review Group on whether sufficient technologies for 2012 application date.

Type Approved Technologies

• PureBallast - A/ Laval	Filter + UV + AS
• SEDNA / Peraclean	Filter + Active S
• Techross	Filter + Electrolysis
• OceanSaver –	Filter, Cavitation Nitro + Active S
• NK-03 – Blueballast	Filter Ozone
• GLO En Patrol	Filtration + UV
• NEI Treatment	Deoxygenation
• Hyde Guardian	Filter + UV
• Optimarin	Hydocylone , UV

- SEDNA tested in Fresh Water, but out of the business as of February 2010 (the Active Substance used in SEDNA -Periclean Ocean is now utilized in Special Pipe) but not currently tested for Fresh water

- As of June 1 2010, no technologies currently type approved (and commercially available) have been tested for fresh water

Approved Technologies awaiting Type Approval

- **HHI – Eco ballast** Filtration + Electrolysis
- **ClearBallast – Hitachi** Coagulation, Floc, Filter
- **Greenship Sedinox** Hydocyclone, Electrolysis
- **CleanBallast – RWO** Filter / Electrolysis - Tested in Fresh Water
- **JFE – Ballast Cleaner** Filtration + 2 A Substances
- **Resource BW Tech** Cavitation + Ozone + Electrolysis

MEPC 61

- **Systems submitted for Final Approval**

- **Ocean Guard** Filtration / Ultrasound / Electrolysis
- **Severn Trent de Nora** Filtration / Chlorination
- **Special Pipe** Filtration / Ozone (added Periclean)
- **Special Pipe** Filtration / Ozone
- **Ecochlor** Filtration / Chorine Dioxide
- **ARA (Blue Ocean Guardian)** Filtration / Plasma/ UV
- **BalChlor (Sunrui)** Filtration / Electrolysis

MEPC 61

- Systems Submitted for Basic Approval

• TWECO Purimar	Fitration + Electrolysis
• AquaStar	Filtration + Electrolysis
• FineBallast	Filtration + Membrane separation
• Kurary	Filtration + Active Substance
• ERMA First	Filtration + Electrolysis
• Blue Seas	Filtration + Electrolysis

Systems already received Basic Approval

- DESMI Filtration / Ozone / UV
- HHI Hi Ballast Filtration / Electrolysis
- Kwang Sang En Ballast Filtration / Electrolysis
- Aqua Tri Comb Filtration / Ultrasound / UV

- Additional 15 system at various stages of development

B.W Exchange will be reality for majority of ships until treatment comes on line

- Safety Issues
  - BWMP
  - Many not specific to ship
- Documentation vs Sampling
- Regulatory regime starting in many parts of the world

Port State Control

- Awaiting FSI
- Concerns re sampling from Industry
- What happens when “black box” doesn’t work?
- Discharge conditions appropriate as per Type Approval Certificate

BALLAST WATER MANAGEMENT INSPECTION REPORT

9 Is there an approved Ballast Water Treatment system on board ?

10 Is the treatment system approved for use in:

SALT WATER BRACKISH WATER FRESH WATER

11. Was the Ballast Water Treatment system operated in the conditions identified on the Type Test Certificate?

Fresh Water Issue
Type Approval

- MEPC.125 (53) Guidelines for Approval of Ballast Water Management Systems (G8)
- Annex 3 2.3.16 Salinity Range to be chosen Fresh, Brackish, Marine (Test 2 of 3)
- Type Certificate issued for specific application for which BWMS is approved – specific flow rates, salinity or temperature regimes, other limiting conditions

Table (1) – List of ballast water management systems that make use of Active Substances which received Basic Approval from IMO*

	Name of the system and proposing country	Name of manufacturer	Date of Basic Approval
1	SEDNA® Ballast Water Management System (Using Peraclean® Ocean), Germany	Degussa Gmbh, Germany	24 March 2006
2	Electro-Clean (electrolytic disinfection) system (subsequently changed to Electro-Cleen™), the Republic of Korea	Techcross Ltd. and Korea Ocean Research and Development Institute (KORDI)	24 March 2006
3	Special Pipe Ballast Water Management System (combined with Ozone treatment), Japan	Japan Association of Marine Safety (JAMS)	13 October 2006
4	EctoSys™ electrochemical System, Sweden	Permascand AB, Sweden, subsequently acquired by RWO GmbH, Germany	13 October 2006
5	PureBallast System, Sweden	Alfa Laval/ Wallenius Water AB	13 July 2007
6	NK Ballast Water Treatment System, the Republic of Korea (subsequently changed to NK-O3 BlueBallast System (Ozone))	NK Company Ltd., the Republic of Korea	13 July 2007
7	Hitachi Ballast Water Purification System (ClearBallast), Japan	Hitachi, Ltd. /Hitachi Plant technologies, Ltd.	4 April 2008
8	Resource Ballast Technologies System, South Africa	Resource Ballast Technologies (Pty) Ltd.	4 April 2008
9	GloEn-PatrolTM Ballast Water Management System, the Republic of Korea	Panasia Co., Ltd.	4 April 2008
10	OceanSaver® Ballast Water Management System (OS BWMS), Norway	MetaFil AS	4 April 2008
11	TG Ballastcleaner and TG Environmentalguard System (subsequently changed to JFE Ballast Water Management System), Japan	The Toagosei Group (TG Corporation, Toagosei Co. Ltd. and Tsurumi Soda Co. Ltd.)	10 October 2008
12	Greenship Sedinox Ballast Water Management System, the Netherlands	Greenship Ltd	10 October 2008
13	Ecochlor® Ballast Water Treatment System, Germany	Ecochlor, INC, Acton, the United States	10 October 2008

Table 1 (continue)

	Name of the system and proposing country	**Name of manufacturer**	**Date of Basic Approval**
14	Blue Ocean Shield Ballast Water Management System, China	China Ocean Shipping (Group) Company (COSCO)	17 July 2009
15	Hyundai Heavy Industries Co., Ltd. (HHI) Ballast Water Management System (EcoBallast), the Republic of Korea	Hyundai Heavy Industries Co., Ltd. the Republic of Korea	17 July 2009
16	AquaTriComb™ Ballast Water Treatment System, Germany	Aquaworx ATC GmbH	17 July 2009
17	SiCURETM Ballast Water Management System, Germany	Siemens Water Technologies	26 March 2010
18	Sunrui Ballast Water Management System, China	Qingdao Sunrui Corrosion and Fouling Control Company	26 March 2010
19	DESMI Ocean Guard Ballast Water Management System, Denmark	DESMI Ocean Guard A/S	26 March 2010
20	Blue Ocean Guardian (BOG) Ballast Water Management System, the Republic of Korea	21st Century Shipbuilding Co., Ltd,	26 March 2010
21	Hyundai Heavy Industries Co., Ltd. (HHI) Ballast Water Management System (HiBallast), the Republic of Korea	Hyundai Heavy Industries Co., Ltd. the Republic of Korea	26 March 2010
22	Kwang San Co., Ltd. (KS) Ballast Water Management System "En-Ballast", the Republic of Korea	Kwang San Co., Ltd.	26 March 2010
23	OceanGuard™ Ballast Water Management System, Norway	Qingdao Headway Technology Co., Ltd.	26 March 2010
24	Severn Trent DeNora BalPure® Ballast Water Management System, Germany	Severn Trent De Nora (STDN), LLC	26 March 2010

More comprehensive information regarding these systems is available in document BWM.2/Circ.23.

Table (2) – List of ballast water management systems that make use of Active Substances which received Final Approval from IMO*

	Name of the system and proposing country	Name of manufacturer	Date of Final Approval
1	PureBallast System, Norway	Alfa Laval / Wallenius Water AB	13 July 2007
2	SEDNA® Ballast Water Management System (Using Peraclean® Ocean), Germany	Degussa Gmbh, Germany	4 April 2008
3	Electro-Cleen™ System, the Republic of Korea	Techcross Ltd. and Korea Ocean Research and Development Institute (KORDI)	10 October 2008
4	OceanSaver® Ballast Water Management System (OS BWMS), Norway	MetaFil AS	10 October 2008
5	Ballast Water Management System (CleanBallast), Germany	RWO GmbH Marine Water Technology, Germany	17 July 2009
6	NK-O3 BlueBallast System (Ozone), the Republic of Korea	NK Company Ltd., the Republic of Korea	17 July 2009
7	Hitachi Ballast Water Purification System (ClearBallast), Japan	Hitachi, Ltd. /Hitachi Plant technologies, Ltd.	17 July 2009
8	Greenship Sedinox Ballast Water Management System, the Netherlands	Greenship Ltd	17 July 2009
9	GloEn-Patrol™ Ballast Water Management System, the Republic of Korea	Panasia Co., Ltd.	26 March 2010
10	Resource Ballast Technologies System, South Africa	Resource Ballast Technologies (Pty) Ltd.	26 March 2010
11	JFE Ballast Water Management System, Japan	JFE Engineering Corporation	26 March 2010
12	Hyundai Heavy Industries Co., Ltd. (HHI) Ballast Water Management System (EcoBallast), the Republic of Korea	Hyundai Heavy Industries Co., Ltd. the Republic of Korea	26 March 2010

*More comprehensive information regarding these systems is available in document BWM.2/Circ.23.

Table (3) – List of ballast water management systems that make use of Active Substances which received Type Approval Certification by their respective Administrations, following Final Approval by IMO (resolution MEPC 175 (58))*

	Approval Date	Name of the Administration	Name of the ballast water management system	Copy of Type Approval Certificate	Active Substance employed	MEPC report granting Final Approval
1	June 2008	Det Norske Veritas, as delegated by the Norwegian Administration	PureBallast System	To be provided	free radicals Cl2-, ClBr-, Br2- and CO3- (refer to MEPC 56/2/2, annex 5)	MEPC 56/23, paragraph 2.8
2	10 June 2008	Federal Maritime and Hydrographic Agency, Germany	SEDNA® Ballast Water Management System (Using Peraclean® Ocean)	Provided	PERACLEAN ® Ocean (refer to MEPC 57/2/10 annex 7	MEPC 57/21, paragraph 2.16
3	31 December 2008	Ministry of Land, Transport and MarITIME Affairs, the Republic of Korea	Electro-Cleen™ System	Provided	HOCl (OCl-), HOBr (OBr-), O3 (H2O2), OH- (refer to MEPC 58/2/7, annex 7)	MEPC 58/23, paragraph 2.8
4	17 April 2009	Det Norske Veritas, as delegated by the Norwegian Administration	OceanSaver® Ballast Water Management System (OS BWMS)	Provided	HClO, Cl_2, O_3, H_2O_2, ClO_2 and ClO^- (refer to MEPC 58/2/8, annex 4)	MEPC 58/23, paragraph 2.10
5	24 November 2009	Ministry of Land, Transport and MarITIME Affairs, the Republic of Korea	NK-O3 BlueBallast System (Ozone)	Provided	O_3	MEPC 59/24, paragraph 2.8.

* This list was compiled based on the information provided by the respective Administrations.

Table (4) – List of ballast water management systems that DO NOT use Active Substances certified by their respective Administrations (resolution MEPC 175 (58))*

	Approval Date	Name of the Administration	Name of the ballast water management system	Copy of Type Approval Certificate
1	2 September 2008	Office of the Maritime Administration, Marshall Islands	NEI Treatment System VOS-2500-101	Provided
2	29 April 2009	Lloyd's Register, as delegated by the Administration of the United Kingdom	the Hyde GUARDIAN™ ballast water management system	Provided

* This list was compiled based on the information provided by the respective Administrations.

Note: lists above updated April 2010.