Global **Ballast Water** Management Programme

Ballast Water Treatment

R&D Directory

2nd Edition

NOVEMBER 2004

GEF UNDP IMO

A cooperative initiative of the Global Environment Facility,
United Nations Development Programme and International Maritime Organization.

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2nd Edition

November 2004

November 2004 update

This Ballast Water Treatment R&D Directory has been compiled by Jose Matheickal, Steve Raaymakers and Ravi Tandon of the GloBallast Programme Coordination Unit, International Maritime Organization, London.

Information contained in the Directory has been provided by the various research groups listed in the Directory or obtained from published reports.

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The Global Ballast Water Management Programme (GloBallast) is a cooperative initiative of the Global Environment Facility (GEF), United Nations Development Programme (UNDP) and International Maritime Organization (IMO) to assist developing countries to reduce the transfer of harmful organisms in ships' ballast water.

The opinions expressed in this document are not necessarily those of GEF, UNDP or IMO

Contents

Background

The International Maritime Organization (IMO), with funding provided by the Global Environment Facility (GEF) through the United Nations Development Programme (UNDP), has initiated the Global Ballast Water Management Programme (GloBallast).

To implement the programme, a Programme Coordination Unit (PCU) has been established at IMO in London. One of the many functions of the PCU is to establish and maintain an information resource centre and clearing house, in order to improve the global communication and dissemination of information relating to this issue, and thus facilitate increased coordination and cooperation between the many parties involved. This Ballast Water Treatment R&D Directory has been developed as part of this effort.

Structure of the Directory

This directory lists research and development projects that are focussed specifically on the physical, mechanical and/or chemical treatment of ballast water to prevent/reduce the transfer of aquatic organisms and on technologies for monitoring treatment efficacy. It does not list broader research projects relating to ballast water or bio-invasion issues in general (see Aquatic Invasions Research Directory (AIRD) below).

The directory is organised into two primary divisions:

- Projects Completed
- Projects Under Way

Within each primary division research projects are listed by country.

Within each country they are listed in alphabetical order by name of the principal researcher.

Finally, information categories for each research project are:

- Name of project
- Treatment options researched
- Principal researcher
- Contact details
- Host institution
- Location of research
- Funding level
- Funding source(s)
- Timeframe
- Aims and objectives
- Research methods
- Results.

Where information categories are left blank for certain projects this indicates that the information was not provided/is not available.

Future of the Directory

This hard copy directory has been developed into a searchable database accessible on the GloBallast web site, **http://globallast.imo.org/research/**. It has also been provided to the Smithsonian Environmental Research Centre (SERC) for use in the Aquatic Invasions Research Directory (AIRD) (see below).

The GloBallast PCU continues to periodically update the electronic version of the directory on the web site, and this printed version is the second edition to be published in hard copy.

Request for Submissions

It should be noted that this directory is by no means exhaustive. There may be many ballast water treatment research and development activities underway around the world that have not yet been identified and/or entered into the directory. R&D groups conducting projects not currently listed are invited to complete the standard data form and submit it to the contacts listed on the inner title page, preferably electronically.

The form can be downloaded as a Word document from **http://globallast.imo.org/research/** and is also printed in Appendix One.

The Aquatic Invasions Research Directory (AIRD)

It should be noted that a broader database of scientific research covering all disciplines relating to the issue of marine bio-invasions in general has been developed by SERC in Maryland, USA. This is called the Aquatic Invasions Research Directory (AIRD). AIRD can be accessed on http://invasions.si.edu/aird.htm.

This Ballast Water Treatment R&D Directory is far more focussed than AIRD. It is intended to supplement AIRD by providing more detailed entries on ballast water treatment R&D specifically. These are of greater immediate interest, relevance and utility to IMO's shipping and ballast water focussed constituencies than the general science of marine bio-invasions.

Disclaimer

The information presented has been included in this R&D directory largely as submitted, with basic editing and formatting only, and without any scientific or technical peer review.

Neither the GloBallast Programme nor the International Maritime Organisation (IMO) take any responsibility whatsoever for any statement and claims made in this directory, for the quality, accuracy and validity of data presented, or for any other contents in this directory.

Individuals and organisations that make use of any data or other information contained in this directory do so entirely at their own risk.

Inclusion of information in this R&D directory in no way constitutes any form of endorsement whatsoever by IMO or GloBallast.

1. Projects Completed

Australia

Name of Project	Ports Corporation of Queensland Ballast Water Initiative No. 2: R&D of Ballast Water Treatment Technology
Treatment options researched	*pH adjustment, coagulation/flocculation, filtration, UV & ozone.*
Principal Researcher(s)	Darren Oemcke.
Contact Details	United Water International Pty Ltd GPO Box 1875 Adelaide SA 5001, Australia Tel: +61 8 8301 2709 Fax: +61 8 8357 9728 Email: darren.oemcke@uwi.com.au.
Host Institution(s)	CRC Reef Research Centre.
Location of Research	Townsville, Australia.
Funding Level	Ports Corporation of Queensland (PCQ) (AUD$92,000), CRC (AUD$90,000).
Funding Source(s)	PCQ, CRC.
Timeframe of the Project	July 1995 to June 1998.
Aims and objectives of the project	• Evaluate the effectiveness of treatment options tested and estimate cost for ballast water treatment. • Determine sizes of treatment plant, design a full-scale pilot treatment plant. • Evaluate environmental impacts of treatment options, assess expected risk reduction vs. cost.
Research Methods	• Literature review. • Ballast water sampling: - Identification of potential problem species and characteristics of ballast water which affect the disinfection technologies. • Disinfection testing: - Ozone, ultraviolet light and membrane filtration. - Pre-treatments examined included: pH adjustment, coagulation/ flocculation, filtration. • Pilot Plant Design.
Results	The initial literature review suggested that ozone, UV irradiation and filtration were strong candidates for ballast water treatment. Experiments showed UV preceded by filtration to remove sediments and larger organisms as having the most potential as an effective ballast water treatment at doses which could be cost effective. A pilot plant design for follow-up research was proposed.

Name of Project	**Ballast Water Exchange and Marine Plankton Distribution Trials on the M.V. *Iron Whyalla***
Treatment options researched	*Ballast Water Exchange*
Principal Researcher(s)	Geoff Rigby and Gustaff Hallegraeff
Contact Details	Geoff Rigby Reninna Consulting 36 Creswell Avenue Charlestown NSW 2290 Australia Tel: +61 2 49 430 450 Fax: +61 2 49 478 938 Email: rigby@mail.com
Host Institution(s)	Australian Quarantine and Inspection Service (AQIS) and the Broken Hill Propriety Limited (BHP).
Location of Research	Onboard the Bulk Carrier M.V. *Iron Whyalla.*
Funding Level	
Funding Source(s)	AQIS and BHP.
Timeframe of the Project	Trials carried out in 1990 and 1992.
Aims and objectives of the project	Understand the behaviour of ballast tank sediments and identify procedures to minimise the transfer of marine organisms. Identify practical aspects of ballast exchange in terms of efficiency and study the effect of enclosing a natural community of microscopic marine plankton, including algae and animals, in a closed tank during the ship's voyage.
Research Methods	Onboard full scale trials on a 150,000 DWT bulk carrier.
Results	Inspection of ballast tanks showed only minor amounts of sediment. Approximately 100kg of sediment was estimated in the 55,000 tonnes of water discharged, and 50% was present as inorganic sediment. 80% of this sediment was smaller than 10 µm. Containment of plankton resulted in differential survival of various organisms present. Computer based simulation of still-water shear forces and bending moments indicated that emptying and refilling ballast tanks is unsafe as a general practice for a ship of this size and design. Continuous flushing does not significantly affect stresses and bending moments. Exchange trials showed that approximately 4% of the original water remained after exchanging three tank volumes and about 5% of the dead plankton of Japanese origin was retained. The efficiency of exchange under stagnant conditions was less effective. For the *Iron Whyalla,* the cost of replacing three tank volumes was estimated at approximately AUD$2,300. References: Rigby, G.R. and Hallegraeff, G.M. (1993). Shipping ballast water trials on the bulk carrier M.V. *Iron Whyalla. AQIS Ballast Water Series Report No.2, Sept.* 123 pages. Rigby, G.R. and Hallegraeff, G.M.(1994). The transfer and control of marine organisms in shipping ballast water: behaviour of marine plankton and ballast water exchange trials on the M.V. *Iron Whyalla. J. Marine Env. Engg., Vol. 1*, pp 91-110. Rigby, G.R. (2001). Ocean exchange as a means of mitigating the risks of translocating ballast water organisms - a review of progress 10 years down the line. *J. Marine Env. Engg., Vol 6*, pp. 153-173.

Name of Project	**Ballast Water Heating and Sampling Trials on the BHP Ship MV *Iron Whyalla***
Treatment options researched	*Heat Treatment.*
Principal Researcher(s)	Geoff Rigby, Gustaff Hallegraeff, Caroline Sutton.
Contact Details	Geoff Rigby Reninna Consulting 36 Creswell Avenue Charlestown NSW 2290 Australia Tel: +61 2 49 430 450 Fax: +61 2 49 478 938 Email: rigby@mail.com
Host Institution(s)	Australian Quarantine and Inspection Service (AQIS) and the Broken Hill Propriety Limited (BHP).
Location of Research	Onboard the MV *Iron Whyalla*.
Funding Level	
Funding Source(s)	AQIS and BHP.
Timeframe of the Project	The project consisted of two shipboard tests – the first in April 1997 on a coastal voyage between Port Kembla in New South Wales to Port Hedland in Western Australia. The second in June 1997 between Mizushima, Japan and Port Hedland. The report was printed in October 1997.
Aims and objectives of the project	To test the viability of heat treatment as a means of minimising the risk of introducing new organisms into the ports where ballast is discharged.
Research Methods	Involved onboard trials using ship's engine heat to heat ballast water and sampling of ballast tanks for temperatures achieved and organism survival.
Results	Earlier laboratory experiments indicated that toxic dinoflaggellate cysts are killed after 4.5 hours at 38°C. The full-scale shipboard trial showed that all ballast water in the ballast tank exceeded 38°C after 30 hours of heating. They showed that none of the zooplankton and only limited phytoplankton survived the heat treatment. The report concluded that heat treatment holds considerable potential and deserves further R&D effort. It is attractive since it does not necessitate the use of biocides that could be harmful to the environment. It is safe since the tanks are always full of water and cost effective since it makes use of waste heat normally discarded and is likely to be of practical use for a range of ships. Variables that affect the viability of this method include the length of the ship's voyage and the temperature of the surrounding seawater. References: Rigby, G.R., Hallegraeff, G.M. and Sutton, C. (1999). Novel ballast water heating technique offers cost-effective treatment to reduce the risk of global transport of harmful marine organisms. *Mar. Ecol. Prog. Ser. 191*: 289-293

Name of Project	**Ballast Water Treatment to Minimise the Risks of Introducing Nonindigenous Marine Organisms into Australian Waters – A Review of Current Technologies and Comparative Costs of Practical Options**
Treatment options researched	*All treatment options of practical interest have been reviewed, especially those that have or are being demonstrated at practical scales.*
Principal Researcher(s)	Dr Geoff Rigby (Reninna Consulting) and Alan Taylor (Alan H Taylor and Associates).
Contact Details	Reninna Consulting 36 Creswell Avenue Charlestown NSW 2290 Australia Tel: +61 2 49 430 450 Fax: +61 2 49 478 938 Email: rigby@mail.com.
Host Institution(s)	Reninna Consulting and Alan H Taylor and Associates.
Location of Research	Australia.
Funding Level	Approximately AUD$30,000.
Funding Source(s)	Funded from the Australian Quarantine and Inspection Service Ballast Water Research Programme budget, which has come from a levy on ships calling on Australian ports.
Timeframe of the Project	Project completed January 2001.
Aims and objectives of the project	The main objective was to review the current status and technical effectiveness of appropriate treatment technologies and to develop indicative cost data for use of these options as a basis for selection of the most appropriate technologies.
Research Methods	Desktop review through local and international networks of researchers together with links and contacts with the shipping industry, regulators, equipment vendors, classification societies and ship builders.
Results	Detailed results and summary available in *AFFA Ballast Water Research Series Report No. 13*, January 2001 (http://www.affa.gov.au). References: Rigby, G. and Taylor, A. (2001). Ballast water management and treatment. *Trans ImarE, Vol 113, Part 3*, pp 79-99; Rigby, G.R. (2001). Ocean exchange as a means of mitigating the risks of translocating ballast water organisms - a review of progress 10 years down the line. *J. Marine Env. Engg., Vol 6*, pp. 153-173; Rigby, G.R. and Hallegraeff, G.M. (2002). On the nature of ballast tank sediments and their role in ship's transport of harmful marine microorganisms. *J. Marine Environ. Engg*. In press.

Name of Project	**Ballast Water Exchange and Marine plankton Distribution Trials on the M.V. *Iron Whyalla***
Treatment options researched	*Ballast Water Exchange*
Principal Researcher(s)	Geoff Rigby and Gustaff Hallegraeff
Contact Details	Geoff Rigby Reninna Consulting 36 Creswell Avenue Charlestown NSW 2290 Australia Tel: +61 2 49 430 450 Fax: +61 2 49 478 938 Email: rigby@mail.com
Host Institution(s)	Australian Quarantine and Inspection Service (AQIS) and the Broken Hill Propriety Limited (BHP).
Location of Research	Onboard the Bulk Carrier M.V. *Iron Whyalla.*
Funding Level	
Funding Source(s)	AQIS and BHP.
Timeframe of the Project	Trials carried out in 1990 and 1992.
Aims and objectives of the project	Understand the behaviour of ballast tank sediments and identify procedures to minmimise the transfer of marine organisms. Identify practical aspects of ballast exchange in terms of efficiency and study the effect of enclosing a natural community of microscopic marine plankton, including algae and animals, in a closed tank during the ship's voyage.
Research Methods	Onboard full-scale trials on a 150,000 DWT bulk carrier.
Results	Inspection of ballast tanks showed only minor amounts of sediment. Approximately 100kg of sediment was estimated in the 55,000 tonnes of water discharged, and 50% was present as inorganic sediment. 80% of this sediment was smaller than 10 µm. Containment of plankton resulted in differential survival of various organisms present. Computer based simulation of still-water shear forces and bending moments indicated that emptying and refilling ballast tanks is unsafe as a general practice for a ship of this size and design. Continuous flushing does not significantly affect stresses and bending moments. Exchange trials showed that approximately 4% of the original water remained after exchanging three tank volumes and about 5% of the dead plankton of Japanese origin was retained. The efficiency of exchange under stagnant conditions was less effective. For the *Iron Whyalla,* the cost of replacing three tank volumes was estimated at approximately A$2,300. References: Rigby, G.R. and Hallegraeff, G.M. (1993). Shipping ballast water trials on the bulk carrier M.V. *Iron Whyalla. AQIS Ballast Water Series Report No.2, Sept*. 123 pp. Rigby, G.R. and Hallegraeff, G.M. (1994). The transfer and control of marine organisms in shipping ballast water: behaviour of marine plankton and ballast water exchange trials on the M.V. *Iron Whyalla. J. Marine Env. Engg., Vol. 1*, pp 91-110. Rigby, G.R. (2001). Ocean exchange as a means of mitigating the risks of translocating ballast water organisms - a review of progress 10 years down the line, *J. Marine Env. Engg., Vol 6*, pp. 153-173.

Name of Project	Does Heat Offer a Superior Ballast Water Treatment Option?
Treatment options researched	*This work involves the use of heat treatment using various engineering designs to kill or inactivate harmful organisms present in ballast water*
Principal Researcher(s)	Geoff Rigby[1], Gustaaf Hallegraeff[2] and Alan Taylor[3]
Contact Details	[1]36 Creswell Avenue Charlestown NSW 2290 Australia Tel: +61 2 4943 0450 Fax: 61 2 4947 8938 Email : rigby@mail.com [2]Private Bag 55 Hobart Tasmania 7001 Australia Tel: +61 3 6226 2623 Fax: +61 3 6226 2698 Email : Hallegraeff@plant.utas.edu.au [3]59 Hillcrest Drive Templestowe Victoria 3106 Australia Tel/Fax: +61 3 9846 2650 Email : aht@ahtaylor.com
Host Institution(s)	Reninna Pty Limited, University of Tasmania, Alan H Taylor & Associates
Location of Research	Hobart and Newcastle, Australia and on-board the *Iron Whyalla*
Funding Level	Estimated overall program costs approximately A$250,000
Funding Source(s)	BHP, AQIS, Shipping Industry, Reninna Pty Ltd, University of Tasmania, Alan H Taylor & Associates
Timeframe of the Project	1993 to present time
Aims and objectives of the project	The overall project objective has been to test the viability of heat treatment as a means of killing or inactivating harmful ballast water organisms and to develop practical and cost effective designs for implementation of the technology. The most recent work has sought to gain a better understanding of the biological effects of heat for the range of organisms and conditions likely to be encountered in ballast water and to extend the initial range of options and designs for future extension and implementation of this technology.
Research Methods	This work has involved a range of laboratory studies coupled with on-board full-scale ship trials on the *Iron Whyalla* as well as the investigation of engineering designs, cost effectiveness and practicality of a range of designs for various ships and voyages.
Results	New data and biological interpretations of the effects of heat on marine organisms have identified that a threshold treatment temperature of 40-45^{O}C is generally sufficient to kill or inactivate most organisms of concern in ballast water. Lower temperatures with longer treatment times are likely to be more effective than shorter times at higher temperatures. A number of full scale shipboard case studies for various heating regimes utilising waste heat from the ship's cooling systems, auxiliary steam condenser cooling water auxiliary boiler and other heat sources are presented for a variety of ships, voyages and operating conditions.

Name of Project	Suggested Designs to Facilitate Improved Management and Treatment of Ballast Water on New and Existing Ships
Treatment options researched	*Design options for ballast water exchange (sequential and flow-through), heating via main engine cooling water, chemical, filtration, hydrocyclones, ultraviolet irradiation, fresh or recirculated water, discharge to shore based or dedicated treatment ships and best practice design aspects related to sea chests, ballast tanks (especially strength, water flow and minimisation of sediment accumulation), ballast pumps and pipework and chain lockers in relation to sediments.*
Principal Researcher(s)	Alan H Taylor (Alan H Taylor and Associates) and Dr Geoff Rigby (Reninna consulting).
Contact Details	Alan H Taylor and Associates Pty Limited 59 Hillcroft Drive Templestowe Vic 3106 Australia Tel: +61 (0)3 9846 2650 Fax: +61 (0)3 9846 2650 Email: aht@ahtaylor.com Web: www.ahtaylor.com
Host Institution(s)	Alan H Taylor & Associates and Reninna Consulting.
Location of Research	Australia.
Funding Level	Approximately AUD$15,000.
Funding Source(s)	Funded from the Australian Quarantine and Inspection Service Ballast Water Research Programme budget which has come from a levy on ships calling at Australian ports.
Timeframe of the Project	Project completed January 2001.
Aims and objectives of the project	To suggest designs to enhance ballast water management on new and existing ships.
Research Methods	Review of designs of existing ships and new ships and develop further designs and enhancements to facilitated better ballast water management.
Results	Detailed results and summary available in the Department of Agriculture, Forestry and Fisheries Australia (AFFA) Ballast Water Research Series Report No.12, January 2001 (http:www.affa.gov.au).

Name of Project	Hi Tech Marine HT2001
Treatment options researched	*Proprietary Biocide*
Principal Researcher(s)	Glenn Thornton, Dr. Marcus Scammell, Rohm & Haas.
Contact Details	Hi Tech Marine Pty Ltd PO Box 524 Newport NSW 2106 Australia Tel: +61 2 9997 7494 Fax: +61 2 9997 8962 Email: gthornton@htmarine.com.au
Host Institution(s)	
Location of Research	Hawkesbury River & Sydney, Australia; Philadelphia, USA.
Funding Level	US$ 750,000.
Funding Source(s)	Joint venture Hi Tech Marine, Rohm & Haas.
Timeframe of the Project	2.5 years – 1991-1993.
Aims and objectives of the project	To evaluate the effectiveness and bio-degradability of a chemical Biocide technology, environmental risk assessment and indicative cost data.
Research Methods	Plate leaching trials, biota mortality trials, and environmental degradation trials.
Results	Positive. However, prior to sea trials in 1993, advised by AQIS (Department of Agriculture) that chemical treatment of ballast water was not acceptable.

Name of Project	Hi Tech Marine SeaSafe (Onboard) & WaterSafe (Shore based) Systems
Treatment options researched	*Biocidal Heat Treatment.*
Principal Researcher(s)	Glenn Thornton & Bob Prentice
Contact Details	Hi Tech Marine Pty Ltd PO Box 524 Newport NSW 2106 Australia Tel: +61 2 9997 7494 Fax: +61 2 9997 8962 Email: gthornton@htmarine.com.au
Host Institution(s)	Independent.
Location of Research	Sydney, Australia; Hobart, Australia.
Funding Level	AUD$2,500,000.
Funding Source(s)	Hi Tech Marine Pty Ltd (principal), BDT Senior Thermal Engineering Pty Ltd, Hisaka Works Ltd., Intercontinental Ship Management Pty Ltd, Lloyds Register.
Timeframe of the Project	1995 – 2001.
Aims and objectives of the project	To evaluate the effectiveness of our heat treatment technology and to develop indicative cost data.
Research Methods	SeaSafe sea trials Adelaide – Hobart; Sydney – Hobart; Geelong – Hobart, M.V. 'Sandra Marie' 1997. WaterSafe system first demonstrated June 1997. For methodology of systems see http://www.htmarine.com.au. Treatment time/temperatures based on mortality figures of toxic Dinoflagellate cysts (*G. catenatum*), from Bolch & Hallegraeff, Hallegraeff & Rigby, and human pathogen mortality figures from Dr. B.J. Hudson, Chief Microbiologist, Royal North Shore Hospital, Sydney. WaterSafe system now elevated to 90°C for 60 seconds.
Results	On-board (SeaSafe system): Sea trial (Sydney – Hobart) was conducted in gale-force weather and achieved an 80-90% kill rate for *G. catenatum cysts*, at temperatures of 50°C for 45 seconds. Trial monitored by AQIS, test results obtained by Dr. G. Hallegraeff in Hobart. Shore-based (WaterSafe system): Shore based demonstration at Sydney, Australia, monitored by AQIS, NSW Government and various shipping industry representatives. Results obtained by Dr. R. Campbell 100% mortality of all marine organisms including *G. catenatum cysts* at temperature of 80°C for a period of 60 seconds. WaterSafe system now elevated to 90°C for 60 seconds, which has resulted in a mortality of 99.9% of human pathogens including *Hepatitis A virus* (per Qld Dept Public Health). Reviewed by: Rigby G.R. and A.H. Taylor 'Ballast Water Treatment Report No. 13 – Ballast Water treatment to Minimise the Risks of Introducing Nonindigenous Marine Organisms into Australian Ports.' January 2001. Agriculture, Fisheries and Forestry – Australia ISBN 0-642-47669-1. Report on results of testing available on request or visit: http://www.htmarine.com.au

Brazil

Name of Project	Use of Chlorine for Ballast Water Treatment
Treatment options researched	*Chlorine*
Principal Researcher(s)	Julieta Salles Vianna da Silva Flavio da Costa Fernandes
Contact Details	Julieta Salles Vianna da Silva Address : 253 Kioto Street, – Arraial do Cabo/RJ – Brazil – 28930-000 Tel : 55 21 22 26229013 Fax : 55 21 22 26229093 Email : julieta@mar.com.br Flavio da Costa Fernandes Address : 253 Kioto Street, – Arraial do Cabo/RJ – Brazil – 28930-000 Tel : 55 21 22 26229013 Fax : 55 21 22 26229093 Email : flaviocofe@yahoo.com
Host Institution(s)	IEAPM – Admiral Paulo Moreira Marine Research Institute
Location of Research	Bulker Frotargentina
Funding Level	
Funding Source(s)	Petrobras – Brazilian Petroleum S/A
Timeframe of the Project	March 1999 to September 2001
Aims and objectives of the project	The objective of this study was to assess the chlorine efficacy, to determine its minimum concentration eliminate organisms in ballast water and to observe the formation of trihalomethane on board. This study also is concerned about the evaluation of survival of microalgae and trihalomethane formation in laboratory in different concentrations of chlorine and cells.
Research Methods	The experiment was done in 8 wing tanks: 4 tanks used as control and 4 tanks treated with chlorine at 1, 3, 5 and 10 ppm. Every day, during six to eight days, samples were taken from every tank to analyze salinity, pH, temperature, dissolved oxygen, nitrite, nitrate, ammonium, phosphate, chlorine, trihalomethane, zooplankton and phytoplankton. Experiments in laboratory were made to assess the THM formation using *Tetraselmis chui* in different concentrations.
Results	The maximum mortality of total zoo- and phytoplankton was 76.4% and we did not find significant differences (<0.05) among treatments. Concentrations above 3 ppm are not recommended due to formation of high values of THM (>100µg/L). The lowest chlorine concentration tested (1ppm) presented the lowest THM concentration. It is suggested the use of low concentration of chlorine in continuous flux, to improve the chlorine efficiency.

Canada

Name of Project	Ballast Water Treatment Evaluation Using Copper and Sodium Hypochlorite as Ballast Water Biocides
Treatment options researched	*Copper ion and Sodium Hypochlorite*
Principal Researcher(s)	Fleet Technology Ltd. 311 Legget Drive Kanata, Ontario, Canada K2K 1Z8 In partnership with ESG International Inc. Guelph, Ontario, Canada
Contact Details	David Stocks Fleet Technology Ltd. 311 Legget Drive Kanata, Ontario, Canada K2K 1Z8 Tel: 613-592-2830 Email: dstocks@fleetech.com Barry Burns Michigan Department of Environmental Quality Constitution Hall 525 west Allegan Street Lansing, Michigan 48913 Tel: 517-335-3301 Email: burnsb@michigan.gov
Host Institution(s)	Michigan Department of Environmental Quality Constitution Hall 525 West Allegan Street Lansing, Michigan 48913
Location of Research	Field studies conducted in Europe and Great Lakes. Laboratory studies conducted in Ontario, Canada.
Funding Level	US$190,000.
Funding Source(s)	Michigan Great Lakes Protection Fund. Office of the Great Lakes, Michigan Department of Environmental Quality. U.S. Fish and Wildlife Service.
Timeframe of the Project	7/15/2001 – 6/1/2002.
Aims and objectives of the project	The project aims to help MDEQ to determine whether practical methods of treating ballast water are currently available. The determination is required by recent state legislation.
Research Methods	Laboratory and ship-board testing.
Results	**Copper Ion Biocide** – The study's toxicity data suggest that in sufficiently high concentrations, copper ion could be an effective biocide. However, at the concentrations needed to achieve the desired effectiveness, the level would be far too high to be discharged into the Great Lakes. Given this, and the absence of any known neutralizing agent that would allow copper to be safely discharged into the Great Lakes, it was concluded that copper ion cannot be considered to be a viable ballast water biocide at this time. **Hypochlorite Biocide** – The conclusions of the 2001/2002 shipboard and laboratory study using sodium hypochlorite as a ballast water biocide were limited and considered preliminary. A follow-up study on sediment impacts on hypochlorite toxicity and ballast tank corrosion was conducted in 2003/2004 to

complement the previous work. The follow-up study further addressed environmental and safety concerns, treatment costs, and a conceptual shipboard dosing system.

Laboratory toxicity tests were conducted to assess hypochlorite toxicity with various amounts of ballast water sediment present. Most microorganisms and adult organisms tested were killed at total residual chlorine (TRC) levels of 10 ppm or less. The highest 48-hour LC90 for the 1000 ppm sediment concentration was 9 ppm TRC.

The following conclusions were drawn following the ballast tank corrosion study.

- The addition of hypochlorite at the dose levels necessary to be biologically effective has no effect on the standard ship-type coating system (paint permeability).

- Corrosion rates of bare steel are increased by the presence of hypochlorite at the biologically effective dose rates under constant exposure conditions. However, the amount of increased corrosion is not considered significant over the life of a ship due to the relatively small amount of time that elevated hypochlorite concentrations would be present in a ballast tank.

The remaining 2003/2004 hypochlorite evaluations (environmental/safety concerns, costs, and shipboard installation) were favorable in that no apparent prohibitions for its use as a ballast water biocide were found. Provided proper safety standards, dosing, and de-chlorination techniques are followed, compliance with environmental and safety standards would not be an expected problem.

Name of Project	Treatment of Residual Ballast Water in the NOBOB Ship using Heat.
Treatment options researched	*Heat*
Principal Researcher(s)	[1]David T. Stocks, [2]Martin O'Reilly.
Contact Details	[1.] BMT/Fleet Technology Ltd., Kanata, ON. Canada. Email: dstocks@fleetech.com [2.] ESG Stantec Consulting Inc., Guelph, ON. Canada
Host Institution(s)	
Location of Research	Great lakes Region Canada
Funding Level	$150,000
Funding Source(s)	NOAA.
Timeframe of the Project	2003
Aims and objectives of the project	Heat treatment of ballast water to reduce aquatic invasive species has been proposed and tested in large ocean going ships where time in ballast and available energy is such that sufficient rise in temperature of the ballast water can be achieved. In the Great Lakes, ships do not have long periods of time in ballast nor sufficient energy to perform full ballast tank heating. By restricting the heat treatment to the residual ballast water, the time and energy requirements for treatment are significantly reduced to within the capacity of the typical NOBOB ship entering the Great Lakes. The study examines the heat requirements for the thermal treatment of residuals in a NOBOB ship, and determines if the energy demand for the treatment is within the capacity of a ship's normal generation and/or can be done economically using shore based equipment. Objectives are; To establish heat energy input requirements through numerical modelling verified by at ship experiments. To establish thermo-toxicity of typical ballast-borne biota through laboratory toxicity testing.
Research Methods	Ship board trials, heat dissipation modelling, thermo toxicity testing. A heat dissipation model is developed, using variational finite difference techniques, to quantify heat loss from the residual ballast water to the surrounding environment. An at ship experiment using portable heat (steam) generating equipment is conducted to calibrate the heat dissipation model and demonstrate the energy requirements needed to achieve the temperature profile deemed effective in the thermo-toxicity tests. A series of thermo toxicity tests are performed over a representative range of biota to establish time temperature lethality
Results	Not provided.

Name of Project	Sodium Hypochlorite as a Ballast Water Biocide
Treatment options researched	*Biocides*
Principal Researcher(s)	[1]David T. Stocks, [2]Martin O'Reilly. [3]William McKracken
Contact Details	[1.] BMT/Fleet Technology Ltd., Kanata, ON. Canada. Email: dstocks@fleetech.com [2.] ESG Stantec Consulting Inc., Guelph, ON. Canada [3.] Consultant Michigan, USA
Host Institution(s)	
Location of Research	Great lakes Region Canada
Funding Level	$300,000
Funding Source(s)	State of Michigan, Great lakes Protection Fund, Transport Canada
Timeframe of the Project	2001-2004
Aims and objectives of the project	Evaluate the efficacy and impact of using Sodium Hypochlorite as a biocide for application to Great Lakes shipping. To address the concerns of the Michigan Environmental Science Board review of Phase 1 work and assist the State of Michigan in their legislation of ballast water treatment options.
Research Methods	A field demonstration on-board the MV *Federal Yukon*, Toxicology testing in the biological laboratory, Discharge impact assessment Corrosion testing in the material laboratory. Engineering development of ship systems and Economic evaluation
Results	Phase 1 results are not fully conclusive but demonstrate that Sodium Hypochlorite is an effective biocide, is economically feasible, has some detrimental effects on ship steel (corrosion). The assessment of impact on the receiving environment is still being developed.

China

Name of Project	Effects of the Chlorination Treatment for Ballast Water
Treatment options researched	*Chemical biocide*
Principal Researcher(s)	S Zhang, X Chen, D Yang, W Gong, Q Wang, J Xiao, H Zhang, Q Wang,
Contact Details	Dalian Maritime University Environmental science and engineering college Dalian Maritime University Lingshui Road 1,Dalian, 116026 P.R. China Tel: +86 411 4725440 Fax: +86 411 4729777 Email: zhangshuohui@yahoo.com.cn
Host Institution(s)	Dalian Maritime University, P.R. China
Location of Research	Dalian Maritime University, P.R. China
Funding Level	USD 40000
Funding Source(s)	GloBallast Programme
Timeframe of the Project	2002 – 2004
Aims and objectives of the project	This project deals with the effects of the chlorination treatment for ballast water.
Research Methods	• Bacteria test • Phytoplankton test • Natural seawater test • Amphipod test • Brine shrimp (*Artemia salina*) test • Breakdown test of available chlorine • Natural seawater, ballast water and sediment were treated with chlorination in the laboratory Three or four parallel samples are used in the test according to standard methods, such as: German ATS Benchmark or Chinese National Standard. Most of the tests are replicated. Some of the tests are replicated many times. Optimal conditions for test organisms are selected and the reliability of test organisms was ensured through employing a standard biocide. Although there are a few differences among the test data of the replicating test, the test data appears to be reliable. There is a control group in every test and once the mortality of control is over 10%, the data will be invalid.
Results	Our experiments selected Sodium Hypochlorite as biocide. The results indicate that chlorination treatment is effective in killing organisms and bacteria in seawater. They also show that available chlorine with concentration of 20 mg/L is able to kill almost all the bacteria in the seawater. However, the concentrations of available chlorine for phytoplankton, zooplankton and benthic invertebrate's treatment vary depending on the species and the density of them, ranging from 5 mg/L to 100mg/L.

Germany

Name of Project	Process for the Removal of Organisms from Different Waters
Treatment options researched	*Chemical treatment: oxidising, environmentally friendly biocide formulation Peraclean® Ocean; with and without separation of solids*
Principal Researcher(s)	Degussa AG
Contact Details	Degussa AG, BW-FEA-A Rodenbacher Chaussee 4 D-63457 Hanau-Wolfgang Germany Tel: +49 6181-59-3892 Fax: +49 6181-59-3311 e-mail: rainer-g.fuchs@degussa.com Web: www.degussa.com
Host Institution(s)	Degussa.
Location of Research	Germany.
Funding Level	Ca. US$200,000.
Funding Source(s)	Federal Ministry for Research and Technology of Germany.
Timeframe of the Project	1998-2002.
Aims and objectives of the project	• Develop laboratory test methods to compare different chemical treatment options as a prescreening to full scale testing. • Compare different treatment options in full scale testing. • Develop dosage equipment for full scale testing.
Research Methods	• Chemical treatment options were tested in the lab with the testing standard ATS = Artemia Testing Standard by Dr. Voigt-Consulting, Germany. • Full scale testing was enabled by taking part in a shipboard testing program by Maritime Solutions Inc., USA in 2001; more testing planned in 2002. • Field trials were conducted together with Hamann Wassertechnik, Germany in 2001; more testing planned in 2002.
Results	• Laboratory tests showed complete mortality of different species with 400 ppm Peraclean® Ocean or less. • Field trial aboard a ship (together with Maritime Solutions Inc.) in USA, 2001, showed 99-100% mortality of all examined zooplankton, phytoplankton and a 3 log. removal of culturable bacteria with 200 ppm Peraclean® Ocean (stand alone treatment). • Field trial at Hamburg, Germany in 2001, together with Hamann Wassertechnik showed complete killing and/or separation of the observed* or added** species at a dosage rate of 100 ppm Peraclean® Ocean or more. • Treatment with Peraclean® Ocean after separation of solids: planned for 2002. * Cyclops (Copepode), Daphnia, Copepode nauplii, Rotifiers, Ciliates, Nematodes, undetermined eggs, larval Polychaetes, Cladocera, Foraminifera. ** Artemia nauplii and Artemia eggs.

Name of Project	Peraclean® Ocean – a Potential Treatment Option for Ballast Water
Treatment options researched	*Chemical treatment*
Principal Researcher(s)	Rainer Fuchs
Contact Details	Degussa AG Dr. Rainer Fuchs Rodenbacher Chaussee 4 D-63457 Hanau-Wolfgang Germany Tel: +49 6181-59-3892 Fax: +49 6181-59-3311 Email: rainer-g.fuchs@degussa.com Web: www.degussa.com
Host Institution(s)	
Location of Research	Degussa AG, Germany
Funding Level	50% BMBF, 50% Degussa AG
Funding Source(s)	1) German Federal Ministry of Education and Research (BMBF), Germany 2) Degussa AG, Germany.
Timeframe of the Project	1998-2003
Aims and objectives of the project	The project was set up to explore possibilities for peroxygen chemicals to treat ballast water in an environmentally friendly way. Laboratory trials and field trials, e.g. on a ship, were planned.
Research Methods	Treatment of different waters that contained different species was done. Killing rates after different exposure times with different formulations and different species were observed.
Results	Peraclean® Ocean, a liquid oxidizer formulation showed promising results. Treatment of different waters that contained different species was done. For a first evaluation of the performance of Peraclean® Ocean, the *Artemia* Testing Standard (ATS-benchmark; contact: m.voigt@drvoigt-consulting.de) was applied at lab-scale. This benchmark test uses the brine shrimp, *Artemia salina*, as indicator organism. The ATS involves 4 different development stages of the brine shrimp: adults, larvae, nauplius-stages, pre-incubated eggs and cysts. The ATS-data showed that the addition of Peraclean® Ocean at levels of above 350 ppm resulted in 100% mortality of all *Artemia* live stages. Further experiments were carried out with a number of other indicator organisms. Dosing rates of 50 – 350 ppm Peraclean® Ocean and exposure times of 2-72 hours proved to be 100% effective (no survivals) for many different species. Peraclean® Ocean can be used alone or in combination with a solid separation technology.

Japan

Name of Project	Unwanted Aquatic Organisms in Ballast Tank – Report of the Ballast Water Management by Heat Treatment using Main Engine Water Cooling Circuit and Findings of the On-Board Research
Treatment options researched	*Heat treatment.*
Principal Researcher(s)	Japanese Shipowners' Association.
Contact Details	Kaiun Bldg No 6-4, 2-Chome Hirakawa-cho Chiyoda-ku Tokyo 102, Japan Tel: +81 3 3264 7171 Fax: +81 3 3262 4760 Web: www.jsanet.or.jp.
Host Institution(s)	Japanese Shipowners' Association.
Location of Research	On board the ore carrier MV Onde Maru in the Japanese port of Kure and en-route to Port Walcott in Australia.
Funding Level	
Funding Source(s)	
Timeframe of the Project	February 1995.
Aims and objectives of the project	To determine: • The results of treating ballast water with heat obtained from the cooling circuit of the main engine. • The effect of re-ballasting at sea. • The viability of the phytoplankton in the ballast tank.
Research Methods	Conducted an at-sea analysis of heat treatment, re-ballasting and the viability of phytoplankton between Japan and Australia.
Results	The experiment discovered that: • The marine organisms in the ballast tank were minimised by the heat treatment, but the question of how to make the prescribed water temperature uniform in the ballast tank still remained. • None of the phytoplankton in the original ballast tank survived the journey to Port Walcott, but there was still the possibility of cysts surviving in bottom sediments. • Other harmful aquatic organisms were taken into the ballast tank when reballasting at sea. • The ballast water was heated to a high of 43°C at the inlet but only reached 35^0C at the point of the ballast tank furthermost from the inlet.

Netherlands

Name of Project	Global Market Analysis of Ballast Water Treatment Technology
Treatment options researched	*All treatment options of practical interest are reviewed.*
Principal Researcher(s)	H.A. Schilperoord and F.J. Tjallingii
Contact Details	Royal Haskoning PO Box 94241 1090 GE Amsterdam Tel. +31 (0)20 569 77 83 Fax +31 (0)20 569 77 66 Email: h.schilperoord@royalhaskoning.com Web: www.royalhaskoning.com
Host Institution(s)	Royal Haskoning.
Location of Research	Amsterdam, The Netherlands.
Funding Level	
Funding Source(s)	Northeast Midwest Institute, USA.
Timeframe of the Project	June-November 2001.
Aims and objectives of the project	Provide a global analysis of the market for a ballast water treatment technology industry. An insight in the probable market for ballast water treatment systems in light of forthcoming national and international ballast water management requirements.
Research Methods	Based on an analysis of Lloyds Register of Ships and discussions by an expert group consisting of representatives of the shipping and port industry and shipping experts at Royal Haskoning a number of assumptions regarding the IMO's Convention on ballast water are drawn.
Results	The study resulted in an estimation of the potential market (in number of vessels) in three time periods (-2003, 2003-2008 and 2008-2013). The calculations on potential turnover were made by multiplying the numbers of vessels with the cost of fitting a modal (existing or new) vessel with a treatment system. From 2008 the potential market is estimated to be between USD700 million and USD1 billion per annum. The report is shown on: www.nemw.org/Haskoningreport.pdf

New Zealand

Name of Project	Heat Treatment of Ships' Ballast Water: Development and Application of a Model Based on Laboratory Studies
Treatment options researched	*Heat Treatment.*
Principal Researcher(s)	D Mountfort, C Hay, M Taylor, S Buchanan, W Gibbs
Contact Details	Cawthron Institute 98 Halifax Street East Private Bag 2 Nelson Nelson New Zealand Tel: +64 (0)3 548 2319 Fax: +64 (0)3 546 9464 Email : doug@cawthron.org.nz Web: www.cawthron.org.nz.
Host Institution(s)	Cawthron Institute.
Location of Research	Nelson, New Zealand.
Funding Level	
Funding Source(s)	
Timeframe of the Project	Report printed 1999.
Aims and objectives of the project	To determine, using laboratory methods, the optimum conditions required for the application of heating to kill invasive species in ballast water.
Research Methods	Adult samples of the starfish *Coscinasterias calamaria,* the zoospores of the seaweed *Undaria pinnatifida*, and the larvae of *Crassostrea gigas* were used for laboratory study of effects of heat treatment.
Results	The study assumed that the organisms could be transported in ballast water in a viable state for the duration of a sea journey and therefore pose a threat. The study developed a linear model intended for use in the prediction of kill times over a temperature range of between 35-48°C.

Name of Project	Shipboard Heat Treatment of Ballast Water
Treatment options researched	*Heat Treatment.*
Principal Researcher(s)	D Mountfort, C Hay, M Taylor, S Buchanan, W Gibbs
Contact Details	Cawthron Institute 98 Halifax Street East Private Bag 2 Nelson Nelson New Zealand Tel: +64 (0)3 548 2319 Fax: +64 (0)3 546 9464 Email : info@cawthron.org.nz Web: www.cawthron.org.nz.
Host Institution(s)	Cawthron Institute.
Location of Research	RoRo vessel *Rotoma*.
Funding Level	
Funding Source(s)	
Timeframe of the Project	
Aims and objectives of the project	To test the shipboard efficacy of heat treatment.
Research Methods	Cawthron developed a shipboard system on the RoRo vessel *Rotoma* for the heat treatment of ballast water. Water from ballast tanks is pumped through a heat exchanger, which is heated by the vessel's engine exhaust.
Results	Studies have shown that a complete kill of test organisms can be achieved in 6-10 hours by heating to 36-38°C.

Name of Project	Oxygen Deprivation as a Treatment for Ships' Ballast Water – Laboratory Studies and Evaluation
Treatment options researched	*Oxygen deprivation.*
Principal Researcher(s)	D Mountfort, C Hay, M Taylor, S Buchanan, W Gibbs.
Contact Details	Cawthron Institute 98 Halifax Street East Private Bag 2 Nelson Nelson New Zealand Tel: +64 (0)3 548 2319 Fax: +64 (0)3 546 9464 Email: doug@cawthron.org.nz Web: www.cawthron.org.nz.
Host Institution(s)	Cawthron Institute.
Location of Research	Nelson, New Zealand.
Funding Level	
Funding Source(s)	
Timeframe of the Project	Report printed in 1999.
Aims and objectives of the project	To demonstrate the potential for the use of oxygen deprivation as a treatment option for infected ballast water.
Research Methods	Adult samples of the starfish *Coscinasterias calamaria,* the zoospores of the seaweed *Undaria pinnatifida*, and the larvae of *Crassostrea gigas* were used for laboratory study of effects of nitrogen, sulphide and glucose in killing the sample organisms through oxygen depletion.
Results	Study concluded that lowering the level of oxygen to less than 3 mg/L leads to effective kills of *Undaria* zoospores and *Coscinasterias calamaria* larvae. However, more research is required both into the species range affected by deoxygenation and into the practicality of the various methods before shipboard investigations of this technology can be conducted.

Name of Project	Mid Ocean Ballast Water Exchange: Shipboard Trials of Methods for Verifying Efficiency
Treatment options researched	*Ballast Water Exchange.*
Principal Researcher(s)	Michael Taylor (Cawthron Institute) and Elizabeth Bruce (Battelle).
Contact Details	Cawthron Institute 98 Halifax Street East Private Bag 2 Nelson Nelson New Zealand Tel: +64 (0)3 548 2319 Fax: +64 (0)3 546 9464 Email : info@cawthron.org.nz Web: www.cawthron.org.nz.
Host Institution(s)	Cawthron Institute (New Zealand) and Battelle (USA).
Location of Research	Onboard testing conducted on the coastal container vessel MV *Spirit of Vision* and the trans-Pacific chemical carrier MT *Iver Stream.*
Funding Level	
Funding Source(s)	
Timeframe of the Project	Report published in August 1999.
Aims and objectives of the project	• To review the availability of existing methods to measure and record the volumes of water pumped through the ballast tanks and determine the efficiency of mid-ocean ballast water exchange practice. • To verify ship compliance with mid-ocean ballast water exchange controls and guidelines. • To develop and pilot test, including on at least two ships with different ballast tank configurations, ballast water exchange verification methodologies.
Research Methods	The study used: • A series of laboratory-based experiments which assessed the suitability of Rhodamine WT tracer dye for measuring the dilution efficiency of mid-ocean exchange; • Three voyages on the *Spirit of Vision* and one voyage aboard the *Iver Stream.*
Results	The study found that the tracer dye Rhodamine WT is particularly useful for measuring the dilution efficiency of mid-ocean ballast water exchanges. In each of the mid-ocean ballast water exchange trials, all of which used the flow-through dilution method, the dilution efficiency of the completed exchange was in excess of 90% for the *Spirit of Vision* (capacity tank = 114 cubic metres) and 99% for the *Iver Stream* (capacity tank = 1435 cubic metres).

Name of Project	**Shipboard Trials on Chemical Carrier MT *Iver Stream* and Use of Models for Designing Heat Treatment Systems**
Treatment options researched	*Heat*
Principal Researcher(s)	Doug Mountfort, Tim Dodgshun and Michael Taylor (Cawthron).
Contact Details	Cawthron Institute 98 Halifax Street East Private Bag 2 Nelson Nelson, New Zealand Tel: +64 (0)3 548 2319 Fax: +64 (0)3 546 9464 Email: info@cawthron.org.nz Web: www.cawthron.org.nz.
Host Institution(s)	Cawthron Institute (New Zealand).
Location of Research	On-board heat treatment trials conducted on the trans-Pacific chemical carrier MT *Iver Stream.*
Funding Level	Confidential.
Funding Source(s)	New Zealand Foundation of Research Science and Technology.
Timeframe of the Project	2001- 2002
Aims and objectives of the project	• Using sea-going trials identify factors that must be considered for optimisation of heat treatment of ship's ballast water. • By developing models, achieve optimal design and performance standards for heat treatment systems.
Research Methods	Trials on the chemical carrier *Iver Stream* (32,000 tons) were conducted during passage from Japan to New Zealand in February 2001 using tanks (1500 m^3 capacity) in the bottoms of which steam heated coils were fitted as standard equipment. Details on sampling and analysis can be found in Proc 1st Int Ballast Water Treatment R&D Symposium, IMO. London, 2001.
Results	The results of the first phase of this study showed that: • Temperature variability (thermocline) occurred in heated tanks in calm sea conditions. Uniform temperatures of tank contents could be achieved (raising the tank temperature to 35^{o}C for > 30 h) in moderate to rough sea conditions leading to effective kills of ballast organisms. • Heat loss from tanks was a key consideration in achieving the desired tank temperature. It was concluded that: • Some organisms might develop a tolerance to heating depending on whether the treatment is "fast" or "slow". • Priority should be given to optimising design of heat treatment systems so that heat losses are minimized and contents are adequately mixed during treatment. • Details on operating and installation costs of treatment systems need to accompany the design concept.

Norway

Name of Project	**Use of Gas Supersaturation to Remove Organisms in Ballast Water**
Treatment options researched	*Injections of gas (air and N2) to create gas supersaturation*
Principal Researcher(s)	Anders Jelmert
Contact Details	Dr. O. Enger Forinnova A/S Thormøhlensgate 55 N-5008 Bergen Norway www.forinnova.no
Host Institution(s)	Forinnova A/S
Location of Research	Institute of Marine Research Austevoll Aquaculture Research Station N5392 Storebø, Norway
Funding Level	US$35,000
Funding Source(s)	Norwegian Research Board: 50% Industry: 50%
Timeframe of the Project	Autumn 2000 – Summer 2001
Aims and objectives of the project	Studies on the effects of gas supersaturation on several organisms in ballast water.
Research Methods	Survival and other chosen end-point measures of organisms as a function of gas mixture, pressure and exposure time.
Results	(Preliminary) Increased mortality in *Artemia sp.* naupleii exposed to air at 1 atm for 18 hours, yielding 119% nitrogen supersaturation.

Name of Project	OptiMar Ballast Systems' Research 1998
Treatment options researched	*Mechanical separation (Lakos separator), UV treatment (MicroKill UV).*
Principal Researcher(s)	Halvor Nilsen.
Contact Details	OptiMarin AS Randabergv. 101 N-4027 Stavanger Norway Tel: +47 51542269 Fax: +47 51542439 Email: halvor.nilsen@stavanger.online.no Web: www.optimarin.com www.microkill.com
Host Institution(s)	Institute of Marine Research, Bergen, Norway.
Location of Research	Austevoll Aquaculture Research Institute Station.
Funding Level	ECU 50,000.
Funding Source(s)	Norwegian Maritime Directorate & OptiMarin AS.
Timeframe of the Project	March/April 1998.
Aims and objectives of the project	To develop a system of remove as many suspended solids and uni- and multi-cellular organisms through primary mechanical and secondary UV treatment.
Research Methods	The results were obtained in a semi-scale laboratory test of an integrated hydrocyclone-UV unit, designed for removal of exotic species in ballast water.
Results	The removal of particles and mortality of the various biota at four consecutive stages through the treatment system was recorded. Cysts of the brine shrimp *Artemia sp*. were removed at an efficiency of 13.7% in the hydrocyclone, and the naupilus-larva of *Artemia* were removed at an efficiency of 8.3%. Through the UV-unit, the naupleii showed a mortality of 99.5% and the numbers of hatching cysts was 26 % lower than the numbers before the unit. The microalga were removed with an efficacy of 10 - 30 % range in the hydrocyclone, and showed a mortality in the UV-unit of 84.7% and 87.6 %, respectively for *P. minimum* and *Tetraselmis sp*. The removal of bacteria in the hydrocyclone was negligible, while the bacterial numbers were reduced corresponding to a -2.3 log and -1.9 log elimination respectively, by UV treatment in two separate trials.

Name of Project	OptiMar Ballast Systems Research 1999
Treatment options researched	*Mechnical separation (Lakos separator), UV treatment (MicroKill UV).*
Principal Researcher(s)	Halvor Nilsen.
Contact Details	OptiMarin AS Randabergv. 101 N-4027 Stavanger Norway Tel: +47 51542269 Fax: +47 51542439 Email: halvor.nilsen@stavanger.online.no Web: www.optimarin.com www.microkill.com
Host Institution(s)	Institute of Marine Research, Bergen, Norway.
Location of Research	Austevoll Aquaculture Research Institute Station.
Funding Level	ECU 60,000.
Funding Source(s)	OptiMarin AS.
Timeframe of the Project	March/April 1999.
Aims and objectives of the project	Repeat of the 1998 test but with another separator.
Research Methods	The results were obtained in a semi-scale laboratory test of an integrated hydrocyclone-UV unit, designed for removal of exotic species in ballast water.
Results	Same as 1998. Subsequent to these tests, the Optimar Ballast Water Treatment System has been installed aboard the cruise-liner *Regal Princess* and is the first fully functional ballast water treatment system aboard an operating vessel. Further tests are required, especially in relation to scaling-up to handle larger quantities of ballast water on tankers and bulk carriers.

Name of Project	Ballast Water Treatment by Ozonation
Treatment options researched	*Ozone treatment.*
Principal Researcher(s)	Aage Bjørn Andersen, Egil Dragsund, Bjørn Olav Johannessen.
Contact Details	Det Norske Veritas Veritasveien 1 N-1322 Høvik Norway Tel: +47 67 57 85 86 Fax: +47 67 57 99 11 Email: aage.bjorn.andersen@dnv.com Web: www.dnv.com
Host Institution(s)	DNV Høvik, Norway.
Location of Research	DNV Høvik and University of Oslo.
Funding Level	NOK 800,000 (NOK 500,000 for 1999-2000; NOK 300,000 for 2000-1).
Funding Source(s)	Barber Ship Management.
Timeframe of the Project	1999 – 2001.
Aims and objectives of the project	To evaluate and test whether ozone represents an appropriate risk reducing alternative for ballast water treatment.
Research Methods	• Review of recent literature. • Laboratory testing of: - Efficiency of ozone disinfection. - Oxidant decay rates in seawater. - Corrosivity of ozone treated seawater.
Results	Literature review has identified ozonation as a potentially efficient option representing a chemical method without environmental harmful side effects. Findings from the literature have been an input to the planning of the laboratory testing phase. The estimated increase in corrosivity of the ballast water is based on a limited short period experiment. Prior to a full-scale evaluation of ballast water ozonation, a more detailed long-term test on corrosion should be undertaken. Further work will encompass full-scale methodology verification aboard a vessel trading between the USA and Australia. This will be performed in co-operation with Australian Quarantine and Inspection Service (AQIS) and US Coast Guard (USCG). Final arrangements have not yet been formalised.

Name of Project	Corrosion Effects of Ballast Water Treatment Methods
Treatment options researched	*N/A.*
Principal Researcher(s)	Egil Dragsund (DNV), Bjørn Olav Johannessen (DNV), Aage Bjørn Andersen (DNV), John Olav Nøkleby
Contact Details	Det Norske Veritas Egil.dragsund@dnv.com
Host Institution(s)	Det Norske Veritas, Veritasveien 1, 1322 Høvik, Norway
Location of Research	Det Norske Veritas, Veritasveien 1, 1322 Høvik, Norway
Funding Level	700,000.- NoK
Funding Source(s)	DNV Research funds
Timeframe of the Project	01.01.03 – 15.12.03
Aims and objectives of the project	This project is an integrated element of a larger research programme undertaken by DNV and Norwegian Institute of Water Research (NIVA). This programme was initiated in 2003 and will run until 2005. The overall aim is to expand the understanding associated to proposed treatment options for non-indigenous species introductions and to develop methods, standards and norms for risk reducing measures (treatment methods).
Research Methods	Literature review, laboratory studies, full scale verification studies
Results	Ballast Water Verification Protocol Standard for Certification Performance criteria – Ship/Crew safety

Poland

Name of Project	System for Destruction of Microorganisms Occurring in Ballast Waters: Technical Assumptions
Treatment options researched	*Heat treatment.*
Principal Researcher(s)	Zdzislaw Sobol, Wladyslaw Korczak, Bohdan Wojaliewicz.
Contact Details	Institute of Maritime and Tropical Medicine in Gdynia Department of Protection of the Environment and Hygiene of Transport Ul. Powstania Styczniowego 9B 81-519 Gdynia Poland Tel: +48 58 622 30 11 Fax: +48 58 622 33 54 Web: www.immt.gdynia.pl.
Host Institution(s)	Institute of Maritime and Tropical Medicine in Gdynia.
Location of Research	Gdynia, Poland.
Funding Level	
Funding Source(s)	
Timeframe of the Project	Report Date – 1995.
Aims and objectives of the project	Selection of appliances for the treatment of micro- and macro-organisms occurring in ballast water.
Research Methods	
Results	Heat treatment is preferable to chemical treatment as it does not require carrying chemicals onboard, and heat is continuously available from boiler steam or main and auxiliary engine cooling system. The costs are also small when compared with other methods. The chemical method required final deactivation before it is discharged into the sea, making heat more competitive. Use of UV was not considered, as ballast water is extremely dirty and coloured. Disinfecting methods using radiation was not considered, as its use is not neutral to a natural sea environment.

Singapore

Name of Project	**Development of Dinoflagellate "Cyst-on-Demand" Protocol, and Comparison of Particle Monitoring Techniques for Ballast Water Treatment Evaluation**
Treatment options researched	*Filtration, Hydrocyclone, UV, Biocides and Photocatalysis*
Principal Researcher(s)	Dr. Jose Matheickal (IESE) and Dr. Michael Holmes (TMSI)
Contact Details	Institute of Environmental Science and Engineering Nanyang Technological University, Innovation Centre, Unit 237, Block 2 18 Nanyang Drive Singapore 637723 Tel: +65 67941556 Fax: +65 67921291 Email: jtmath@ntu.edu.sg
Host Institution(s)	Institute of Environmental Science and Engineering
Location of Research	Singapore
Funding Level	-
Funding Source(s)	-
Timeframe of the Project	2002-2003
Aims and objectives of the project	• to evaluate the use of particle counting as a measure of ballast water filtration efficiency and to continuously monitor filter performance • to develop and optimise a culturing protocol for mass-culturing of dinoflagellate cysts
Research Methods	• lab-scale and pilot scale evaluation of filtration systems • comparison of various particle monitoring techniques using different water samples • excystment and encystment studies using dinoflagellate cultures
Results	Dramatic variations in particle counts were present between electrical sensing zone based particle counters and the commonly used light obscuration based counters. The latter one dramatically undercounted particles in smaller size classes compared with the research grade ESZ instruments for all types of samples. However, light obscuration particle counters can give a cheap and practical solution for online monitoring of ballast water, provided the instrument is calibrated using appropriate calibration standards, right concentration of particles used and correct flow rate is chosen. It is strongly recommended that ballast water monitoring be conducted using an electrical sensing zone based particle counting instrument for any verification purposes. The second part of the study developed culture protocols for producing hypnozygotes (cysts) of the CCMP1735 strain of dinoflagellate *Scrippsiella Sp.* on demand. It was observed that transferring a large biomass of motile cells to nutrient deficient media induces cyst formation. Once the hypnozygotes mature they begin spontaneously excysting after about 2 days. However, hypnozygotes can be stored in a quiescent state for up to 2 months in the dark at 5 to 7 ^{o}C, although the proportion of viable cells drops after about 1 month storage. The time to excystment of cold-stored hypnozygotes can be predicted from the time of cold storage. Dinoflagellate, being an invasive species of international concern, can be an ideal surrogate organism for treatment system evaluation. The protocol developed in this study can be used to produce sufficiently large number of dinoflagellate cysts.

Name of Project	Dockside Evaluation of Various Self-cleaning Filtration Technologies
Treatment options researched	*Self-cleaning Filtration*
Principal Researcher(s)	Dr. Jose Matheickal (IESE)
Contact Details	Institute of Environmental Science and Engineering Nanyang Technological University, Innovation Centre, Unit 237, Block 2 18 Nanyang Drive Singapore 637723 Tel: +65 67941556 Fax: +65 67921291 Email: jtmath@ntu.edu.sg
Host Institution(s)	Institute of Environmental Science and Engineering
Location of Research	Singapore.
Funding Level	S$ 1 million
Funding Source(s)	IESE and Maritime and Port Authority of Singapore.
Timeframe of the Project	2002-2003.
Aims and objectives of the project	To develop a filtration system coupled with a secondary treatment system for ballast water treatment and to study the biological and hydraulic performance of the system.
Research Methods	Pilot-scale test runs using a dockside facility. Use flow cytometers, particle size distribution and specific DNA probes for system performance evaluation.
Results	Self-cleaning Filter systems showed promising results in terms of hydraulic performance as well as biological efficacy. Tests using various screen types showed that candle type screen elements offered the best results in terms of filter backwashing efficiency.

Name of Project	Development of Methods and Diagnostic Kits for Rapid Microbiological Monitoring of Ballast Water Quality
Treatment options researched	*Development of rapid monitoring technologies*
Principal Researcher(s)	Tay Joo Hwa, Tay Tiong Lee Stephen, Volodymyr Ivanov
Contact Details	Maritime Research Centre Nanyang Technological University 50 Nanyang Avenue, Singapore 639798
Host Institution(s)	Maritime Research Centre, School of Civil and Environmental Engineering Nanyang Technological University
Location of Research	Maritime Research Centre Blk N1, # B3b-29 50, Nanyang Avenue, Singapore 639798
Funding Level	USD100,000.00
Funding Source(s)	Maritime and Port Authority of Singapore, Maritime Research Centre Nanyang Technological University
Timeframe of the Project	Dec 2000 – Dec 2003
Aims and objectives of the project	The objectives of the research project are 1) to develop and optimise the quantitative method for fast microbiological examination of ballast water using a flow cytometer; 2) to develop and optimise the semi-quantitative method and diagnostic kit for microbiological examination of ballast water suitable for any operator unskilled in microbiology; and 3) to perform the field tests of ballast water in Singapore using these developed methods.
Research Methods	The following methods were used for the microbiological monitoring of ballast water: Fast approach for microbiological monitoring of ballast water by skilled technician in specialized laboratory using a combination of hybridization of whole-cell rRNA with fluorescent-labeled oligonucleotide probes measured by flow cytometer. Fast approach for microbiological monitoring of ballast water by unskilled operator in simple laboratory or even on board through the counting of the particles in narrow range of size which is specific for bacterial cells, probably between 1 to 10 µm. Simple approach for microbiological monitoring of ballast water using chromogenic indication of bacteria presence in ballast water.
Results	The concentrations of total bacteria, enterobacteria, Vibrio spp., and E.coli have been compared for ballast water samples taken from ships in Singapore Harbour. The cell concentrations were enumerated using FISH and flow cytometry. The data were highly variable, reflecting the many influences upon ballast water as it is utilized in proportion of the total concentration of cells for the ballast water sampled. For the ballast water sampled these concentrations were 0.67-39.55% for eubacteria, 0-2.46% for enterobacteria, 0.18-35.82% for Vibrio spp., and 0-2.46% for E.coli. Correlations were found between the number of particles and the number cells measured for seawater and ballast water samples for various size ranges in an attempt to determine the best size range for analysis. The range of size examined were 0.2, 0.5, 1, 2, 4 and 6 µm. The range of cell sizes, which would give an optimal measurement between the number of particles and the number of cells, was found to be 1-6 µm. The size range would be of use for practical analysis of environmental samples on the basis of forward scattering

	of light. Analysis of ballast water samples by flow cytometry was found to be compatible with analysis by a particle counter. Particle counting in the size ranges of 1 to 2 µm and 1 to 4 µm and bacterial cell enumeration (eutrophs and oligotrophs) by plates was performed for ballast water samples. Portable particle counter could be used for estimation of bacterial cell concentration in ballast water. It takes 16 seconds for analysis of one sample, while conventional plate counting takes 3 to 7 days. The coefficient of correlation was 0.9. Total number of the particles (bacterial cells) detected by particle counter was lower than that of the cells enumerated. The particle counting had the coefficient of variation from 0.1 to 14% and coefficient of variation for plate counting was 2 to 53%. Simple and portable test kit based on the chromogenic detection of coliforms in ballast water was also developed. Performance of test kit was studied in the laboratory with the suspension of test bacteria and with the samples of ballast water. Linear relation was observed between the length of stained part of the test kit with logarithm of test bacteria concentration. Best minimum detection limit with test bacteria was 400 cells with β-galactosidase activity/ml. However, in the analysis of ballast water samples the minimum detection limit was approximately 1 cell with β-galactosidase activity/ml. Developed test kit is very portable and simple to use. It could be employed by anybody for microbiological analysis of ballast water on-site. The presence and absence of coliforms could be determined by coloration on the scaled band and can be used for semi-quantitative enumeration of coliforms in the ballast water.

United Kingdom

Name of Project	Disinfection of Ballast Water – A Review of Potential Options
Treatment options researched	*Mechanical (filtration), physical (UV and heat treatment), chemical.*
Principal Researcher(s)	K Müller, J S Carlton
Contact Details	Lloyds Register Engineering Services Lloyds Register House 29 Wellesley Road Croyden CR0 2AJ United Kingdom Tel: +44 (0)20 8681 4040 Fax: +44 (0)20 8681 6814
Host Institution(s)	Lloyds Register, Engineering Services, Technical Investigation, Propulsion & Environmental Engineering Department.
Location of Research	
Funding Level	
Funding Source(s)	
Timeframe of the Project	Report date – July 1995.
Aims and objectives of the project	Evaluate disinfection options for ballast water.
Research Methods	Study comprised desk based review of various disinfection options and laboratory-based trials to examine likely effectiveness of selected disinfection methods for onboard use.
Results	Treatment options for the disinfection of ballast water at sea or at the port of origin (as an alternative to the exchange of ballast water at sea) are described in terms of efficiency, practicality, cost, environmental impact and safety considerations.

Name of Project	Testing Ballast Water Treatment Equipment
Treatment options researched	*Not applicable*
Principal Researcher(s)	Prof. Arne E Holdø
Contact Details	Faculty of Engineering and Information Sciences University of Hertfordshire College Lane Hatfield Herts. AL10 9AB United Kingdom Phone: +44 1707 284272 Fax: +44 1707 285086 Email: a.e.holdo@herts.ac.uk
Host Institution(s)	University of Hertfordshire
Location of Research	University of Hertfordshire
Funding Level	internal
Funding Source(s)	internal
Timeframe of the Project	End of July 2003
Aims and objectives of the project	Construction and testing of facility enabling ballast water treatment equipment to be tested for certification/ classification
Research Methods	Fluid mechanic designs
Results	Availability of facility

Name of Project	Efficiency of Ballast Water Exchange in Regional Seas
Treatment options researched	*Ballast water exchange*
Principal Researcher(s)	Tracy McCollin
Contact Details	Tracy McCollin FRS Marine Laboratory PO Box 101 Victoria Road Aberdeen AB11 9DB Tel: +44 (0)1224 295 573 Fax: +44 (0)1224 295 511 Email: mccollint@marlab.ac.uk
Host Institution(s)	FRS Marine Laboratory.
Location of Research	Scotland, United Kingdom.
Funding Level	Approx £325 000.
Funding Source(s)	Scottish Executive Environmental and Rural Affairs Department and Scottish Natural Heritage.
Timeframe of the Project	July 1999-January 2003
Aims and objectives of the project	• Carry out a detailed assessment of the efficiency of in-transit exchange in the North Sea and Irish Sea on planktonic organisms in ship's ballast tanks. • Assess the survival of planktonic organisms whilst on passage in ballast tanks.
Research Methods	Marine Laboratory staff travel with a vessel on the ballast leg of its journey back to the west coast of Scotland from ports within northern Europe. The vessel carries out a ballast exchange process and samples are taken from the ballast tanks before, during and after exchange.
Results	When low salinity port water was exchanged the final salinity of the water in the ballast tanks after exchange was always lower in comparison to the final values obtained after exchanging higher salinity port water. This indicates that some of the original port water remained in the tanks and had a dilution effect on the water loaded into the tanks during exchange. For zooplankton, ballast water exchange generally resulted in an increase, or no change, in the number of taxa and diversity but a decrease in abundance. The phytoplankton results did not have such a clear pattern. There was generally a decrease in abundance after exchange. More detailed analysis of the similarity of the taxa present before and after exchange is being carried out.

United States of America

Name of Project	Electro-Ionization Treatment for Ballast Water; First Assessment of Effectiveness Against Marine Microbiota and Design of Shipboard, Shore Based, and Tender Ballast Treatment Systems
Treatment options researched	*Electro Ionization(EIMS™)*
Principal Researcher(s)	Joe Aliotta, Ph.D – Marine Environmental Partners, Inc Dr. Andrew Rogerson, Ph.D – Nova Southeastern University, Ft. Lauderdale, FL
Contact Details	Marine Environmental Partners, Inc. 3001 W. State Road 84 Ft. Lauderdale, FL 33312 United States of America Tel: +1 954 791 3700 Fax: +1 954 791 2447 E-mail: mark@mepi.net Web: www.mepi.net Capt. "Bud" C.E. Leffler, President Jon Stewart, Exe. VP Sales & Marketing Mark Yonge, Exe. VP – Maritime Affairs
Host Institution(s)	Nova Southeastern University, Ft. Lauderdale, FL.
Location of Research	Ft. Lauderdale, Florida USA.
Funding Level	Private.
Funding Source(s)	Marine Environmental Partners, Inc.
Timeframe of the Project	October, 2000 – January, 2001.
Aims and objectives of the project	To evaluate & demonstrate the effectiveness of electro-ionization technology in killing marine microbes similar to those found in ballast water and to design a best available technology treatment system process for ship, land based and tender installations. To develop data from which to design an electro-ionization treatment system for the treatment of ballast water.
Research Methods	Marine Environmental Partners, Inc. supplied a pilot system to Nova Ocean Research Center. The system components are 150 gal. Tank containing seawater to mimic ballast tanks, a NI-OX/L™ gas generator and a Clorin™ gas generator. High-pressure pumps, & differential pressure injectors. Sea Water (salinity ca.32 g/l) from the port is used as well as seeding with ca.50liters of seawater enriched with a mixture of protists (algae and protozoa). Bacteria were counted by standard plate counting methods. Plates incubated and number of colonies recorded. Protists are counted by enrichment cultivation using methods fully detailed in Rogerson and Gwaltney (2000). All data converted to percentage survival levels to normalize for any differences in the numbers of starting organisms. Chlorine levels were kept below detection in the treated water.
Results	The results of this project are incorporated in the results of Project "Electro-sanitization of Ballast Water" in this directory.

Name of Project	AquaHabiStatÔ, or AHSÔ
Treatment options researched	*Removal of dissolved oxygen as water enters ballast tank through use of a vacuum tank. Maintaining low DO for duration of voyage.*
Principal Researcher(s)	Browning Transport Management, Inc.
Contact Details	Wilson Browning Jr and Wilson Browning III Browning Transport Management, Inc. 127 Bank Street Norfolk, VA 23510 United States of America Tel: +1 757 622 3321 Fax: +1 757 625 7456 Email: will@wjbrowning.com leslie@wjbrowning.com Web: www.wjbrowning.com
Host Institution(s)	The Commonwealth of Virginia; Old Dominion University; Hampton Roads Sanitation District; Virginia Institute of Maritime Science.
Location of Research	Hampton Roads, VA.
Funding Level	>US$2.5 million.
Funding Source(s)	Browning Transport Management and the Commonwealth of Virginia.
Timeframe of the Project	The project consisted of three 10-day time series tests completed in summer 2000 and two 10-day series tests completed December 2000.
Aims and objectives of the project	To measure the decline, by microscopic counts, of "ambient zooplankton other than copepods" as a marker group for larval forms to compare the deoxygenated water with the normal simulated ballast water. Did not consider copepods' activities to mimic larval forms as much as would other zooplankton.
Research Methods	A pump located near the bulkhead moved ambient water from Elizabeth River (VA) into a 5,000 liter (18 foot diameter) plastic swimming pool. From there, a computer controlled system pumped the water out of the first pool and used a propriety spray system to inject the water into a vacuum tank that was kept near or below 1 psia by a vacuum pump under the direction of the computer control system. A second pump pulled the water out of the vacuum and placed it in a duplicate, treated pool. Both pools were covered to simulate a ballast tank. Daily samples were taken. Of the first three 10-day series tests, the first two were done microscopically from relatively warm water (20-26°C). The third 10-day test, also in 20-26°C water, was analysed microscopically and by ATP analysis. The water arrived in the treated tank with a DO of 1ppm or less and in general declined to 0.5ppm in five days and to zero in ten days.
Results	After ten days, the treated tank had no organisms present, while the untreated tank did.

Name of Project	Progress Report on the AquaHabiStat (AHS) Deoxygenation System
Treatment options researched	*Mechanical deoxygenation on intake*
Principal Researcher(s)	Wilson J. Browning, Jr. (Inventor and Coordinating Investigator), J. Parker Davis, Wilson J. Browning III Captain Claude Thompson, US Coast Guard (Ret.) Former Chief of the Engineering Faculty of the USCG Academy Dr. Roger Mann, PHD, Professor of Marine Biology and Deputy Director of the Virginia Institute of Marine Science
Contact Details	AquaHabiStat 223 East City Hall Ave. Suite 200 Norfolk, Virginia 23510 Tel: +1 757-233-7278 Fax: +1 757-625-7456 www.AquaHabiStat.com Email@aquahabistat.com
Host Institution(s)	Virginia Institute of Marine Science Old Dominion University Hampton Roads Sanitation District
Location of Research	South Eastern Virginia, United States
Funding Level	Approximately $4 million
Funding Source(s)	State government, Private Investors, NOAA
Timeframe of the Project	Initial prototype testing summer and fall 2000. Anticipated vessel and flow rate testing summer and fall 2003
Aims and objectives of the project	The main objective is to study the effectiveness of AHS system in reducing larval aquatic invaders in the ballast water of ships at high flow rates. While the AHS prototype has demonstrated capability of functionality suitable for many commercial vessels, it would like to broaden the spectrum capabilities to coordinate with the cargo discharge rates of the normal operational procedures of larger vessels such as tankers. Current planning and funding is in process to show that the same prototype system will maintain efficacy at an anticipated flow rate of 300 tons per hour, onboard a vessel or barge. AHS anticipates executing onboard comparison tests that will allow it to gather direct data of the effects of vacuum deoxygenation as compared directly to ballast exchange procedures.
Research Methods	In the experiments taken in summer of 2000, micro-organisms including zooplankton (>75 and 80 µm) as well as biomass were monitored in treated and untreated water samples using 18 foot diameter 20,000 litre pools loosely covered with black plastic for better simulation of a dark ballast tank. Replication and Control methodology was established in multiple stages. First, The entire experiment consisted of three separate, sequential 10-day time - series tests, simulating the ballast voyages of three separate bulk carriers returning to Hampton Roads in ballast from Europe, to load a new cargo of coal. Sampling was conducted about 1000 meters from the coal piers, which receive the highest concentration of ballast water discharge in the United States. The three replicate simulated voyages were organized as if they carried both treated and untreated ballast water. Also, each of the three separate individual sequential tests provided a control on any one single other of the individual tests in the event that a single test encountered unusual conditions in the ambient water being drawn from the Elizabeth River for testing. Averages of the three were used for reporting purposes. Additional replication and control issues were addressed by utilizing two separate laboratories from two separate disciplines [i.e. university, and

	municipal forensic sanitation laboratories]. Each of these maintained their own replicate and control procedures as outlined in "Pool Sampling". Neither of these laboratories are affiliated with AHS except to having received remuneration for their efforts. AHS served only as the Engineering and Coordinating Investigator. The obvious high correlation of the various separate tests, different sampling techniques, and separate double-lab analyses created a high enough level of confidence in the results such that funds were not expended on formal statistical correlations and cross correlations. The water in the pools was monitored for water quality (dissolved oxygen, temperature, salinity, conductivity, and pH).
Results	The AHS system removed dissolved oxygen (DO) from ballast water to levels below 1 ppm with a vacuum equivalent of negative 14.2 psi and, after three days in the treated water, all larval stages that could become "nuisance species" and other organisms 75 microns and above were eliminated.

Name of Project	The Great Lakes Ballast Water Technology Demonstration Project: Filtration Mechanical Test Program
Treatment options researched	*Mechanical filtration.*
Principal Researcher(s)	Allegra Cangelosi, MS (Northeast/Midwest Institute) and Richard Harkins, PE, (Lake Carriers' Association); with Ivor Knight, PhD, James Madison University, Mary Balcer, PhD, University of Wisconsin – Superior; Michael Parsons, PhD, University of Michigan; David Wright, PhD, and Rodger Dawson, PhD, University of Maryland; and Donald Ried, MS, Napean, Ontario.
Contact Details	Northeast/Midwest Institute 218 D Street, SE Washington, DC 20003 United States of America Tel: +1 202 544 5200 Fax: +1 202 544 0043 Email: acangelo@nemw.org Web: www.nemw.org.
Host Institution(s)	Northeast-Midwest Institute.
Location of Research	Gulf of St Lawrence, Great Lakes, Duluth Harbor.
Funding Level	Over $1.5 million
Funding Source(s)	Great Lakes Protection Fund, Legislative Commission on Minnesota Resources, US Environmental Protection Agency Great Lakes National Program Office.
Timeframe of the Project	1996 – 1998.
Aims and objectives of the project	To establish the biological and operational effectiveness of ballast filtration.
Research Methods	Testing was conducted on the Canadian seaway sized (222.5m x 22.86m) bulk carrier MV *Algonorth* in 1997 and a barge in Lake Superior in 1998. The test programme involved extended testing with 25 and 50 micron filter screens at 1500 US gpm with and without a prefilter. Bioeffectiveness was measured in matched treatment and control tanks and evaluated for relative zooplankton, phytoplanklton and microbial concentrations.
Results	Study concluded that filtration at 25 and 50 microns yielded similar biological results: macrozooplankton removed at a rate of 96 percent or higher, 2) microzooplankton (rotifers) and total phytoplankton removed at rate of 70-80 percent; and 3) no significant reduction in total bacteria, though attached bacteria significantly reduced. Zooplankton width, rather than length, was dimension most predictive of removal efficiency. Filtration is suitable for some shipboard applications and particle removal will reduce sedimentation in ballast tanks. Future designs must have improved features to facilitate handling of the heavy filter screen elements.

Name of Project	Great Lakes Ballast Technology Demonstration Program Field Trials and Comparison of Commercially Available Primary and Secondary Ballast Treament Alternatives
Treatment options researched	*Filtration and UV; Cyclonic Separation and UV.*
Principal Researcher(s)	Allegra Cangelosi, MS (Northeast/Midwest Institute) and Richard Harkins, PE, (Lake Carriers' Association) with Ivor Knight, PhD, James Madison University, Mary Balcer, PhD, University of Wisconsin – Superior; Mike Parsons, PhD, University of Michigan; David Wright, PhD, and Rodger Dawson, PhD, University of Maryland; Donald Ried, MS, Napien, Ontario, and Nicole Mays, NEMWI.
Contact Details	Northeast/Midwest Institute 218 D Street, SE Washington, DC 20003 United States of America Tel : +1 202-544-5200 Fax: +1 202-544-0043 Email: acangelo@nemw.org Web: www.nemw.org
Host Institution(s)	Northeast Midwest Institute.
Location of Research	Barge-based tests: Duluth-Superior Harbor, MN and Two Harbors, MN; Ship-board tests: M/S *Regal Princess* Vancouver to Alaska voyages.
Funding Level	Approximately US$600,000.
Funding Source(s)	US EPA Great Lakes National Program Office, National Sea Grant Association, US Coast Guard.
Timeframe of the Project	Fieldwork took place May-September 2000.
Aims and objectives of the project	To develop protocols for assessing biological and operational effectiveness of ballast treatments on a barge-based platform and ship installation; to assess and compare the relative effectiveness of filtration/UV and cyclonic separation/ UV under field conditions at a flow rate of 1500 gpm; to draw conclusions about the generalizability of barge-based information to ship context.
Research Methods	Barge-based biological tests involved sampling triplicate matched treatment and control collection tanks at two time intervals and turbidity levels. Samples were subjected to live/dead and density analysis of zooplankton; total chlorophyll a, growth rate, and density analysis of phytoplankton; inactivation rate of a spiked MS 2 bacteriophage; and total bacteria counts. Particle removal, flow rate, and power consumption were measured. M/S *Regal Princess* tests involved three before/after in-line tests; three ballast tank "time zero" tests (water was placed in matched treatment and control ballast tanks and then removed immediately); and three ballast tank "retention tests" (water was retained for 18-24 hours). Samples were analyzed for density/inactivation of zooplankton, phytoplankton and bacteria.
Results	Not provided.

Name of Project	M/T Stolt Aspiration (Parcel Tanker)
Treatment options researched	*OptiMar Ballast System (Separation and UV)*
Principal Researcher(s)	Allegra Cangelosi
Contact Details	Northeast/Midwest Institute 218 D Street, SE Washington, DC 20003 USA Tel : +1 202-544-5200 Fax: +1 202-544-0043 Email: acangelo@nemw.org Web: www.nemw.org
Host Institution(s)	Great Lakes Ballast Technology Demonstration Project.
Location of Research	Great Lakes and Western Europe.
Funding Level	
Funding Source(s)	Great Lakes Protection Fund.
Timeframe of the Project	Summer/fall 2002.
Aims and objectives of the project	Verify effectiveness of the OptiMar System.
Research Methods	On board sampling.
Results	Not provided.

Name of Project	Inactivation of Human Pathogens through Photon Engineering
Treatment options researched	*UV light.*
Principal Researcher(s)	Fred C. Dobbs and Mounir Laroussi.
Contact Details	Dr Fred C. Dobbs Department of Ocean, Earth and Atmospheric Sciences Old Dominion University 4600 Elkhorn Avenue Norfolk, VA 23529-0276 United States of America Tel: +1 757-683-5329 Fax: +1 757-683-5303 Email: fdobbs@odu.edu Web: www.ocean.odu.edu/dobbs/dobbsnew.htm Dr Mounir Laroussi Department of Electrical and Computer Engineering, Old Dominion University, Applied Research Center Newport News, VA 23606 United States of America Tel: +1 757-269-5640 Email: laroussi@jlab.org
Host Institution(s)	Old Dominion University.
Location of Research	Old Dominion University, Norfolk, Virginia, USA.
Funding Level	US$99,903.
Funding Source(s)	National Sea Grant College Program.
Timeframe of the Project	1 Oct 1999 - 31 March 2001.
Aims and objectives of the project	To design, construct, and develop a laboratory prototype UV reactor that will provide an effective second step, following filtration, to minimize microorganisms in ships' ballast waters.
Research Methods	Bench-top studies to test the efficacy of a UV lamp in killing bacteria and dinoflagellates and inactivating viruses in flowing water. Tests will proceed under various flow rates and with various repeated-pass scenarios.
Results	Not provided.

Name of Project	The Feasibility of Biocide Application in Controlling the Release on Nonindigenous Aquatic Species from Ballast Water
Treatment options researched	*Biocide treatment of ballast water using glutaraldehyde.*
Principal Researcher(s)	Dr Michael Parsons, Dr Peter Landrum, Ms Larissa Sano, Lt Curtis s C. Potter, Ms Ann Krueger.
Contact Details	Dr Michael Parsons 236A NA&ME Bldg., Room 2145 Ann Arbor, MI 48105 United States of America Tel: +1 734 763 3081 Fax: +1 734 936 8820 E-mail: parsons@engin.umich.edu
Host Institution(s)	Cooperative Institute for Limnology and Ecosystems Research (University of Michigan, College of Engineering) and the Great Lakes Environmental Research Lab (National Oceanic and Atmospheric Association).
Location of Research	Ann Arbor, Michigan.
Funding Level	US$306,000.
Funding Source(s)	Great Lakes Fishery Trust Fund.
Timeframe of the Project	March 1998 – February 2001.
Aims and objectives of the project	To investigate the potential for biocide treatment in helping reduce the number of nonindigenous species released into Great Lakes' waters. Components of this objective are to establish the concentrations of glutaraldehyde required to achieve 90% mortality rates (LC90) in 24-hour water-only exposures using a range of representative aquatic organisms; Determine the effect of sediments on glutaraldehyde efficacy in 24-h water-sediment exposures; Measure degradation rates of glutaraldehyde under conditions similar to those found in ballast tanks; Determine the concentrations of glutaraldehyde that may pose a risk to organisms exposed in receiving waters; Conduct a field trial of glutaraldehyde treatment using a foreign NOBOB (no ballast on board) vessel transiting from the Baltic area to the Great Lakes.
Research Methods	Laboratory testing, which included a 24-hour acute lethal toxicity bioassays, chronic toxicity bioassays, degradation experiments and shipboard application (still in development).
Results	Not provided.

Name of Project	Evaluation of SeaKleen® for controlling aquatic pests in ships' ballast water
Treatment options researched	*Chemical (Biocide)*
Principal Researcher(s)	Stephen J. Cutler*, Horace G. Cutler, Jan Glinski, David Wright, Rodger Dawson and Denis Lauren
Contact Details	Garnett, Inc. 1050 Creek Hollow Run Watkinsville, GA 30677 USA *Tel: +1 770 552 9895 Email: cutlers1@bellsouth.net
Host Institution(s)	*Garnett Inc., Watkinsville, GA 30677 USA [2]Planta Analytica, New Fairfield, CT 06812 USA [3]University of Maryland, Center for Environmental Science Chesapeake Biological Laboratory, Solomons, MD 20688 USA [4]HortResearch , Ruakura Research Centre, Hamilton, New Zealand
Location of Research	Same as Host Institution
Funding Level	$2,500,000
Funding Source(s)	Private Company
Timeframe of the Project	July 2001-June 2003
Aims and objectives of the project	This project includes the evaluation of SeaKleen® against a variety of aquatic nuisance species residing in ballast tanks of ships. Furthermore, this study includes the degradation of the active component in fresh and salt water studies using High Performance Liquid Chromatography (HPLC).
Research Methods	While investigating the use of various natural products as molluskocidal agents, it was observed that several agents belonging to the chemical class of naphthoquinones were found to be highly effective. Further investigation in the structure-activity-relationship led to the biologically active agent menadione, which is being developed under the trademark SeaKleen®. This product has been shown to possess significant efficacy against a wide variety of estuarine and fresh water organisms including *Cyprinodon variegatus*, *Eurytemora affinis*, *Isochrysis* sp., *Neochloris* sp., and *Glenodinium foliacium* cysts. In addition, current studies have shown SeaKleen® is very effective against free swimming *Glenodinium foliacium*, *Cyclopoidea* sp (Cyclops). In order to gain a better understating of its effects, studies were designed to evaluate SeaKleen® against the edible oyster, *Mytilus galloprovincialis* . Based on the broad spectrum activity of SeaKleen® against marine organisms, it was of interest to determine the degradation of the active component, menadione, when subjected to normal applications. Using an HPLC assay, SeaKleen® was subjected to sterilized and unsterilized sea and fresh water over a period of 72 hours, and samples taken at 24 hour intervals, to determine longevity and breakdown.
Results	Not provided.

Name of Project	**Electro-Ionization Treatment for Ballast Water; Shipboard Installation on Carnival M/S *Elation***
Treatment options researched	*NI-OX gas system interfaced with seawater electrolysis*
Principal Researcher(s)	C. E. Bud Leffler , William Paul, Marine Environmental Partners Dr. Andrew Rogerson Ph.D. & Courtney Campbell Nova Southeastern University, Ft. Lauderdale, Fla.
Contact De tails	Marine Environmental Partners, Inc. 255 E. Dania Beach Blvd. Suite 220 Dania Beach, Fla. U.S. 33004 Tel: +1 954-924-5500 Fax: +1 954-924-5508 Email: bud@mepi.net jon@mepi.net Web: www.mepi.net C.E. Bud Leffler – President & CEO, Jon Stewart – V.P. Sales & Marketing Bill Paul – Manager Installation & Service Engineering
Host Institution(s)	NOVA Southeastern University Oceanographic Research Center, Ft. Lauderdale, Fla.
Location of Research	Fort Lauderdale Florida USA and Long Beach, California USA.
Funding Level	Private.
Funding Source(s)	Private.
Timeframe of the Project	Installation was completed Jan 2002. Testing will be completed 17 March 2002.
Aims and objectives of the project	Evaluate and demonstrate the viability of utilizing multiple processes of electro-disinfection to eliminate biota in ship's ballast water.
Research Methods	Verification of killing effectiveness was determined by indirect counting methods. These are all enrichment cultivation methods that rely on scoring the growth of organisms after treatment. Growth is a strong index of survival because only healthy, undamaged cells will reproduce. Bacteria were enumerated by standard plate counting methods using Marine agar 2216 to nourish total heterotrophic bacteria. Protists (algae and protozoa) were counted by growing cells in tissue culture wells after inoculating with a small aliquot (around 20 microliter) of treated water. Growth of any protists was assumed to have originated from a single cell inoculated into the well. In this way, an approximate count of each population was attained (i.e. amoebae, heterotrophic flagellates, ciliates, diatoms, dinoflagellates and autotrophic flagellates). The number of macroinvertebrates was determined by direct observation after collecting organisms on an 80 micron mesh. Typically 10 litres or more was processed.
Results	The current prototype system has been tested with the pending Coast Guard Protocol to obtain samples, provide a growth medium and then count the living organisms that have survived. The initial results were very promising as they had 99.9% elimination of biota. These first tests were done looking at bacteria and a current round is under way to look at all levels of growth including zooplankton. From the results of these tests a permanent shipboard system has been designed capable of treating all of the ballast on the ship and having the redundancy of a back up system. This unit will be PLC controlled and be able to provide signals to verify that the system has operated for the required time and the ballast is now safe to discharge. This signal could be sent to the internet and this would allow any port to access this information. The system would also log when ballast was taken on board and where if that is required. The redundancy of the system is such that a failure of any component causes a spare to be turned on and thus maintain the optimum performance.

Name of Project	Electro-Sanitization of Ballast Water
Treatment options researched	*Electro-ionization*
Principal Researcher(s)	C.E.Leffler[1], Andrew Rogerson[2]
Contact Details	[1] Marine Environmental Partners, Inc. (MEP) 3874 Fiscal Court, Suite 200 West Palm Beach Florida 33404 USA Phone: +1 561 842 9900 Fax: +1 561 842 9922 Email: bud@mepi.net Website: www.mepi.net [2] Nova Southeastern University
Host Institution(s)	Marine Environmental Partners, Inc.
Location of Research	Marine Environmental Partners, Inc. Nova Southeastern University
Funding Level	Private funding
Funding Source(s)	Marine Environmental Partners
Timeframe of the Project	Spring 2002 – May 2003
Aims and objectives of the project	Refine laboratory and shipboard electro-ionization systems for ballast water sanitization. Develop biological and chemical tests to evaluate performance and safety of treatment. Design a scalable system to treat ballast on diverse ship types.
Research Methods	Sanitization Efficacy - Bacteria and Protist Enumeration - Chlorine/Bromine (4500-ClF. DPD Ferrous Titrimetric Method) - Oxidative Reduction Potential (ORP) (2580 Oxidation-Reduction Potential) - Reduction Potential Analysis (Conducted by Nanospec Company) Effluent Safety - Acute and Chronic Toxicity (Conducted by Toxikon Corporation) - Chlorinated/Brominated organics (Mass Spectroscopy Method 8260) conducted by Spectrum Laboratories General - Dissolved oxygen (4500-0 G. Membrane Electrode Method) - pH (4500-H+) - Temperature (2550) - Conductivity/Salinity (2520 B. Electrical Conductivity Method) - Turbidity (2130 B, Nephelometric Method)
Results	MEP's electro-ionization system shows promise for use in sanitizing ballast water. The system as tested on Carnival's ELATION disinfected seawater (California coast, Pacific Ocean, and Florida coast, Atlantic Ocean) to at least a 95% kill of biota. The effluent safety also shows promise. No detectable trihalomethanes were present at de-ballast from the ELATION pilot trials. The concentrations of reactive halogens present at ballast discharge from the 1/20th scale model testing to date were ecologically non-toxic producing no mysid shrimp mortality and no effect on mysid shrimp growth or fecundity. Chemical and biological research methods that were tested provided useful information for system development and for determining efficacy and safety.

Name of Project	Onboard Ballast Water Treatment/Management with Ozone & Sonics Phase I
Treatment options researched	*Filtration, low frequency sonics and ozone*
Principal Researcher(s)	Thomas L. Maddox
Contact Details	T.L. Maddox Companies 16149 Westwoods Business Park Ellisville, MO 63021-4505 United States of America Tel: +1 636 394 8161 Fax: +1 636 394 6776 Email: tlm@tlmcos.com Web: www.zebra-mussels.com http://invasions.si.edu
Host Institution(s)	United States Department of Commerce. National Oceanic & Atmospheric Administration (NOAA). National Sea Grant Program.
Location of Research	Lab work in USA.
Funding Level	US$175,000.
Funding Source(s)	National Sea Grant College Program NA96RG0478.
Timeframe of the Project	Phase I: October 1, 1999 – September 30, 2000.
Aims and objectives of the project	Develop a ballast treatment system which treats only the ballast water actually being discharged at any given point in time@ 5,000GPM . This system would kill bacteria, phytoplankton, zooplankton, dinoflagellates, etc. All of this to occur without producing any byproducts. This system would also be: compact, quiet, safe, user friendly, reliable, durable, low maintenance, environmentally friendly, PLC controlled and monitored, use off-the-shelf components, flexible and scalable for use on any size, age, and type of ship, economical to operate, and have no moving parts.
Research Methods	Phase I - Demonstrate the effectiveness of combining the use of filtration and a low-frequency sonic contact reactor with ozone. Phase II - Demonstrating the unit dockside at several locations @ 150 GPM. Phase III - Incorporate the findings from early work into an operable, shipboard system @ 5,000 GPM. The method uses a mechanically driven acoustic transducer operating at low-frequency to promote intimate mixing of gases, liquids, and solids to improve the contact between the organisms in ballast water and ozone bubbles, resulting in greater mortality at small dosing rates. The processes produce high-intensity acoustic compression and rarefaction waves which are propagated throughout the reactor. The intense pressure and turbulence induced shear caused by these waves will stress and traumatize the organisms, increasing their vulnerability to the ozone.
Results	Phase I Final Report available upon request. Also available are the lab results by Dr. Robert A. Andersen at Provasoli-Guillard National Center for Culture of Marine Phytoplankton, Bigelow Laboratory for Ocean Sciences, West Boothbay Harbor, ME 04575 USA.

Name of Project	Onboard Ballast Water Treatment/Management with Ozone & Sonics – Phase II
Treatment options researched	*Filtration, low frequency sonics and ozone*
Principal Researcher(s)	Thomas L. Maddox
Contact Details	Environmental Technologies, Inc., a T.L. Maddox Company 16149 Westwoods Business Park Ellisville, MO 63021-4505 United States of America Tel: +1 636 394 8161 Fax: +1 636 394 6776 Email: tlm@tlmcos.com Web: www.zebra-mussels.com http://invasions.si.edu
Host Institution(s)	United States Department of Commerce National Oceanic & Atmospheric Administration (NOAA) National Sea Grant Program United States Dept. of the Interior, Fish & Wildlife United States Department of Transportation United States Maritime Administration
Location of Research	On dock or barge in the Chesapeake Bay area, USA.
Funding Level	US$250,000.
Funding Source(s)	National Sea Grant College Program NA03AR4170008.
Timeframe of the Project	Phase II: 1 March 2003 – 29 February 2004
Aims and objectives of the project	Develop a ballast treatment system which treats only the ballast water actually being discharged at any given point in time@ 5,000GPM . This system aims to kill bacteria, phytoplankton, zooplankton, dinoflagellates, etc. All of this to occur without producing any byproducts. This system would also need to be: compact, quiet, safe, user friendly, reliable, durable, low maintenance, environmentally friendly, PLC controlled and monitored, use off-the-shelf components, flexible and scalable for use on any size, age, and type of ship, economical to operate, and have no moving parts.
Research Methods	Phase I - Demonstrate the effectiveness of combining the use of filtration and a low-frequency sonic contact reactor with ozone (Completed). Phase II - Demonstrating the unit dockside at several locations @ 150 GPM. (Current Phase). Phase III - Incorporate the findings from early work into an operable, shipboard system @ 5,000 GPM (Future). The method uses a mechanically driven acoustic transducer operating at low-frequency to promote intimate mixing of gases, liquids, and solids to improve the contact between the organisms in ballast water and ozone bubbles, resulting in greater mortality at small dosing rates. The processes produce high-intensity acoustic compression and rarefaction waves which are propagated throughout the reactor. The intense pressure and turbulence induced shear caused by these waves will stress and traumatize the organisms, increasing their vulnerability to the ozone. For details of lab methods used to evaluate the effectiveness of these techniques, see next section.
Results	Phase I final report available upon request. Also available are the lab results by Dr. Robert A. Andersen at Provasoli-Guillard National Center for Culture of Marine Phytoplankton, Bigelow Laboratory for Ocean Sciences, West Boothbay Harbor, ME 04575 USA. Phase II results to be determined

Name of Project	An Evaluation of the Feasibility and Efficacy of Biocide Application in Controlling the Release of Nonindigenous Aquatic Species from Ballast Water
Treatment options researched	*Chemical - Use of glutaraldehyde.*
Principal Researcher(s)	Russell A Moll, Michael G Parsons, Larissa M Lubomudrov.
Contact Details	Dr Michael Parsons Department of Naval Architecture and Marine Engineering University of Michigan 236A NA&ME Bldg., Room 2145 Ann Arbor, Michigan, 48104 United States of America Tel: +1 734 763 3081 Fax: +1 734 936 8820 Email: parsons@engin.umich.edu.
Host Institution(s)	University of Michigan.
Location of Research	Ann Arbor, Michigan, USA.
Funding Level	
Funding Source(s)	Office of the Great Lakes, Michigan Department of Environmental Quality, Coastal Zone Management Program, Great Lakes Fishery Commission.
Timeframe of the Project	Report Date – April 1997.
Aims and objectives of the project	To evaluate the feasibility and efficacy of biocide application in controlling the release of nonindigenous aquatic species from ballast water
Research Methods	The results were obtained mainly through laboratory experiments and theoretical studies.
Results	Preliminary results indicated that treating ballast water with glutaraldehyde may prove to be a viable option if the chemical costs can be substantially reduced, however there are still critical gaps. Study concluded that treating ballast water with the chemical glutaraldehyde could be readily implemented by installing pumps to gauge the chemical into ballast tanks as they are filled. Glutaraldehyde demonstrates broad biocidal activity and can be effective in eliminating various organisms in ballast water, however it is considered non-biocidal at low concentrations. It is currently classified as a non-carcinogen and non-mutagen, however some studies have reported positive results for these effects under certain laboratory conditions. Studies show that the greatest human risks associated with glutaraldehyde exposure are irritation to the skin and respiratory tract. The half-life of glutaraldehyde will probably be short (between 12 and 24 hours) and may vary with pH, temperature and the amount of chemical constituents in the water. The residence time of the chemical in water will be an important factor affecting the concentration released into the environment. It decomposes into carbon dioxide under aerobic conditions, which helps to limit the environmental risks.

Name of Project	Acrolein as a Potential Treatment Alternative for Control of Microorganisms in Ballast Tanks: Five Day Sea Trial
Treatment options researched	*Chemical Treatment: Acrolein Technology (2-propenal)*
Principal Researcher(s)	Joseph E. Penkala, Ph.D., Melissa Law, and Jennifer Cowan, M.S.
Contact Details	Joseph Penkala Baker Petrolite Corporation 12645 West Airport Blvd. Sugar Land, Texas 77478, USA Tel: +1 281 276 5674 Fax: +1 281 276 5492 Email: Joseph.Penkala@BakerPetrolite.com
Host Institution(s)	Baker Petrolite Corporation
Location of Research	Baker Petrolite Corporation: Sugar Land TX Technology Laboratories Gulf of Mexico: Guanta, VZ to Panama City, FL Houston Ship Channel
Funding Level	Corporate Allocation from Baker Petrolite Corporation
Funding Source(s)	Baker Petrolite Corporation
Timeframe of the Project	January 2002 to December 2002 Voyage: November 4, 2002-November 10, 2002
Aims and objectives of the project	Investigate the efficacy of acrolein in the control of microorganisms in ballast tanks aboard an 8000 MT DWT cargo ship on a 5 day voyage in the Gulf of Mexico.
Research Methods	Monitored growth of aerobic and sulphate reducing bacteria and levels of chemical residual daily from uptake to discharge. Utilized serial dilution culture techniques for enumeration of viable bacteria. Utilized differential pulse poloragraphy to monitor acrolein residuals. Sampling was conducted via port in ballast line during uptake and discharge and via ballast tank sounding tubes during voyage. Chemical application was into ballast line at the suction side of the ballast pump. The sample port and chemical port were on parallel lines to avoid mixing. A sea trial was conducted on board an 8000 MT DWT container vessel during a 5 day voyage from Venezuela to Florida. Dedicated ballast tanks were treated with 1, 3, 9, or 15 ppm of acrolein during ballast intake in Venezuela. Monitoring of viable bacteria and acrolein residuals was conducted prior to treating, daily during the voyage, and during discharge. Residuals of 1, 3, 9, and 15 ppm of acrolein were tested in this study.
Results	Acrolein is a broad spectrum biocide with proven efficacy against bacteria, algae, and other microorganisms. Extensive toxicity testing has demonstrated its effectiveness against macroorganisms as well, including mollusks, crustaceans, fish, and aquatic plants. Recent laboratory studies demonstrated that 1-3 ppm of acrolein can effectively control various marine microorganisms. When applied at treatment concentrations of 9 ppm, acrolein maintained 99.99 % efficacy for 2 days. At 15 ppm, acrolein was shown to be 99.9999 % effective for 3 days as compared to untreated ballast tanks. En route monitoring confirmed that regrowth of microorganisms was minimized when the acrolein residual was maintained at $\geq$2 ppm. At the time of discharge, the acrolein residuals were zero ppm, a consequence of its reaction with water, thus allowing its safe discharge overboard. These findings show the potential of acrolein as an effective treatment strategy which can be managed safely, can be safely discharged into the marine environment, and is economical in the control of organisms in ballast water.

Name of Project	Shipboard Trial of Primary and Secondary Ballast Water Treatment Systems
Treatment options researched	*Voraxial (cyclonic separator), UV, Biocide (SEAKLEEN registered trade name).*
Principal Researcher(s)	Dr David Wright and Rodger Dawson.
Contact Details	Dr David Wright University of Maryland Center for Environmental Science Chesapeake Biological Laboratory P O Box 38 Solomons, MD 20688 United States of America Tel: +1 410 326 7240 Fax: +1 410 326 7210 Email: wright@cbl.umces.edu.
Host Institution(s)	University of Maryland, Center for Environmental Science, Chesapeake Biological Laboratory.
Location of Research	Baltimore, Maryland, USA.
Funding Level	US$700,000.
Funding Source(s)	National Oceanic & Atmospheric Administration. Maryland Port Administration.
Timeframe of the Project	September 2000 – March 2002.
Aims and objectives of the project	Demonstrate the effectiveness and cost effectiveness of the above methods.
Research Methods	Ballast water taken onto the *Cape May* (with 37,000 MT – 23 Ballast tanks) from Chesapeake Bay will be subjected to UV or biocide treatments and their effectiveness and efficiency in killing organisms in the ballast water will be tested using plankton counts, a variety of methods for live/dead assessment, fluorescence (phytoplankton), laser particle counting, bacterial plating.
Results	UV was 90-94% [input concentration not provided] effective at killing zooplankton at a dose of ca. 200 mWsec cm^2 using a 32kW system at a flow rate of ca. 350 tons h^{-1}. Two biocides were completely effective at killing zooplankton. Peraclean Ocean® was effective at 100mg l^{-1}. Seakleen® was effective at <2 mg l^{-1}. All three treatment were effective in inhibiting phytoplankton growth at lower doses. No primary separation/filtration was required to achieve these performances.

Name of Project	**Chesapeake Bay Ballast Water: an Investigative Assessment of Excimer UV as a Method of Shipboard and Dockside Treatment**
Treatment options researched	*Ultra Violet*
Principal Researcher(s)	Dr David Wright and Rodger Dawson
Contact Details	Dr David Wright University of Maryland Center for Environmental Science Chesapeake Biological Laboratory P O Box 38 Solomons, MD 20688 United States of America Tel: +1 410 326 7240 Fax: +1 410 326 7210 Email: wright@cbl.umces.edu.
Host Institution(s)	University of Maryland.
Location of Research	Solomons and Maryland.
Funding Level	US$247,000.
Funding Source(s)	
Timeframe of the Project	01.10.98 – 30.06.02
Aims and objectives of the project	
Research Methods	
Results	Using benchtop and mesocosm-scale systems it was determined that an effective UV treatment for ballast water would require a dose in the region of 200 mW sec cm2 at flow rates of above 1000 gallons per min. To effectively treat large vessels many systems would have to be mounted in parallel and the over power requirements would be in the megawatt range.

Name of Project	Field Tests on Alternatives to Ballast Exchange
Treatment options researched	*Self Cleaning 50 micron Screen, Hydrocyclone, UV*
Principal Researcher(s)	Thomas D. Waite, Junko Kazumi
Contact Details	College of Engineering University of Miami Coral Gables, FL 33124 United States of America Tel: +1 305 284 3467 Fax: +1 305 284 2885 Email: twaite@miami.edu, jkazumi@miami.edu
Host Institution(s)	University of Miami.
Location of Research	University of Miami Rosenstiel School for Marine and Atmospheric Science, Biscayne Bay, Miami, Florida.
Funding Level	Approx. US$400,000.
Funding Source(s)	US Coast Guard.
Timeframe of the Project	August 2000 – September 2001.
Aims and objectives of the project	Determine treatment effectiveness of the unit processes listed above, and evaluate effects of turbidity on these processes, in particular, UV treatment.
Research Methods	A dockside pilot facility operating at 340 m^3/h was constructed. Samples were taken before and after these unit processes. Samples were evaluated using standard protocols for removal or inactivation of bacteria, phytoplankton and zooplankton, and changes in ATP and protein concentrations.
Results	Hydrocyclone was not as effective as the screen in removing zooplankton. UV was effective in inactivating bacteria but not phytoplankton. Paper describing results has been published in *Marine Ecology Progress Series.*

Name of Project	Ballast Water Filter-Ultraviolet Treatment Technology Parameter Tests
Treatment options researched	*Self Cleaning 50 micron Screen, Hydrocyclone, UV, Media Filter*
Principal Researcher(s)	Thomas D. Waite, Junko Kazumi
Contact Details	twaite@miami.edu, jkazumi@miami.edu
Host Institution(s)	University of Miami.
Location of Research	Miami, FL, USA.
Funding Level	Approx. US$250,000.
Funding Source(s)	US Coast Guard.
Timeframe of the Project	October 2001 – June 2003.
Aims and objectives of the project	Evaluate effects of color on unit processes of screen, hydrocyclone and UV at large scale (340 m^3/h). Evaluate feasibility of media filters for removing particles from ambient seawater.
Research Methods	Samples taken before and after the unit processes were evaluated for removal or inactivation of bacteria, phytoplankton, zooplankton, and changes in ATP and protein levels. Particle counts were used to monitor the effectiveness of various media at different hydraulic loading rates.
Results	Not provided.

Name of Project	West Coast Regional Applied Ballast Management Research and Demonstration Project
Treatment options researched	*Cyclonic Separation and UV (Optimar Ballast System).*
Principal Researcher(s)	Maurya B. Falkner, California State Lands Commission, Marine Facilities Division with Nick Welschmeyer, Ph.D., Moss Landing Marine Laboratories, San Jose State University Foundation and Stephen Bollens, Ph.D., Romburg Tiburon Center for Environmental Studies, San Francisco State University
Contact Details	Maurya B. Falkner California State Lands Commission Marine Facilities Division 200 Oceangate, Suite 900 Long Beach, CA 90802 Tel: +1 562-499-6312 Fax: +1 562-499-6317 Email: falknem@slc.ca.gov
Host Institution(s)	California State Lands Commission. Marine Facilities Division.
Location of Research	California State Lands Commission, Moss Landing Marine Laboratories and Romberg-Tiburon Center, San Francisco State University.
Funding Level	Approximately US $300,000.
Funding Source(s)	U.S. Fish & Wildlife Service and Port of Oakland.
Timeframe of the Project	September 2000 - December 2002.
Aims and objectives of the project	Provide cost estimates and ballast water treatment options to the maritime industry. Conduct applied research, in cooperation with California State Water Resources Control Board, U.S. Coast Guard, the maritime industry and technology vendors on ballast water treatment.
Research Methods	Utilize full-scale engineering designs to install the Optimar Ballast System on two vessels, the *Sea Princess* and the *R.J. Pfeiffer*. Conduct shipboard biological and operational evaluations of these systems under normal vessel conditions. Biological efficacy testing includes sampling of treatment and control tanks. Samples will be evaluated for zoo- and phytoplankton, bacteria and virus removal and inactivation.
Results	Not provided.

Name of Project	RJ Pfeiffer (Panamax containership) Sea Princess and Star Princess (Cruise ships)
Treatment options researched	*OptiMar Ballast System (Separation and UV)*
Principal Researcher(s)	Nick Welschmeyer and Steve Bollens
Contact Details	
Host Institution(s)	Moss Landing Marine Laboratories and Romberg-Tiburon Center, San Francisco State University.
Location of Research	West coast of USA.
Funding Level	
Funding Source(s)	California State Lands Commission and California State Water Resources Control Board.
Timeframe of the Project	Spring/Summer 2002.
Aims and objectives of the project	Verify effectiveness of the OptiMar System.
Research Methods	On board sampling.
Results	Not provided.

Name of Project	Electrochemically Generated Ozone for On-Board Control of Nonindigenous Invasive Species in Ballast Water
Treatment options researched	*Electrochemically generated ozone.*
Principal Researcher(s)	Dr. Tom D. Rogers, Principal Investigator, Dr. Dalibor Hodko (Lynntech, Inc.) Associate Investigator, Capt. Phil Jenkins, Jenkins and Associates Ltd, Fonthill, Ontario, Canada (Subcontractor).
Contact Details	Lynntech, Inc 7610 Eastmark Dr College Station, TX 77840 United States of America Tel: +1 979 693 0017 Fax: +1 979 764 7479 Email: trogers@lynntech.com Web: www.lynntech.com
Host Institution(s)	Lynntech, Inc.
Location of Research	College Station, Texas and Ontario, Canada.
Funding Level	US$200,000.
Funding Source(s)	U.S. Department of Commerce (Sea Grant).
Timeframe of the Project	1 September 2000 – 31 August 2002
Aims and objectives of the project	Evaluate: • Methods of on-board use of ozone (i.e., intake pulse treatment, in-tank contacting). • Various factors pertaining to corrosion when using ozone. • Dose-rate requirements for ozone related to various water qualities typical of representative ports and waterways. • Requirements for system integration into specific types of ships. • Safety requirements for on-board use of ozone. • Cost estimates for scale-up of technology and systems to meet on-board implementation.
Research Methods	Laboratory and pilot scale tests will be performed to meet tasks defined within the scope of the project as presented to the U.S. Department of Commerce.
Results	Not provided.

Name of Project	Pacific Ballast Water Treatment Pilot Project
Treatment options researched	*Various.*
Principal Researcher(s)	Scott Smith.
Contact Details	Washington State Aquatic Nuisance Species Coordinator Washington Department of Fish and Wildlife 600 Capitol Way N. Olympia, WA 98501 United States of America Tel: +1 360 902 2724 Fax: +1 360 902 2845 Email: smithsss@dfw.wa.gov
Host Institution(s)	Washington Department of Fish and Wildlife, USGS Biological Resources, US Fish and Wildlife Services, Hyde Marine, Velox, California State Lands Commission, University of Washington.
Location of Research	Marrowstone Marine Field Station, WA, USA.
Funding Level	US$330,000 plus in-kind contributions.
Funding Source(s)	US Fish and Wildlife Service, USGS Biological Resources, Velox Technologies, Hyde Marine.
Timeframe of the Project	Phase I (Project Planning, Organisation and Funding): April 2000-October 2000. Phase II (All project deliverables completed. Final report submitted within six months): October 2000-June 2001.
Aims and objectives of the project	This project aims to recommend a standard for the discharge of treated ballast water and recommend a sampling/monitoring protocol to verify an adequate ballast water exchange. The final report will be made available for distribution in the US.
Research Methods	Laboratory and on-board tests.
Results	Not provided.

Name of Project	Clean Ballast Water
Treatment options researched	*Innovative application of high frequency ultrasound*
Principal Researcher(s)	Dr. Christopher Sullivan
Contact Details	Dr. Christopher Sullivan Oceanit Laboratories, Inc. 1001 Bishop Street Pacific Tower, Suite 2970 Honolulu, Hawaii 96813 United States Tel: +1 808 531 3017 Fax: +1 808 531 3177 Email: Csullivan@oceanit.com
Host Institution(s)	
Location of Research	Honolulu, Hawaii.
Funding Level	US $350,000.
Funding Source(s)	U.S. Department of Commerce. U.S. Department of Transportation/Coast Guard. High Technology Development Corp.
Timeframe of the Project	Through 2002.
Aims and objectives of the project	To design, build and demonstrate an effective ballast water treatment system that cleans ballast water of marine organisms by utilizing a unique high-frequency ultrasound technology.
Research Methods	Use innovative application of high-frequency ultrasound, with unique treatment vessel configurations, to produce a viable ultrasonic ballast water treatment system.
Results	Not provided.

Name of Project	Evaluations of Deoxygenation as a Ballast Water Treatment to Prevent Aquatic Invasions and Ship Corrosion
Treatment options researched	*Deoxygenation through Venturi Oxygen Stripping*
Principal Researcher(s)	Dr. Mario N. Tamburri, Chesapeake Biological Laboratory, UMCES Dr. Brenda J. Little, Naval Research Laboratory, Stennis Space Center Dr. Gregory M. Ruiz, Smithsonian Environmental Research Center Mr. Peter D. McNulty, NEI Treatment Systems, Inc.
Contact Details	Dr. Mario N. Tamburri, Chief Scientist Chesapeake Biological Laboratory University of Maryland Center for Environmental Science P.O. Box 38 / One Williams Street Solomons, MD 20688 Tel: +1 410 326 7440 Fax: +1 410 326 7428
Host Institution(s)	Chesapeake Biological Laboratory, Solomons, MD
Location of Research	Solomons MD, Key West FL and Stennis Space Center, MS
Funding Level	Approximately $500,000
Funding Source(s)	NOAA/Sea Grant
Timeframe of the Project	January 2003 – September 2004
Aims and objectives of the project	Our current investigations are providing the critical information required to evaluate the efficacy and feasibility of deoxygenation as a ballast water treatment to prevent aquatic invasions and tank corrosion. Specifically, we are: • exploring a rapid, in-line oxygen stripping system developed by NEI Treatment Systems, Inc. to optimize the deoxygenation process, • examining the impact of this oxygen stripping technique on the immediate and long-term survival of natural Chesapeake Bay planktonic organisms, and • quantifying corrosion rates and establishing the mechanism under deoxygenated conditions (with particular emphasis on microbiologically influenced corrosion). These results will ultimately lead to a full-scale shipboard evaluation of deoxygenation as a cost-saving ballast water treatment.
Research Methods	Dockside, mesocosm experiments at the Chesapeake Biological Laboratory, Solomons, MD. Natural seawater is pumped from one meter below the surface into 10 identical 20-gallon, airtight acrylic cylinders, held inside a laboratory at the end of the CBL pier. In five control cylinders, seawater is delivered directly from the pump and in five treated cylinders the seawater first passes through the rapid, in-line oxygen stripping system. Physical conditions are monitored throughout the experiments with oxygen, temperature, and conductivity sensors sealed within the cylinders. To examine mortality over time as a result of deoxygenation, one treated and one control cylinder are drained completely through a bottom valve 1, 24, 48, 72, and 96 hours after filling. Total abundance and living versus dead zooplankton (greater than 50 µm) are determined by visual counts under a dissecting scope. Phytoplankton are examined under a compound microscope to identify major algae groups and estimation of abundance are be determined by fluorometry. Finally, the density of bacterial cells are determined by flow cytometry.

	Corrosion experiments with control and deoxygenated natural seawater are being conducted at the Naval Research Laboratory Corrosion Facility, in Key West, FL and at the NRL Stennis Space Center, MS. Individual tank are maintained with either oxygenated seawater or seawater that has passed through the rapid, in-line oxygen stripping system. Samples are collected every two weeks over one year to assess changes in dissolved and particulate water chemistry (dissolved oxygen, dissolved organic carbon and nitrogen, particulate organic carbon and nitrogen, bulk pH, sulfide concentration) using standard techniques. Serial dilutions are used to determine numbers of APB, SRB, general heterotrophic aerobes, and anaerobes. Carbon steel coupons are also exposed in each tank of oxygenated and deoxygenated natural seawater. Samples from both containers are removed every two weeks and examined to assess the extent of biofilm formation and corrosion morphology. Environmental scanning electron microscopy and energy dispersive spectroscopy is being used to characterize the corrosion morphology, biofilm structure and corrosion product composition on the metal surface. Swabs made of the coupon surface and serial dilutions used to determine the microbial composition of the biofilm. Finally microelectrodes are used to make O_2 profiles through the biofilms.
Results	Not provided.

2. Projects Under Way

Australia

Name of Project	A Portable Pilot Plant to Test the Treatment of Ships' Ballast Water
Treatment options researched	*Filtration, Ultraviolet, Ultrasonic shear*
Principal Researcher(s)	S Hillman, P Schneider, F Hoedt
Contact Details	Tel: +61 7 4781 4779 Fax: +61 7 4775 1184 Email: steve.hillman@jcu.edu.au
Host Institution(s)	CRC Reef Research Centre at the School of Engineering, James Cook University
Location of Research	Douglas Campus Townsville Queensland Australia 4811
Funding Level	A$670,000 (approx)
Funding Source(s)	Environment Australia, Ports Corporation of Queensland, Townsville, Mackay and Gladstone Port Authorities, Amiad Australia, CRC Reef Research Centre, Great Barrier Reef Research Foundation, Pasminco.
Timeframe of the Project	2002 – 2004
Aims and objectives of the project	The objective of project is to build a pilot treatment plant based on existing technologies and off the shelf equipment. Based on existing research results and applications developed by others, the pilot plant uses various technologies, as well as chemicals on a 'plug and play' basis. The medium to longer term aim is to develop a system that will be scaled up and used aboard ships.
Research Methods	Seawater is stored in two 27,000-litre tanks. The water is drained to a 10,000-litre tank where it can be inoculated with the organism of choice. This tank is mixed using and aeration system to enhance homogeneity. This tank is connected to the main pump which delivers the water to any, or all, of the Amiad filter, the sonic disintegrator and the ultra-violet unit. Sampling points are available pre and post the pump and each treatment unit. This filter can be used with a number of different sized screens and the project has available to it 20, 50 and 80 micron screens. To date only the 80-micron screen has been used. The sonic disintegrator is driven by a variable frequency drive that allows the speed of the machine to be varied to optimise effects. The ultra-violet unit operates at 254 nanometres. All components are designed to be able to be operated at greater than the design capacity of 3 litres per second. We have innoculated a 10,000 litre tank of seawater with varying numbers of *Artemia* (50 to 80 per litre). We have sampled at a number of points after the culture leaves the tank. These are pre and post the pump, filter and sonic disintegrator. We have done this with no treatment except the pump as well as with the filter engaged or the disintegrator in operation.
Results	Under development

Canada

Name of Project	The Effect of an Integrated Cyclone/UV Ballast Water Treatment System on the Survivorship of Marine Phytoplankton and Invertebrate Larvae
Treatment options researched	*Primary cyclonic separation and secondary UV irradiation.*
Principal Researcher(s)	Dr Terri Sutherland and Dr Colin Levings.
Contact Details	Fisheries and Oceans Canada DFO, West Vancouver Laboratory 4160 Marine Drive West Vancouver, BC V7V 1N6 Canada Tel: +1 604 666 8537 Fax: +1 604 666 3497 Email: sutherlandt@pac.dfo-mpo.gc.ca
Host Institution(s)	Fisheries and Oceans Canada.
Location of Research	West Vancouver Laboratory.
Funding Level	Financial and in-kind support.
Funding Source(s)	Fisheries and Oceans Canada Industrial Research Assistance Program (IRAP) Velox Technology Inc.
Timeframe of the Project	Initiated in April 1999 – research ongoing
Aims and objectives of the project	To determine the effect of the treatment system on the survivability of marine invertebrate larvae and potentially harmful phytoplankton.
Research Methods	The research methods and results are currently under peer review and will be published in the Marine Ecology Progress Series.
Results	As above.

Croatia

Name of Project	Croatian Ballast Water Treatment Project
Treatment options researched	*Various Ballast Water Treatment Options*
Principal Researcher(s)	Prof. dr. sc. Josip Lovric, Dr. sc. Adam Benovic, Prof. dr. sc. Nikola Ruzinski
Contact Details	Prof. dr. sc. Josip Lovric Collegium Ragusinum Cira Carica 4 20 000 Dubrovnik Croatia Tel: +385 (0)20 44 57 00 Fax: +385 (0)20 43 55 90 E-Mail: rektorat@vdu.hr Web: www.vdu.hr
Host Institution(s)	University of Applied Sciences – *Collegium Ragusinum,* Dubrovnik, Croatia. Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb, Croatia.
Location of Research	Research and Development Center for Mariculture, Bistrina, Mali Ston, Dubrovnik, Croatia.
Funding Level	€ 200,000
Funding Source(s)	Ministry of Science and Technology, Republic of Croatia and Janaf d.d. Adriatic Pipeline, Zagreb, Croatia.
Timeframe of the Project	Project started in 1998. Second segment: November 2002 – November 2005.
Aims and objectives of the project	The main objective in first two years was getting information on possible ballast water treatment technologies on board, and key issues related to ballast water. The last two years research mainly focused on removal of various species from water samples. Currently a pilot project is researching the effectiveness of different technologies for removal of macro and micro organisms from ballast water in the timeframe the ship spends between two harbours.
Research Methods	Degradation trials, Mechanical separation processes, Biocides, Heat treatment.
Results	Biocides (UV and Ozone)showed promising results; Some success in mechanical separation; Waste-heat process and its possible usage in ballast water treatment was theoretically evaluated.

China

Name of Project	Killing of Invasive Marine Species of Ship's Ballast Water using Hydroxyl Radical on Board in the Main Pipe of Discharge
Treatment options researched	*Strong ionisation discharge; hydroxyl radical*
Principal Researcher(s)	Xiyao Bai, Mindong Bai, Zhitao Zhang, Bo Yang, Mindi Bai
Contact Details	Key laboratory of strong electric -field ionization discharge of Liaoning Province; Environmental Engineering Institute Dalian Maritime University Dalian 116026, Liaoning P. R.China E-mail: mindong-bai@163.com hjs@dlmu.edu.cn
Host Institution(s)	Dalian Maritime University
Location of Research	Dalian City (116026), Liaoning Province, P. R.China
Funding Level	$500,000 USD
Funding Source(s)	National Foundation Research of Science and Technology Ministry of China, (2002CCC00900) National Natural Science Foundation of China (NSFC: 60031001; 60371035)
Timeframe of the Project	2002~2006
Aims and objectives of the project	• To demonstrate that a strong ionisation discharge based ballast water treatment technology can generate large quantities of hydroxyl radical at high concentration. • To study the efficacy of hydroxyl radical in killing invasive marine species within the main pipe used for the discharge of ship's ballast water. • To demonstrate that the energy consumption is only 20Wh/m^3 of ship's ballast water. • To demonstrate that the production of hydroxyl radical with the strong ionisation discharge accords to 12 principles of Green Chemistry. • To realize the Zero Pollution, Zero Emission in the whole processes for the production of hydroxyl radical and the treatment of ship's ballast water.
Research Methods	With the Strong ionization discharge method, the strong electric field (E_d = 400Td, 1Td- 10^{-17}Vcm^2) is formed with the thinner a-Al_2O_3 dielectric layer in the micro-gap at a high pressure (P = 0.1Mpa or n- 2.6×10^{-19}/cm^3). The electrons achieve the average energy of above 12eV. As a result, O_2 in air and H_2O in seawater are ionized and dissociated into a number of activated particles such as OH, O_2^+, $O(^1D)$, HO_2 radicals, and then dissolved into a part of ballast water to form the dissolved hydroxyl radicals. Also the hydroxyl radical is produced using excited ozone and water.
Results	• The hydroxyl radical concentration is 23.4mg/L in 20t/h pilot-scale system. • The concentration of hydroxyl radical required for the killing of invasive species in ship's ballast water is only 0.63mg/L. • The duration to kill mono-cell algae, bacteria and protozoan are very fast and takes only 2.67s. • The hydroxyl radicals have much stronger oxidization and degradation action on the photosynthesis pigments of phytoplankton. The contents of chl-a, chl-b, chl-c and carotenoid are decreased to 35%-64% within 8.0s and then to the lowest limit of detection after 5 minutes. • The lipid peroxide degree of cell is increased three times. The basic life substances, monose, amylose, protein, DNA and RNA of cell, are greatly destroyed. Also CAT, POD and SOD of antioxidant enzyme system are destroyed. Biochemistry reactions are the main reasons of organism cell death.

- The quality of ballast water is greatly improved. With the duration of 2.67s, the decrease rates of COD, nitrite and ammonium salt are 100%, 98.3% and 99.5% respectively, and the turbidity is decreased to 50%. DO is increased 77% due to the decomposition of residual hydroxyl radical.
- The equipment to produce hydroxyl solution has some advantages such as small volume, simple operation, and low running cost only 20Wh/m^3, which is only 1/30 cost in comparison with the open-ocean-exchange of ship's ballast water.

Name of Project	Application Study of Ballast Water Treatment by Electrolysing Seawater
Treatment options researched	*Electrolysis of seawater*.
Principal Researcher(s)	Kun Dang, Peihai Yin, Peiting Sun
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Host Institution(s)	Dalian Maritime University
Location of Research	Marine engineering college, DMU
Funding Level	US$ 4,000+ R¥20,000
Funding Source(s)	GloBallast Programme and COSCO
Timeframe of the Project	2002 -2004
Aims and objectives of the project	• To develop a model of a ballast water treatment unit that is used to treat ballast water by means of electrolysing seawater at a capacity that can meet the requirements of IMO conventions and the requirements of ship survey. • The system can regulate the chlorine concentration produced according to the content of harmful organisms in the seawater and the temperature of the seawater. This then is used to kill all harmful organisms and pathogens with free residual chlorine kept in a minimum level. • To make a blue print for the installation of the system on board.
Research Methods	Raw seawater and seawater with different concentrations of *Artemia salina* are simulated as ships' ballast water and treated by electrolysis
Results	• If the raw seawater is treated by electrolysis, it can kill 4 kinds of alga from 18 kinds with an initial chlorine concentration of 4.0ppm. The total mortality of phytoplankton can be up to72% and the mortality of bacteria is 99.99%. *Euciliata sp* in the seawater can be killed immediately. • If the seawater with an *Artemia salina* density increased from 2 individual/ml to 6 individual/ml is treated by electrolysing with an initial chlorine concentration of 4.0ppm, the mortality of *Artemia salin* is more than 95% after 48 hours of contact. • If the seawater with an *Artemia salina* density of not more than 2 individual/ml is treated by electrolysing with an initial chlorine concentration of 8.0ppm, the mortality of *Artemia salina* is more than 95% after 24 hours of contact. With an initial chlorine concentration of 15 ppm, 99.99% of *Artemia salin*a is killed after 12 hours of contact. • If the residual chlorine in the treated seawater is less than 0.5ppm, the chlorine will have no effect on *Artemia salina*.

Germany

Name of Project	**Basic Examinations of the Biological, Chemical and Physical Characteristics and Loadings of Ballast Water and the Design of Process Modules for its Treatment and Disinfection Onboard**
Treatment options researched	*Different treatment options to evaluate and combine most efficient modular ballast water treatment systems for shipboard use*
Principal Researcher(s)	Ms Dr.-Ing. Anja Kornmueller
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Host Institution(s)	Berkefeld Water Technology, Celle RWO Marine Water Technology (www.rwo.de), Bremen
Location of Research	Celle and Bremen, Germany
Funding Level	Approx. € 1,000,000
Funding Source(s)	Federal Ministry for Research and Technology (Germany) and Berkefeld
Timeframe of the Project	Oct. 2002 – Sept. 2005
Aims and objectives of the project	• To evaluate the basic conditions and requirements for ballast water treatment (BWT) onboard, such as biological and chemical-physical water characteristics, technical specifications and specific requirements of vessel design and operation. • To develop efficient and cost-effective modular process combinations for BWT onboard.
Research Methods	• Basic evaluation by desk based review (literature and internet search; contact with organisations, authorities, research institutes and companies). • Interdisciplinary approach combining the various demands by biological and chemical-physical water characteristics, technical specifications and specific requirements of vessel design and operation. • Practical testing in a land-based pilot plant at three different locations (river, brackish and seawater) to develop and optimise suitable modular treatment systems consisting of particle removal and disinfection. Two parallel test lines enable the direct comparison in the performance of different processes at alternating influent concentrations. • Modular designing of the BWT systems as the precondition for the successful adaptation and installation to any kind of vessel.
Results	• The variations in water quality are decisive for the dimensioning of BWT systems. Because a comprehensive database on water quality does not exist, these data were collected worldwide from major ports. • The land-based testing has to be carried out under worst-case conditions like strong algae blooms and high total suspended solid concentration to guarantee that developed BWT systems will operate successfully onboard under challenging conditions. • The modular design in BWT is necessary to meet the complex requirements in system specifications.

Name of Project	**Bremen-Ballast Water-Project: Development and Construction of an Efficient and Marketable Ballast Water Treatment Plant**
Treatment options researched	*Presently different methods are investigated in order to evaluate possibilities to combine the most promising approaches*
Principal Researcher(s)	Coordination and shipside technology: GAUSS (Chr. Bahlke / O. Kerschek) Biology, Methods, Standards: Dr. Stephan Gollasch Biological Analyses: Alfred Wegener Institute (Prof. Smetacek) Plant construction: Dr. St. Calenberg (Kraeft GmbH) A. Höppner (Motorenwerke Bremerhaven AG)
Contact Details	GAUSS mbH Werderstr. 73, 28199 Bremen, Germany Tel: +49 421 5905 4850 Fax: +49 421 5905 4851 Email: gauss@gauss.org
Host Institution(s)	GAUSS mbH. Email: gauss@gauss.org Motorenwerke Bremerhaven. AG. webmaster@mwb-bremerhaven.de
Location of Research	GAUSS mbH Werderstr. 73, 28199 Bremen, Germany Tel: +49 421 5905 4850 Fax: +49 421 5905 4851 Email: gauss@gauss.org
Funding Level	Financially supported by the Federal State of Bremen and Bremerhaven.
Funding Source(s)	Senator of Building & Environment, Bremen
Timeframe of the Project	Phase 1: 01.10.2001 – 30.07.2002. Phase 2: 01.07.2002 – 31.08.2003. Phase 3: 01.09.2003 – 31.08.2004. (Decision for successive phase is based on results of preceding phase).
Aims and objectives of the project	Creation of an efficient and cost effective shipboard system using the combination of different methods to treat ballast water. Persistent chemicals are to be avoided.
Research Methods	Phase 1: Theoretical investigation. Phase 2: Shore based practical method assessment. Phase 3: Test runs on board different ships.
Results	To be determined.

Name of Project	The Bremen Ballast Water Project
Treatment options researched	*Hydrocyclone, Separation Units, Various FilterTechnologies, High/LowFrequencyUV, Pressuredifferencial Treatment, Ultrasound Technologies, Various electrochemical Methods, Heat treatment*
Principal Researcher(s)	Alfred Wegener Institute for Polar and Marine Research; Ballast Water Consultants GbR; GAUSS Institute for Environmental Protection and Safety in Shipping mbH; MWB Motorenwerke Bremerhaven AG
Contact Details	MWB Motorenwerke Bremerhaven AG, Barkhausenstrasse, 27568 Bremerhaven; Henning von Wedel, Tel.: +49-471-9450-226; Henning.vonWedel@mwb-bremerhaven.de
Host Institution(s)	-
Location of Research	Alfred Wegener Institute for Polar and Marine Research, Bremerhaven; MWB Motorenwerke Bremerhaven AG, Barkhausenstrasse, 27568 Bremerhaven
Funding Level	€ 800,000
Funding Source(s)	BIS Bremerhavener Gesellschaft für Investitionsförderung und Stadtentwicklung mbH; Economic Development Company Ltd.
Timeframe of the Project	August 2004 – December 2004
Aims and objectives of the project	The treatment is multi stage and in line. We are conducting Tests to evaluate which methods are the most efficient (and the most cost efficient also). This Project is a scientific project followed by an appropriate marketing approach. The results of the evaluation will give us an indication about the favourable technologies. Parallel to this, methods and technologies for simple, effective and repeatable tests of the quality of Ballast Water Treatment Plants are also evaluated.
Research Methods	The focus is on technologies rather than the proprietary treatment components of specific manufacturers. Various treatment technologies are tested single, in comparison to similar technologies (e.g. high vs. low frequency UV) and then in combination with other technologies. Infiltration of test organisms is done in a way to evaluate the net effect of the components and to eliminate side effects such as erratic temperature or pressure changes or rotating devices of pumps. Test Organisms are selected to have one representative of the various kinds of organisms, which are potentially dangerous to the environment as an invasive species. For recovery tests the Ballast Tank of a floating Dock of MWB Motorenwerke Bremerhaven AG is used.
Results	It is expected, that we will have an objective overview about the most efficient and cost effective ways to treat Ballast Water for the particular application e.g Tanker, Container Vessel, Bulk Carrier, Cruise Ship etc. We will also know, which technology is not efficient or too expensive. One result is also the knowledge about the upscaling process towards larger vessels with higher volumes of Ballast Water. Further more we are able to benchmark our plant against other plants on the market via our newly developed tests procedures.

Name of Project	TREBAWA- Treatment of Ballast Water
Treatment options researched	*Primary hydrocyclonic separation followed by UV irradiation.*
Principal Researcher(s)	*European partnership of SMEs (Small and Medium-sized Enterprises)* Prime proposer: Reederei Hesse (Germany); Other partners: Vinave (Portugal); Optimarin, Envirotech (Norway); Acomarin, FI; UV Systems (Germany); Sandvik (Norway); Fresti (Portugal) *Research partners:* TTZ Bremerhaven (René Surma, Dolores Fernández) University of Strathclyde (Peilin Zhou) Institute de Soldadura Qualidade (ISQ) (Nuno Cosme)
Contact Details	Dolores Fernández An der Karlstadt 6 D-27568 Bremerhaven, Germany Tel: +49 471 9448-707 Fax: +49 471 9448 722 e-mail: dfernandez@ttz-bremerhaven.de
Host Institution(s)	TTZ Bremerhaven, Germany. University of Strathclyde, UK. Institute de Soldadura Qualidade (ISQ), Portugal.
Location of Research	Portugal, Germany, UK, Norway.
Funding Level	Total budget € 856,000. European funding € 425,000.
Funding Source(s)	European Commission, 5th Framework, CRAFT program.
Timeframe of the Project	2 years. Estimated start date: October 2002.
Aims and objectives of the project	To develop a new technically and economically competitive ballast water treatment system based on a primary cyclonic separation and a UV treatment to achieve the critical points: i. A high degree of separation of in seawater suspended particles; ii. A high performance for the UV system in inactivating and killing all the inwater remaining organisms; and iii. Integrated prototype compact in size, which fulfills the space requirements of a wide range of existing ships.
Research Methods	1- Laboratory tests. 2- Prototype development and pilot tests. 3- Full-scale sea trials.
Results	To be determined.

Name of Project	A New Modular Concept for the Treatment of Ships' Ballast Water
Treatment options researched	*Physical separation: gravity separation and filtration* *Chemical disinfection: non-toxic, chlorine free oxidising agent (Peraclean® Ocean)*
Principal Researcher(s)	Hauke Röpell, Lothar Reinecke, Dr. Matthias Voigt
Contact Details	Hamann Wassertechnik GmbH Brookdamm 6, D-21217 Seevetal, Germany Email: HaukeRopell@HamannWassertechnik.de Dr. Voigt Consulting Kampstraße 7, D-24601 Stolpe, Germany Email: M.Voigt@drvoigt-consulting.de
Host Institution(s)	Hamann Wassertechnik GmbH
Location of Research	Lower Elbe River, Baltic Sea and Port of Hamburg
Funding Level	€ 260,000
Funding Source(s)	AIF (Federal Ministry of Research) Hamann Wassertechnik GmbH Dr. Voigt Consulting
Timeframe of the Project	2000-2003
Aims and objectives of the project	Testing of various physical separation options in combination with chemical disinfection of ballast water. Design of a full scale treatment plant for land based tests and evaluations. Identifying suitable combinations of above methods for various types of ships (e.g. ballast water management scenarios). Development of online monitoring systems for ballast water treatment.
Research Methods	On shore tests done at a flow rate of 135 to 210 m^3/h. Testing of different cyclones (gravity separation) and self cleaning filters at 100 and 50 µm as well as dosing of 50 to 200 ppm Peraclean® Ocean. Test carried out with in situ plankton population as well as selected indicator organisms (different life stages of artemia, ATS).
Results	The combination of gravity separation and filtration (50 µm) with a dosage of 150 ppm Peraclean® Ocean resulted in > 98% removal/mortality of all test organisms. Further full-scale test will be carried out on land and onboard a ship.

Name of Project	The Artemia Testing System for Ballast Water Treatment
Treatment options researched	*Physical separation (cyclone, filter), chemical treatment (oxidising agent)*
Principal Researcher(s)	Dr. Voigt Consulting.
Contact Details	Kampstr. 7 24601 Stolpe Germany Tel: +49 4326 987 37 Fax: +49 4326 987 38 Email: m.voigt@drvoigt-consulting.de Web: www.drvoigt-consulting.de
Host Institution(s)	Dr. Voigt-consulting.
Location of Research	Germany.
Funding Level	
Funding Source(s)	Contract research (consulting).
Timeframe of the Project	1998 – ongoing.
Aims and objectives of the project	To provide full-scale data for the efficiency of ballast water treatment options. Compare different treatment options.
Research Methods	Ballast water treatment options are tested at full-scale flow rates in land-based tests with a specially developed testing protocol (ATS = Artemia Testing System) for the biological efficiency of ballast water treatment options.
Results	The ATS, in combination with at least one more small (< 50µm) test species is a useful tool for evaluation of new treatment options .

Israel

Name of Project	The Ternary Effect for Ballast Water Treatment
Treatment options researched	*Disc Filtration, UV disinfection, Advanced Oxidation Processes*
Principal Researcher(s)	Arkal Filtration Systems, The Hebrew University of Jerusalem, Northeast Midwest Institute
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Host Institution(s)	
Location of Research	Israel, USA
Funding Level	
Funding Source(s)	Arkal Filtration Systems, Northeast Midwest Institute
Timeframe of the Project	
Aims and objectives of the project	To develop a commercial full scale Ballast Water Treatment Unit
Research Methods	Laboratory scale tests: • Reactive Oxygen Species Research to maximize hydroxyl radicals concentration in sea water. • Dose Response tests, to optimise UV dose within the "Ternary System" using Rotifers as indicators. Pilot scale tests: • First set of pilot tests, Arkal Filtration Systems, to check the physics and chemistry of the Ternary System (prototype one). Also-to examine inactivation of taxa. Flow rate-10 m3/hr. Source-Mediteranean Sea. • Second set of pilot tests, Arkal Filtration Systems, to check the physics and chemistry of the Ternary System (prototype two). Also-to examine inactivation of taxa. Flow rate-10 m3/hr. Source - Mediteranean Sea. Engineering tests: To design and operate a full BWT unit onboard a ship. 5 replications taken for each experiment. Raw sea water taken at same time as samples for control.
Results	First prototype pilot plant led to the "Ternary Effect" which was followed by a pending patent. This patent deals mainly with an advanced filtration concept. Regarding taxa inactivation: [No input concentration provided] Microplankton - 93% inactivation (above 80 micron), mainly-toraminiferans and crustaceans. Picoplankton - 100% inactivation, heterotrophic protist as indicator. Nanoplankton - 62% inactivation, mainly - diatoms and ebrida. R.O.S. Research led to a finding of a catalyst which was followed by a second pending patent. Dose response tests are underway. Second prototype pilot plant implementing the "Ternary Effect" is underway.

Japan

Name of Project	Test Procedure for Evaluation of Ballast Water Treatment System using Copepoda as Zooplankton and Dinoflagellates as Phytoplankton
Treatment options researched	*N/A*
Principal Researcher(s)	Dr. Yasuwo Fukuyo, Capt. Takeaki Kikuchi Mr. Seiji Kino, Mr. Katsumi Yoshida
Contact Details	Marine Pollution Prevention Research Department The Japan Association of Marine Safety Kaiyo-Senpaku BLDG., 15-16, Toranomon 1-Chome, Minato-ku, Tokyo 105-0001 JAPAN Tel: +81(3) 3502-3543 Fax: +81(3) 3581-6136
Host Institution(s)	Marine Pollution Prevention Research Department The Japan Association of Marine Safety
Location of Research	Laboratory of Marine Technology of Kyushu-Island.
Funding Level	This project is the second component of "Research and Development of the Special Pipe System for Ballast Water Treatment".
Funding Source(s)	The Nippon Foundation
Timeframe of the Project	The project commenced in April 1999 and is ongoing.
Aims and objectives of the project	The objective of this study is to develop a specific test procedure for evaluation of a ballast water treatment system to terminate and eliminate harmful aquatic organisms in ballast water based on biological and ecological nature of the organisms in coastal waters.
Research Methods	In order to establish an appropriate test procedure, it is essential to analyze the biological and ecological features of organisms in port areas where ballast water is taken on. Seasonal change and regional difference of composition and numbers of plankton in Japanese waters were observed using several references such as Nomura and Yoshida (1997). Special attention was paid to high phytoplankton numbers occurring at red tides. Based on data obtained by the analysis of plankton nature, necessity of selection of test organisms for evaluation of ballast water treatment system was assessed. For the selection, following criteria were considered; 1) the test organisms should be available in a certain amount easily anytime and anywhere to put enough concentration in test water to evaluate the result; 2) the organisms must be found in both near-shore and off-shore waters easily, as the evaluation experiment includes a test bed test on land and a onboard test in ship; 3) the organisms should be easily differentiated its survival or fatality with high accuracy for evaluation of effectiveness of treatments. A test procedure and a standard for ballast water treatment were also designed using results of above mentioned analysis.
Results	The conclusion of the present study is: • The testing organisms for evaluation of ballast water treatment system are *Dinophyceae* from phytoplankton and *Maxillopoda (Copepoda)* from zooplankton. These individuals with 20μm or more in size can be used for experiments.

- Evaluation of efficacy should be based on termination rate of the test organisms before and after treatment. Live or dead can be distinguished by shape and mobility of the test organisms.

- In order to keep reproductivity and accuracy of the evaluation, number of test organisms in test water should be counted no less than three times.

- Standard for treatment approval is termination rate of test organisms more than 95 %. The rate should be set higher along with the development of techniques.

Name of Project	Progress Report on the 'Special Pipe System' as a Potential Mechanical Treatment for Ballast Water
Treatment options	*Mechanical treatment system using a special pipe*
Principal Researcher(s)	Dr.Hiroshi Tokuda, Dr. Hiroharu Kato, Dr. Yasuwo Fukuyo, Capt. Takeaki Kikuchi, Mr. Seiji Kino, Mr. Katsumi Yoshida
Contact Details	Captain Takeaki Kikuchi : The Japan Association of Marine Safety, Toranomon 1-17-1, Minato-ku, Tokyo 105-0001, JAPAN Tel:+81-3-3805-3543 Fax:+81-3-3581-6136 Email:kikuti@oak.ocn.ne.jp
Host Institution(s)	Marine Pollution Prevention Research Department The Japan Association of Marine Safety
Location of Research	Laboratory of Marine Technology of Kyushu-Island.
Funding Level	US$40,000 (1999), US$55,000 (2001), US$370,000(2002), US$450,000(2003)
Funding Source(s)	The Nippon Foundation
Timeframe of the Project	**Phase 1: 1999-2000**: Basic research of the special pipe system with and without addition of ozone to the system **Phase 2: 2001-2002**: Fixed point testing of the improved special pipe systems at Imari Port **Phase 3: 2003**: (in planning and to be carried out before March, 2004): On board testing of the improved special pipe systems
Aims and objectives of the project	The objective of this study is to develop a ballast water treatment system to terminate and eliminate harmful aquatic organisms contained in ballast water with special attention to criteria related to safety of ship and crew, practicability in terms of operational complexity and installation on board ships, cost effectiveness, and consequential environment impacts in addition to the effectiveness of treatment.
Research Methods	The prototype special pipe system was designed to use shear stress to terminate planktonic organisms. The potential was high, as reported at MEPC 44 in 2000, and verbally at the 1st International Ballast Water Treatment R&D Symposium (2001, London) and at the First International Conference on Ballast Water Management (2001, Singapore). This structure was, however, not suitable for practical use, because its pressure loss in passing water was high and needed higher pressure in a pipe with a larger diameter. The higher pressure could not cause higher damage to organisms in the pipe. Then the special pipe was re-designed with a unit generating shear stress and cavitations. Comparison of effectiveness between the former and the developed special pipe systems was made to ascertain the higher level of effect on marine organisms and the smaller pressure loss in the case of developed one.
Results	**Effectiveness of the prototype special pipe** The prototype special pipe can kill or inactivate about 55% of all phytoplankton and 65% of zooplankton respectively, in natural seawater, by one passage through the pipe. And the effectiveness can be increased, by injecting ozone into this pipe, to about 99% of phytoplamkton and 89% of zooplankton respectively, in natural seawater. [No input concentration provided] **Effectiveness of the improved special pipe** The improved special pipe system can kill and inactivate about 70% and 95 % of all phytoplankton and zooplankton respectively, in natural seawater in the case of one-passage treatment at the seawater flow rates 115 m^3/hr. This effectiveness was obtained using 60% of the energy of the prototype pipe. This effectiveness increased about 80% and 100 % respectively by two-times passage treatment, and furthermore they reached 85% and 100 % respectively at flow rates 150m^3/hr. [No input concentration provided]

Name of Project	Superconducting Magnetic Separator for Ballast Water Treatment
Treatment options researched	*Mechanical (filtration and magnetic separation)*
Principal Researcher(s)	Norihide Saho
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Host Institution(s)	The Shipbuilding Research Association of Japan (offering) Corporation for Advanced Transfer & Technology (offering) Ship & Ocean Foundation
Location of Research	Japan
Funding Level	
Funding Source(s)	Corporation for Advanced Transfer & Technology (offering) Ship & Ocean Foundation
Timeframe of the Project	Phase 1: 2003 Basic research of superconducting magnetic separation system for ballast water Phase 2: 2004 Detail design of superconducting magnetic separation system on board Phase 3: 2005 On board testing of the superconducting magnetic separation system
Aims and objectives of the project	To develop a ballast water treatment system that is suitable for rapidly purifying ballast water on board
Research Methods	A prototype water treatment system using a superconductor magnet to clean the ballast water discharged from ships was developed. The system is capable of treating 100 cubic meters of contaminated water a day through the following process sequence: mixing contaminated water with magnetic powder and a flocculant, stirring the mixture to make magnetic flocs, filtering the flocs, transferring them to a rotary magnetic shell, and dumping them in a sludge tank. The system was evaluated in experiments on two types of contaminated water samples, one containing kaolin particles and the other crude oil. Test species used were *Chattonella antiqua* and *Heterosigma akashio*.
Results	The experiment showed that more than 90% of the particles in the contaminated water can be removed in about five minutes. This result indicates that this system is capable of purifying water continuously and at high speed within a limited space. It is concluded that the new water-treatment system has the potential to be effective for the treatment of ballast water, removing 96% of organisms.

Name of Project	Ballast Water Treatment System with Jet Filter
Treatment options researched	*Hybrid system with filtration*
Principal Researcher(s)	Mr. Shunji Sukizaki, Marine Biological Research Institute of Japan Co., Ltd. Mr. Yuichi Takahashi, Fuji Filter Manufacturing Co., Ltd. Mr. Masaaki Yutani, Mitsui O.S.K. Lines
Contact Details	Mr. Masaaki Yutani, Mitsui O.S.K. Lines 1-1 , Toranomon 2-Chome, Minato-ku, Tokyo 105-8688 Tel: +81 3 3587 7206 Fax: +81 3 3587 7722 E-mail: masaaki.yutani@mail.mol.co.jp
Host Institution(s)	Mitsui O.S.K. Lines
Location of Research	Tokyo, Japan
Funding Level	
Funding Source(s)	Private
Timeframe of the Project	2003-2005
Aims and objectives of the project	In 2003, development of filtration system. In 2004, hybridization with optimum disinfection system. In 2005, construction of full scale prototype.
Research Methods	In 2003, land base tests of small models with different size of filter mesh (5μm, 7μm, 20μm, 50μm) In 2004, land base tests of several disinfection systems separately and jointly with filtration system. In 2005, onboard test of full-scale prototype.
Results	The effectiveness of filtration system with optimum mesh size has been confirmed in land base tests. Filtration system with 5-micron filter has satisfied the D-2 requirement except requirement for microbes. The washing system for filtration unit has been developed and its patent application has been made.

Netherlands

Name of Project	Ballast Water Treatments R&D in the Netherlands
Treatment options researched	*Filtration, Hydrocyclone, UV*
Principal Researcher(s)	Dr. Jan P. Boon, Dr. C.C. ten Hallers-Tjabbes, Ing. J.R. van Niekerk, J.L. Brouwer MSc
Contact Details	NIOZ: Dr. Jan P. Boon, Marine Environment P.O. Box 59 1790 AB Den Burg Texel, The Netherlands Tel: +31 (0)222 369466 E-mail: boon@nioz.nl
Host Institution(s)	Royal Netherlands Institute for Sea Research (NIOZ)
Location of Research	NIOZ, Texel
Funding Level	
Funding Source(s)	Netherlands Government
Timeframe of the Project	2003 – 2006
Aims and objectives of the project	To investigate a combination of techniques: filtration & UV / Hydrocyclone & UV
Research Methods	3 phases: • A dockside test • Followed by a semi-full scale test at sea on the research ship The Pelagia • Followed by a full scale test on board of 2 large vessels
Results	No results so far. The testing period starts in the end of 2003

New Zealand

Name of Project	A Proposed Frame-Work for Approving Ballast Water Treatment Technologies
Treatment options researched	*Generic*
Principal Researcher(s)	Dr Doug Mountfort
Contact Details	Dr Doug Mountfort, Cawthron Institute, Private Bag 2, Nelson, New Zealand Phone: +64 03 54 82 319 Fax: +64 03 54 69 464 Email: douglas.mountfort@cawthron.org.nz
Host Institution(s)	Cawthron Institute, Nelson, New Zealand
Location of Research	Cawthron Institute, Nelson, New Zealand
Funding Level	Approx $NZ 20K
Funding Source(s)	New Zealand Foundation for Research, Science and Technology (FRST)
Timeframe of the Project	Ongoing
Aims and objectives of the project	Despite the many technologies that are being advanced for the treatment of ships' ballast water there currently exists no satisfactory procedure for their evaluation, validation and approval. Among the reasons for this are: until recently lack of an international standard for ballast water treatment, lack of an international standard on sampling methodology, lack of agreement on what constitutes a valid range of testing organisms that can be used as an international testing standard. Despite this, new treatment technologies are being installed on ship's without having gone through stringent testing and verification protocols that would be required to meet an international standard. Our objective is to outline a framework that could be adopted in which a new technology would be evaluated, verified and certified before approval for release. Within this framework the mode of operation of a proposed international body approving new treatment technologies is described. The new framework will provide the vendor with clear pathways leading to the eventual approval of a new technology following performance review in each stage of the evaluation chain.
Research Methods	NA
Results	N/A

Norway

Name of Project	Ballast Water Treatment Verification Protocol - DNV
Treatment options researched	*The development of a standard for certification for the approval of ballast water treatment system*
Principal Researcher(s)	Aage Bjørn Andersen (DNV), Bjørn Olav Johannessen (DNV), Egil Dragsund (DNV)
Contact Details	Det Norske Veritas
Host Institution(s)	Det Norske Veritas, Veritasveien 1, 1322 Høvik, Norway
Location of Research	Det Norske Veritas, Veritasveien 1, 1322 Høvik, Norway
Funding Level	700,000.- NoK
Funding Source(s)	DNV Research funds
Timeframe of the Project	01.01.03 – 15.12.03
Aims and objectives of the project	This project is an integrated element of a larger research programme undertaken by DNV and Norwegian Institute of Water Research (NIVA). This programme was initiated in 2003 and will run until 2005. The overall aim is to expand the understanding associated to non-indigenous introductions and to develop methods, standards and norms for risk reducing measures (treatment methods).
Research Methods	Literature review, laboratory studies, full scale verification studies
Results	Ballast Water Verification Protocol Standard for Certification

Singapore

Name of Project	Ballast Water Exchange Verification Test Kit Development
Treatment options researched	*Ballast Water Exchange Verification*
Principal Researcher(s)	Michael R. McNeely, Ph.D.
Contact Details	Michael R. McNeely, Ph.D., President / CTO GattaCo Pte. Ltd. 1 Liang Seah Street #03-06 Liang Seah Place Singapore, 189022 Tel: +65 9390 9570 Fax: +65 6336-1924 Email: mrm@gattaco.com
Host Institution(s)	GattaCo Pte. Ltd.
Location of Research	Singapore
Funding Level	NA
Funding Source(s)	NA
Timeframe of the Project	2003-2005
Aims and objectives of the project	Using proprietary technology for water testing, GattaCo is developing an inexpensive, easy to use, testing kit for ballast water. This kit will identify the concentration of certain chemical markers that can be used to distinguish between port and mid-ocean waters. This kit will be used to independently verify that a ship is carrying water indicative of mid-ocean in its ballast tanks, and, hence, has probably exchanged its ballast water mid-ocean. Mid-ocean exchange is currently an acceptable method of ballast water treatment.
Research Methods	GattaCo has propriety technology for performing chemical analysis of several analytes simultaneously in an inexpensive, easy to use platform. GattaCo is interfacing with several research institutions around the world to identify the most appropriate markers for this chemical analysis.
Results	Project is currently underway.

Name of Project	**Developing Innovative Ballast Water Treatment Technology with a Special Emphasis on Fe(VI) (Ferrate) as a Potential Secondary Disinfectant Chemical**
Treatment options researched	*Ferrate as a Disinfectant Chemical*
Principal Researcher(s)	Pitchaivelu Selvakumar Institute of Environmental Science and Engineering, Singapore Leslie Loke, IESE Luke Daly, Ferrate Treatment Technologies, LLC
Contact Details	Luke J. Daly 1322 Waltham Avenue Orlando, Florida 32809 Tel: +1 407 857 5721 Fax: +1 407 826 0166 Email: luke.daly@ferrate.info
Host Institution(s)	Nanyang Technological University
Location of Research	Singapore
Funding Level	$500,000
Funding Source(s)	IESE, FTT, NOL, MPA
Timeframe of the Project	April 2004 –April 2006
Aims and objectives of the project	1. To protect the public health, shipping, and the port's interests by developing a set of treatment technologies and rapid diagnostic tools to identify and control the transfer of harmful aquatic organisms via a ship's ballast water. 2. To evaluate Ferrate as a secondary treatment chemical to polish the filtration system performance. To meet the IMO standards for microbes using Ferrate.
Research Methods	1. Ferrate was produced on site using commodity feed chemiacals. 2. Zooplankton (>50 microns) and zoo/phyto-plankton (>15 micron and <50 microns) were analysed before and after treatment with Ferrate. Samples were viewed through a microscope to closely monitor the number of viable (live) organisms present in the respective category.
Results	The results indicated that there was not even a single live phyto- and zooplankton (< 50µ) present in the samples for a dosage as low as 1 mg/L, but, considerable number of larger (> 50µ) live zooplankton were present at this dosage (Figure 1). However, at higher dosage all zoo/phytoplankton were killed if dosages were increased to 2 mg/L (Figure 1). Therefore, the optimum dosage for the removal of zoo and phytoplankton may lie between 1 mg/L to 2 mg/L The cost of ferrate treatment (O&M) is estimated to be 1.3 cents (US) per tonne of ballast waterat a dose of 2 mg/L. Therefore ferrate has a potential as a secondary disinfectant chemical in the ballast water treatment technology.

Name of Project	Shipboard Trials Of An Innovative Ballast Water Treatment System For Prevention Of Transfer Of Harmful Organisms
Treatment options researched	*Filtration as primary removal of particles followed by an environmental friendly chemical (Ferrate)*
Principal Researcher(s)	Leslie Loke, Institute of Environmental Science and Engineering, Singapore P Selvakumar, IESE, Singapore Frank Weitz, IESE, Singapore Tay Joo Hwa, IESE, Singapore
Contact Details	Leslie Loke Institute for Environmental Science and Engineering Nanyang Technological University, Innovation Centre Block 2, Unit 237 18 Nanyang Drive Singapore 637723 Tel: (65) 6794 1512 Fax: (65) 6792 1291 Email: ctloke@ntu.edu.sg
Host Institution(s)	Nanyang Technological University, Maritime and Port Authority of Singapore, Tropical Marine Science Institute, Ngee Ann Polytechnic, Neptune Orient Lines Pte Ltd
Location of Research	Singapore
Funding Level	S$ 1,189, 000
Funding Source(s)	TEC, MPA, IESE, NOL, TMSI, NP, ABS, FTT, Hydac
Timeframe of the Project	April 2004 – December 2005
Aims and objectives of the project	• To study the efficiency of filtration plus ferrate based treatment system at a full commercial scale level (1200 m^3/hour) to control the transfer of harmful aquatic organisms via a ship's ballast water. • To evaluate and identify design and engineering needs to produce commercial scale compact Ballast Water Treatment system • To meet the IMO standards for bioinvasive species.
Research Methods	• Install compact system and observe real-time variation and shipboard needs • All samples will be evaluated using standard protocols for zooplankton (>50 microns), zoo/phyto-plankton (>10 micron and <50 microns) and microorganisms o meet the IMO standards.
Results	IESE's research activities were initiated in 1998 to develop suitable technologies. This successive progress from laboratory to pilot plant scale R&D is now has reached a final stage to study at a full commercial scale prototype treatment system. This treatment system is based on self-cleaning filtration as the primary treatment step, followed by a chemical disinfectant (Ferrate) secondary treatment. This will be installed onboard a Neptune Orient Lines (NOL).

South Africa

Name of Project	In-line Ballast Water Treatment System based on Mechanical (Ultrasound), Electro-Chemical and Ozone Treatment
Treatment options researched	*Mechanical (ultrasound), Electro-Chemical, Ozone*
Principal Researcher(s)	Ian Vroom Email: ian@resource-technology.com Mobile: +27 (0)82 579 7966 Bernard Jacobs Email: bernard@resource-technology.com Mobile: +27 (0)82 886 8787 Charles Tapanlis Email: charles@resource-technology.com Mobile: +27 (0)82 292 1326
Contact Details	Resource (Pty.) Ltd. P.O. Box 431, Sea Point, 8060 Cape Town South Africa Tel: +27 (0)21 462 7653 Fax: +27 (0)21 462 7656
Host Institution(s)	Private
Location of Research	Cape Town and Saldanha Bay, Western Cape, South Africa Europe, Australia, USA & sea trials 3rd & 4th Quarter 2004
Funding Level	US$ 450 000
Funding Source(s)	Internal
Timeframe of the Project	2002 – 2005
Aims and objectives of the project	Resource has developed a proprietary (patent-pending) in-line Ballast Water Treatment system, the Reactor, for treatment of ballast water bourn undesirable organisms. The system has been designed for fitment "at sea" if required. Among the advantages of the Reactor System are its effectiveness, simplicity, absence of moving parts or externally added toxic substances, light weight and compactness, ease of installation either as original equipment or by retro-fitting, its low maintenance, capacity to operate for lengthy periods without maintenance, safety, and cost-effectiveness. The system is intended to be available for commercial fitment by the first quarter of 2005.
Research Methods	Dock side sampling, laboratory and dockside testing of scale model. Dock side testing of full scale prototype (600- 1000 m3/h). The "*Artemia Testing System* for ballast water treatment options " as laid out by Dr M Voigt of Dr Voigt - consultants was adopted. Bacteria tests (e*coli, cholera, streptococcus*) Conducted and verified by the South African Bureau of Standards (S.A.B.S.), an internationally accredited testing laboratory according to ISO/EC 17025 (No TO113.)
Results	95-98% kill rate of Artemia samples (scale – dockside) [Input concentration not 100% kill rate of bacteria (scale – dockside) provided] Full Scale testing currently underway. Third party verified data announcement anticipated for August 2004.

Ukraine

Name of Project	Hydrodynamic Cavitation and Filtration Treatment of Ballast Water
Treatment options researched	*Hybrid system including mechanical filtration in combination with hydrodynamic cavitation*
Principal Researcher(s)	Mr Anatoliy Mikhailovich Andryushchenko
Contact Details	Andryuschenko Anatoliy Director, CJSC "Engineering Center TRANSZVUK" 65014 Odessa, 6, Nahimova lane Tel: +38 0482 22 09 31 Fax: +38 0487 28 01 02 ?mail: transsound@paco.net
Host Institution(s)	CJSC "Engineering Center TRANSZVUK"
Location of Research	Institute of Biology of Southern Seas, Odessa Branch National Academy of Sciences of Ukraine
Funding Level	Approximately US$31,500 plus in-kind support
Funding Source(s)	GloBallast Programme
Timeframe of the Project	February 2003 – November 2004
Aims and objectives of the project	• To search of the technological solution for ships' ballast water treatment • Developing of pilot ships installation. • Tests of hydraulic cavitation method efficiency for decontaminating of ballast waters in a combination with filtering. • Study of seawater hydraulic cavitation decontaminating in relation to macro and microorganisms, including bacteria etc. in a combination with filtering. • Analyze of the received results. • Estimation of the specific power costs.
Research Methods	The hydrodynamic cavitation decontamination of fluids is based on local complex high-intense ultrasonic effect on a flow at high-speed phase changes, in combination with instantaneous (exemplary time of effect - 10^{-4}…10^{-6} s) pressure changes. Thus the potentially expensive electronic generators of ultrasound are not applied and the thermal energy is not spent. In zone of sharp differential pressure at movement of fluids there is an instantaneous gas-making and, under certain conditions, generation of an ultrasound of high intensity as a result of hydrodynamic effects. Generated in narrow zone of a flow the ultrasound breaks down macro- and micro-organisms structure. Besides, at a secondary pressure changes (from vacuum to overpressure), there is a so-called pressure jump caused by transition of medium velocity from ultrasonic to subsonic. This pressure jump results in collapse of steam-gaseous bladders, that is accompanied by potent mechanical effect on a fluid. The efficiency of a bactericide effect of ultrasonic oscillations depends on the form of micro-organisms, strength of chemical composition of cellular wall, availability of a sheath, age of culture, ultrasound intensity, frequency of ultrasonic oscillations and duration. It is known, that irradiation of water by ultrasound at specific output more than 3 W/ cm^2 at frequencies 500 to1000 kHz, results in complete break down of micro-organisms in water column at depth of 100 mms.

Results

- Estimation of applicability of hydraulic cavitation decontamination for treating ship ballast waters to meet requirements of Regulations E-1 to E-4.
- Results depends on water decontaminating degree (different macro and micro-organisms), on hydrodynamic parameters, modes of seawater filtering and filter materials.
- Estimation of specific power costs.
- Development of technical advisories on designing full scale system

United Kingdom

Name of Project	EU MARTOB Project
Treatment options researched	*Thermal, UV, US, Ozone, Oxicide, De-Oxygenation and Advance Oxidation*
Principal Researcher(s)	Dr Ehsan Mesbahi (Project Manager) Prof. Atilla Incecik (Project Coordinator) Miss Ana Paula Esteves (Project Administrator)
Contact Details	School of Marine Science and Technology, Armstrong Building University of Newcastle Newcastle upon Tyne, NE1 7RU United Kingdom Tel: +44 191 222 6723 (Ehsan.mesbahi@ncl.ac.uk) : +44 191 222 6724 (Atilla.Incecik@ncl.ac.uk) Fax: +44 191 222 5491
Host Institution(s)	University of Newcastle upon Tyne, UK.
Location of Research	UK: UNEW, ABC, FRS, INTERTANKO, SOU, TQ, ICS Finland: AAU, VTT Netherlands: TNO, TME, BERSON, HW Norway: SINTEF, MARINTEK, Shell MP, WW, FUELTECH, NSA France: IFREMER, BV Sweden: ALFA LAVAL, SSPA Greece: EPE Denmark: MAN B&W.
Funding Level	Approximately €3.8 million.
Funding Source(s)	Partially funded by European Commission under the 5th Framework Programme for research, technological development and demonstration activities, GROWTH, (Directorate-General for Energy and Transport).
Timeframe of the Project	MARTOB started in April 2001and will run for three years.
Aims and objectives of the project	The objectives of MARTOB are: • To investigate methodologies for preventing the introduction of non indigenous species through ships' ballast water; • To develop design tools and treatment equipment to be used in the further development of ballast water treatment techniques; • To assess the direct and indirect environmental aspects of current and newly developed methods; • To develop cost-effective (capital and running), safe, environmentally friendly onboard treatment methods; • To produce guidelines for crew training and criteria for selecting appropriate ballast water management methods for different types of ship; • To assess the financial, technical and operational effects of a sulphur cap on marine bunker fuel in European waters, and propose a verification scheme ensuring compliance with a sulphur cap from all players in the market; To help to facilitate the introduction of an important sulphur emission abatement measure without unintentional distortion of competition in the shipping market.
Research Methods	Theoretical, laboratory tests and onboard sea trials.
Results	Under preparation.

United States of America

Name of Project	**Assessment of On-Shore Treatment of Ballast Water Discharges (a Programme of Several Ongoing, Inter-Related Research Projects, Funded by Various Agencies)**
Treatment options researched	*Onshore treatment plants.*
Principal Researcher(s)	Dr Andrew Cohen (Senior Scientist, Biological Invasions Program, San Francisco Estuary Institute), Dr David Jenkins (Emeritus Professor of Civil and Environmental Engineering, University of California at Berkeley), Arleen Navarett (Senior Marine Biologist, Water Quality Bureau, City and County of San Francisco).
Contact Details	Dr Andrew Cohen San Francisco Estuary Institute 180 Richmond Field Station 1325 S 46th Street Richmond, CA 94804 United States of America Tel: +1 510 231 9423 Fax: +1 510 231 9414 Email: acohen@sfei.org Web: www.sfei.org/invasion.html
Host Institution(s)	San Francisco Estuary Institute University of California at Berkeley City and County of San Francisco
Location of Research	Richmond Field Station, Richmond, CA.
Funding Level	Total of around US$325,000 in received, obligated and pending funding.
Funding Source(s)	US Fish and Wildlife Service, California Sea Grant College System, Pollution Mitigation funds arranged through the San Francisco Bay Regional Water Quality Control Board.
Timeframe of the Project	Began in 1999 and is ongoing
Aims and objectives of the project	To assess the potential and estimate the relative costs of treating ballast water discharges in onshore treatment plants, using either existing wastewater treatment plants or purpose-built treatment plants.
Research Methods	• Benchtop tests and on-paper analyses of potential limitations on ballast water treatment in existing municipal wastewater treatment plants and the probable effectiveness of treatment of ballast water in existing municipal wastewater treatment plants, based in a variety of test organisms; • Design and on-paper analyses of probable effectiveness of treatment of ballast water in purpose-built, onshore ballast treatment plants; • Estimate costs of treatment in existing wastewater treatment plants and purpose-built treatment plants.
Results	To be determined.

Name of Project	Laboratory-Scale Investigation of Ballast Water Treatment using Ferrate
Treatment options researched	*Ferrate addition*
Principal Researcher(s)	Luke Daly, Ferrate Treatment Technologies, LLC Debra Reinhart, University of Central Florida Virender Sharma, Florida Institute of Technology Linda Walters, University of Central Florida Andrew Randall, University of Central Florida
Contact Details	Luke J. Daly 1322 Waltham Avenue Orlando Florida 32809 Tel: +407 857 5721 Fax: +407 826 0166 Email: luke.daly@ferrate.info
Host Institution(s)	University of Central Florida
Location of Research	Orlando, Florida
Funding Level	$178,000
Funding Source(s)	NOAA
Timeframe of the Project	September 1, 2004 –March 31, 2006
Aims and objectives of the project	• To evaluate iron(VI) or ferrate as a cost-effective alternative to existing ballast water treatment technologies. • To eliminate phytoplankton, zooplankton, and other microorganisms from seawater by applying ferrate to samples collected from the Port of Cape Canaveral Florida. • To demonstrate that ferrate is also toxic to larger, more complex marine organisms like fish and invertebrate larvae thereby eliminating the need for primary treatment that is required by other ballast water treatment biocides and UV systems. • To show why ferrate is an environmentally friendly, safe, and easy-to-implement solution for treating ship ballast water.
Research Methods	• Conduct ferrate disinfection tests in the laboratory on zooplankton, phytoplankton, and microorganisms in sea water under various contact times, dosage, and environmental conditions (pH, salinity, and turbidity); and, • Dockside testing of 500 gallons of port seawater from Cape Canaveral, Florida; and, • Based on laboratory and dockside findings, determine the technical and commercial feasibility for a full-scale ferrate ballast water treatment implementation.
Results	Preliminary studies have been conducted with harbour water taken at two locations in the Port of Cape Canaveral, Florida, USA. Sample A was taken at the inner Port, while Sample B was collected to the exit at the Port nearer to the open ocean. Samples were analysed for Total Coliform, *Eschericha. coli*, and Hetrotrophic bacterial counts. The total coliform and *E. coli* in samples A was reduced to non-detectable levels with the addition of a very small ferrate dose of only 0.5 mg/L. The levels of Heterotrophic bacteria in both samples A and B were also reduced to non-detectable values at a dose of approximately 2 mg/L.

Name of Project	**Ballast Water Treatment by De-oxygenation with Elevated CO_2 for a Shipboard Installation**
Treatment options researched	*Hypoxia combined with elevated carbon dioxide levels*
Principal Researcher(s)	Mo Husain and Horst Felbeck
Contact Details	Mo Husain, President MH Systems, Inc. 10951 Sorrento Valley Road, Suite 2F San Diego CA 92121 USA Tel: +858 452 1280 Fax: +858 452 6035 Email: husainm@mhsystemscorp.com
Host Institution(s)	MH Systems, Inc. and Scripps Institution of Oceanography
Location of Research	San Diego, California
Funding Level	Not Available
Funding Source(s)	Internal R&D
Timeframe of the Project	2 Years
Aims and objectives of the project	The goals of the project were: a) Test the effect of "inert gas" on marine organisms as a possible treatment method for ballast water b) Establish a basic design for a full scale treatment system c) Estimate the costs of the treatment for the ship operator
Research Methods	Several different marine invertebrates, plankton and *Vibrio cholerae* were incubated in experiments to determine their survival. The parallel incubations were gassed with nitrogen (anaerobic) or "Trimix" (2% oxygen, 12% carbon dioxide, balance nitrogen). Aerobic controls, which were gassed with air, were done in parallel for each incubation. All incubations were done with several to many specimens of each species (depending on size and availability).
Results	All organisms tested died within a few hours after incubation in Trimix. The survival rate appears to be significantly shorter than an anaerobic incubation alone. All invertebrates showed no mortality in aerobic incubations. *Vibrio cholerae* was non viable (>99%) after an incubation period of 24h.

Name of Project	Ballast and Oily Water Treatment System (BOWTS)
Treatment options researched	*Series of stages that include mechanical separation and filtration, chemical attachment and stripping, and ultraviolet microbial sanitation.*
Principal Researcher(s)	Several and various corporate and alliance members
Contact Details	Martin Fox Director, Emerging Technology Division Santa Barbara Applied Research Incorporated 1925 N. Lynn Street, Suite 1102 Arlington, VA 22209 United States of America Tel: +1 703 526 0022 Fax: +1 703 526 0222 Email: martinfox@sbar.com
Host Institution(s)	Santa Barbara Applied Research Incorporated.
Location of Research	California, USA and Chesapeake Tidewater Area, USA.
Funding Level	Under discussion.
Funding Source(s)	Internal R&D. Seeking institutional/government partners.
Timeframe of the Project	Initial feasibility exploration < 1 year. Establishment of treatment criteria to be determined.
Aims and objectives of the project	1. Prove scalability of existing system to permit increased flow rates and filtration levels appropriate to economic treatment of large capacity ballast. 2. Exploration of the level of ballast water treatment (how clean of what species) that will help establish reasonable criteria, both biologic and economic, for the use of government regulators.
Research Methods	Empirical.
Results	To be determined.

Name of Project	Field Test Demonstration of Improved Methods of Ballast Water Treatment and Monitoring Utilizing Filtration, Ozone and Sonics: Phase III
Treatment options researched	*Filtration, low frequency sonics and ozone*
Principal Researcher(s)	Thomas L. Maddox
Contact Details	Environmental Technologies, Inc. T.L. Maddox Co mpany 16149 Westwoods Business Park Ellisville, MO 63021-4505 Tel: +1 636 394 8161 Fax: + 1 636 394 6776 Email: tlm@tlmcos.com Web: www.zebra-mussels.com http://invasions.si.edu
Host Institution(s)	US Department of Commerce National Oceanic & Atmospheric Administration (NOAA) National Sea Grant Program US Department of the Interior, Fish & Wildlife US Department of Transportation US Maritime Administration
Location of Research	On dock beside the MARAD ship *Cape Wrath* located in Baltimore, MD, USA
Funding Level	US$303,300
Funding Source(s)	National Sea Grant College Program #NA04OAR4170150
Timeframe of the Project	Phase III 1 September 2004 – 31 December 2004
Aims and objectives of the project	Develop a ballast treatment and monitoring system which treats only the ballast water actually discharged at any given point in time @ 5,000 GPM. This system aims to kill phytoplankton, zooplankton, dinoflagellates, etc. All of this to occur without byproducts. This system would also need to be: compact, quiet, safe, user friendly, durable, low maintenance, environmentally friendly, PLC controlled and monitored, use off-the-shelf components, flexible and scalable for use on any size, age, and type, economical to operate, and have no moving parts
Research Methods	Phase I – Demonstrate the effectiveness of combining the use of filtration and a low-frequency sonic contact reactor with ozone in a laboratory environment (Completed). For details of lab methods used to evaluate the effectiveness of these techniques, see next section. Phase II – Demonstrate the unit dockside at 150 GPM along side the MARAD ship *Cape Wrath* located in Baltimore, MD, USA (Completed). For details of lab methods used to evaluate the effectiveness of these techniques, see next section. Phase III – Demonstrate a unit dockside along side the MARAD ship *Cape Wrath* located in Baltimore, MD, USA @ 500 GPM. This next level of testing will also incorporate both a chemical and biological monitoring system capable of satellite data transmission. This monitoring system to insure the ballast water treatment system is working safely, effectively and without harmful by-products whenever the ship's ballast water system is discharging it's ballast (Under way). Phase IV – Incorporate the findings from early work into an operable, monitored shipboard system @ 5,000 GPM. The method uses a mechanically driven acoustic transducer operating at low-frequency to promote intimate mixing of gases, liquids, and solids to improve the contact between the organisms in ballast water and ozone bubbles, resulting in greater mortality at

	small dosing rates. The processes produce high-intensity acoustic compression and rarefaction waves which are propagated throughout the reactor. The intense pressure and turbulence induced shear caused by these waves will stress and traumatize the organisms, increasing their vulnerability to the ozone (Future).
Results	Phase I final report available upon request. Also available are the lab results by Dr. Robert A. Andersen at Provasoli-Guillard National Center for Culture of Marine Phytoplankton, Bigelow Laboratory for Ocean Sciences, West Boothbay Harbor, ME 04575 USA. Phase II final report available upon request. Phase III final report will be available by 31 December 2004.

Name of Project	Ozone Treatment Applied with Diffusers
Treatment options researched	*Ozone*
Principal Researcher(s)	Nutech O3, Inc
Contact Details	5214 Monroe Place Hyattsville, MD 20781 Tel: +703 288 1910 Fax: +301 277 7496 Email: mikej@nutech-o3.com
Host Institution(s)	University of North Carolina at Wilmington, University of Washington, Western Washington University, Smithsonian Environmental Research Center, U.S. Fish and Wildlife Service, Northeast Technical Services Co., Inc., BP Exploration (Alaska) Inc.
Location of Research	Port Angeles, WA; Long Beach, CA; Cherry Point, WA; Valdez, AK
Funding Level	$600,000 plus $225,000 Matching
Funding Source(s)	NOAA, US Fish and Wildlife, BP Exploration, Northeast Technical Services, Nutech O3, Inc.
Timeframe of the Project	October 2001 – May 2005
Aims and objectives of the project	Demonstration of full scale shipboard ozonation system using diffusers for the removal of aquatic nuisance species.
Research Methods	This study is the first of several phases, and measured the effects of ozone treatment and ballast water exchange, replicated on multiple dates with ballast water originating from Puget Sound. The experiments were designed to compare changes in treatment tanks over time to those observed in untreated control tanks. Treatment tanks (designated for ozone or ballast water exchange) were filled from the same source as untreated control tanks and all tanks were sampled at fixed time points throughout the same experiment. Three ozone experiments and two ballast water exchange experiments were conducted. Including a third tank as a control, ballast tanks were filled at the same time and location to obtain a direct comparison between the efficacy of exchange and ozonation. Samples were collected at multiple time points, including before and after treatment, from each tank using several access locations (manways or Butterworth® openings) on the deck of the ship. Treatments were as follows: No. 3 wing port (ozone treatment); No. 3 wing starboard (air-sparged control); and No. 4 port (ballast water exchange). Samples were used to measure changes in biota and water chemistry over time, as described below. Effects of treatment on biota were measured in two ways. First, for organisms entrained in the ballast tanks, samples were collected from treatment and control tanks at least before and after treatment, and sometimes at intermediate time points, to compare changes in concentration and condition of resident organisms between treatments. This approach was used to measure effects of ozone and ballast water exchange treatments on bacteria, phytoplankton, and zooplankton. Second, for larger organisms (which are rare and more difficult to sample), a defined number of individual organisms were placed in various types of cages to measure the effect of ozone treatment. This second approach was used for fish, crabs, mysids, and amphipods. These caged organisms were placed in ozone treated and control tanks to compare mortality rates over time; a similar approach was not used in the BWE tanks, due both to the turbulence associated with this treatment and the mode of action, which was considered to be primarily achieved through removal and not mortality. One preliminary and three full experiments were conducted over the course of one year. The preliminary test, designed to provide data for the full scale

testing, provided information on the chemical reactions of ozone, including by-product formation and their effects on bacteria. Experiment 1 closely mimicked the ozone dosage that could be achieved on the S/T Tonsina during routine operations. During a typical 3.5-day voyage, the ozone system would apply 0.62 mg/L/hours ozone to the 2,850,000 L of each segregated ballast water tank in the vessel for a duration of five hours. This would be achieved by treating the 12 segregated ballast water tanks separately. During experiment 1, the ozone-loading rate was 0.59 mg/L/hours and lasted 5 hours. Experiment 2 achieved an ozone-loading rate of 0.86 mg/L/hours that resulted from improved operation of the ozone generator. In experiment 3, where only the vertical portions of the tanks were treated and the experiment lasted for 10 hours, an ozone-loading rate of 1.35 mg/L/hours was achieved. In Experiments 2 and 3, much larger amounts of ozone were purposely directed to the tank compartments that were sampled.

Results

1. Using this prototype system, 5-10 hours of ballast water ozonation resulted in a 71-99% reduction of selected marine phytoplankton, zooplankton and bacteria. The results depended upon the individual organism and the amount of ozone gas delivered to individual ballast water tanks over time.

2. Large, mobile organisms (especially benthic crabs and amphipods) appeared to be relatively resistant to ozone treatment compared to planktonic organisms.

3. Our experiments may have underestimated the efficacy of ozone treatment resulting from the possible residual toxicity of bromine over time. Some organisms appeared affected by the initial treatment and may succumb over time, however, such effects are not included in our analysis. Additional study under field conditions is warranted to test for such effects.

4. The efficacy of ozone treatment to reduce planktonic organisms was as good as that of BWE aboard the same vessel for which empty-refill exchange resulted in an average reduction of 64% for zooplankton.

5. Both field and laboratory experiments suggested that significant organism mortality can be achieved once concentrations of ozone-produced oxidants reach 1 – 3 mg/L (as chlorine equivalents), or when oxidation-reduction potential reaches levels of 700 – 800 mV. Once further validated, such toxicity thresholds could be used to help develop control targets for aiding the routine operation of ozone systems.

6. Our preliminary results suggested that bromine was the ozone-produced oxidant that was responsible for organism mortality. Furthermore, bromine may persist at toxic concentrations in ballast waters 1 - 2 days following ozonation depending on storage conditions and exposure to sunlight.

Additional experiments are being conducted in the summer of 2004. Results will be published when they become available.

Name of Project	**Venturi Applied Ozone Treatment**
Treatment options researched	*Venturi applied ozone treatment*
Principal Researcher(s)	Nutech O3, Inc.
Contact Details	5214 Monroe Place Hyattsville, MD 20781 Tel: +703 288 1910 Fax: +301 277 7496 Email: mikej@nutech-o3.com
Host Institution(s)	University of North Carolina at Wilmington, University of Washington, Iowa State University, Northeast Technical Services Co., Inc., BP Exploration (Alaska) Inc.
Location of Research	Port Angeles, WA; Long Beach, CA; Cherry Point, WA; Valdez, AK
Funding Level	$1,700,000
Funding Source(s)	NOAA
Timeframe of the Project	June 2004 – August 2005
Aims and objectives of the project	This project, will determine the effectiveness of a new, single point injection technology for injecting ozone into the ballast water. We believe this technology will be more effective in killing the invasive species, because far greater quantities of ozone will be injected and the distribution of ozone will be uniform through the ballast water. It will also be far less expensive to install since only a single 50 foot to 100 foot pipe, and a venturi, will be required to inject the ozone into the ballast water intake pipe. On the S/T Tonsina, nearly 21,000 feet of pipe was required because the ozone was injected into the ship's ballast water tanks. Therefore, our objective will be to prove our theory that injecting ozone into ballast water via a single point is more effective in removing invasive aquatic species than our system onboard the S/T Tonsina. We also plan to demonstrate that ballast water treated with ozone will not create any environmental hazards when it is discharged from the ship. The injected ozone reverts to oxygen within a few seconds. We believe any toxic levels of bromine, or bromate ion, created by the ozone will either rapidly disintegrate to levels that meet with accepted discharge guidelines or may be easily removed by the introduction of additional off-the-shelf chemicals that are routinely used to remove excess chlorine from chlorinated municipal water supplies.
Research Methods	It is our intent to select a ship, design a single point ozone injection system for this ship, install the system on the ship during an early 2005 out-of-service period, and test the effectiveness of this system in the control of invasive aquatic species. The details of this plan are discussed in our statement of work. A general plan for our scientific protocol is found below. Goal: To establish the absolute treatment efficiency of the single point ozonation process for organisms at the various trophic levels in ballast water under "normal" ship operations. <u>Experimental Considerations</u> • Organisms to be studied – Trophic levels a. Bacteria b. Phytoplankton c. Zooplankton d. Caged Organisms • Control Studies No treatment • Time Course

a. TRO concentrations – two maximum
b. TRO decomposition with time (C*T)

- WET Testing

  Function of TRO
- Chemical Characterization
  a. Water Quality Parameters
     i. Baseline data for each experiment
     ii. Have shown extensively that none are altered – necessary to do more?
  b. Bromoform
- Open Ocean Exchange

  None planned
- Laboratory Experiments for selected pathogens and indicator organisms
  a. Vibrio cholerae
  b. Escherichia coli
  c. Enterococcus sp.

Sampling

- Multiple Depths in Treatment Tanks
  a. Flowing water via lines
     i. Bacteria
     ii. Phytoplankton
     iii. Chemistry
  b. Vertical tows
     i. Zooplankton
  c. Niskin Bottles (if necessary)
- Time
  a. e.g. 0, 2.5, 5.0 7.5 and 10 hours for most parameters
  b. 0, 5.0 and 10.0 for zooplankton
- Multiple horizontal sampling points
- Seasonal sampling
- Sampling/tests at both ports of call
  a. North
  b. South

Analysis

- Ship Board
  a. Heterotrophic plate counts (if space is available)
  b. Zooplankton (if space is available)
  c. Chemical Characterization
- Shore Based
  a. Phytoplankton (chlorophyll and flow cytometry)
  b. 3-D Characterization of treated and untreated water

Control and Monitoring

- The goal will be to incorporate both on-line, real-time measurements and individual sample analysis of the effluent (and the water in the ballast tank) to control the TRO.
- Monitoring will be conducted by testing TRO similar to the use of disinfection monitoring used in drinking water.

Output and Anticipated Benefits

The ongoing Sea Grant Funded research at the USGS Marrowstone Marine

	Field Station has indicated that a single point injection system is efficacious and a cost-effective treatment system for a full scale system installation. Our proposed research will thoroughly examine the efficacy of this in line ozonation system on-board our test vessel. The benefits for preventing the introduction of ANS present in ballast water are numerous and well documented. Future introductions of aquatic nuisance species could result in enormous economic and environmental impacts.
Results	This study was funded in June 2004. Testing will begin in early 2005. Results will be posted when they become available.

Name of Project	De-oxygenation through Venture Oxygen Stripping
Treatment options researched	*Deoxygenation*
Principal Researcher(s)	Dr. Mario Tamburri, University of Maryland/Chesapeake Biological Laboratory Dr. Greg Ruiz, Smithsonian Environmental Research Center Mr. Peter McNulty, NEI Treatment Systems
Contact Details	Chesapeake Biological Laboratory University of Maryland Center for Environmental Sciences PO Box 38 / One Williams Street Solomons, Maryland 20688 Tel: +1 410 326 7440 Fax: +1 410 326 7428 Email: tamburri@cbl.umces.edu
Host Institution(s)	Chesapeake Biological Laboratory University of Maryland Center for Environmental Sciences
Location of Research	TECO Ocean Shipping bulk carrier from Port Arthur, Texas and Jacksonville, Florida, USA Teekay Shipping tanker from Singapore the west coast of USA
Funding Level	$380,000
Funding Source(s)	NOAA Ballast Water Technology Demonstration Program
Timeframe of the Project	September 2004 – August 2006
Aims and objectives of the project	The Full-Scale Controlled Experiments Under Real-World Conditions evaluations of Venturi Oxygen Stripping™ will be divided into two distinct phases or objectives. 1) Engineering Efficacy: Install and verify operational abilities, effectiveness to produce intended conditions, and reliability of the VOS systems onboard active vessels, 2) Biological Efficacy: Test the ability of VOS to reduce concentrations living ballast water organisms, during normal vessel operations, to meet IMO standards.
Research Methods	The first objective will be addressed by evaluating engineering efficacy. Teekay and TECO will work with NEI to install and test the mechanical components of the treatment technologies to determine operational abilities, safety, and reliability using standard scientific principles. This will include the continuous monitoring of physical conditions of treated and untreated ballast water (e.g., temperature, salinity, dissolved oxygen, pH), impacts on the vessel structurally and operationally, and basic system performance. The second objective will be addressed by evaluating biological efficacy. Replicate samples will be collected and evaluated for both treated and untreated (control) ballast tanks at two or three depths (to include shallow and deep locations) immediately after filling and just prior to discharge after a voyage. The number of living organisms per unit volume will be determined from the samples for two different size classes: greater than 80 µm and between 80 to 10 µm, using direct microscopic observations, selective staining, and flow cytometry. In addition, the concentrations of total bacteria will also be determined by flow cytometry and the abundance of three specific indicator microbes (*E. coli*, *V. cholera* and intestinal *Enterococci*) will be quantified using direct plate counts and chromogenic substrate methods. This basic design will measure the effect of the VOS treatment on concentrations of live organisms in discharge water, controlling for the effect of initial concentration (before and final samples) and the effects of time (control tanks).
Results	To be determined.

Name of Project	Shipboard Trials of Ballast Water Treatment Systems in the United States
Treatment options researched	*Mechanical: Separation and Filtration* *Chemical: Biocides*
Principal Researcher(s)	Drs. David A. Wright and Rodger Dawson, Chesapeake Biological Laboratory, University of Maryland Center for Environmental Science.
Contact Details	Dr. David Wright Chesapeake Biological Laboratory University of Maryland Center for Environmental Science 1 Williams Street, P.O. Box 38 Solomons, MD 20688 USA Tel: +1 410 326 7240 Fax: +1 410 326 7210 E-Mail: wright@cbl.umces.edu Thomas P. Mackey Hyde marine, Inc. 28045 Ranney Parkway Cleveland, OH 44145 USA Tel: +1 440 871 8000 ext. 112 Fax: +1 440 871 8104 E-mail: tmackey@hydemarine.com
Host Institution(s)	University of Maryland Center for Environmental Science
Location of Research	Baltimore, Maryland USA
Funding Level	$1,200,000
Funding Source(s)	National Oceanic Atmospheric Administration, Maryland Port Administration, U.S. Maritime Administration
Timeframe of the Project	2001-2005
Aims and objectives of the project	A variety of ballast water treatment technologies are scheduled to be tested at full-scale aboard ships of the U.S. reserve fleet. Two biocides and an ultraviolet light irradiation unit have been tested in 2001, and combination technologies including a centrifugal separator, a depth filter plus secondary treatments (biocides and UV) will be tested in 2003-2005.
Research Methods	Treated and untreated water samples from shipboard mesocosms and ballast tanks are examined for zooplankton (microscopic live/dead examination aboard the ship), phytoplankton growth potential (following a grow-out period under fluorescent light), acridine orange fluorescent bacterial counts and cultural bacteria (also following grow-out periods). In all cases treated samples are compared with untreated samples to determine the efficacy of each treatment. Water samples are also examined to determine particulate profile and water quality parameters.
Results	100 ppm Peraclean Ocean®, an inorganic oxidant and 2ppm Seakleen® (an organic, natural product cellular oxidant) were both effective in controlling zooplankton and phytoplankton in ballast water. UV irradiation, using a 32kW system was able to inhibit phytoplankton growth and resulted in zooplankton mortalities of >95% at ballast water flow rates of ca. 1500gpm.

Name of Project	Performance Verification of Ballast Water Treatment Technologies by USEPA/NSF Environmental Technology Verification Program
Treatment options researched	*Performance testing of all treatment technologies*
Principal Researcher(s)	Thomas G. Stevens, Raymond M. Frederick, Richard A. Everett, James T. Hurley, Carlton D. Hunt, Deborah C. Tanis
Contact Details	Thomas Stevens NSF International 789 Dixboro Road Ann Arbor, Michigan 48105 United States Tel: +1 734 769 5347 Fax: +1 734 769 5195 Email: stevenst@nsf.org
Host Institution(s)	U.S. Environmental Protection Agency NSF International U.S. Coast Guard
Location of Research	Multiple locations in United States.
Funding Level	
Funding Source(s)	U.S. Environmental Protection Agency U.S. Coast Guard
Timeframe of the Project	June 2001 – ongoing.
Aims and objectives of the project	Develop and implement a program for verification of the performance of technologies designed to treat ballast water.
Research Methods	Develop testing protocol with stakeholder input, and implement testing program that will produce credible, independent data on performance efficiency and operation and maintenance requirements, and make public the results of the testing for use by purchasers, users and regulators.
Results	A draft protocol has been produced and is in review by a technical panel; the final draft will be available soon for general stakeholder (US and international) review and comment, leading to a final protocol. Pilot testing against the protocol is being planned.

Name of Project	Crumb Rubber Filtration for Ballast Water Treatment
Treatment options researched	*Crumb Rubber Filtration for Ballast Water Treatment*
Principal Researcher(s)	Yuefeng Xie
Contact Details	Environmental Engineering, TL 175 Penn State Harrisburg Middletown, PA 17057, USA Tel: +1 717 948 6415 Fax: +1 717 948 6580 Email: yxx4@psu.edu
Host Institution(s)	Penn State Harrisburg
Location of Research	Middletown, Pennsylvania, USA
Funding Level	$200,000
Funding Source(s)	National Oceanic and Atmospheric Administration, USA United States Geological Survey
Timeframe of the Project	2003 - 2006
Aims and objectives of the project	The objectives of this research are to investigate the application of crumb rubber filtration for ballast water treatment and develop design and operational criteria for on-board crumb rubber ballast water filters for ballast water treatment. The removal of turbidity, particles, phytoplankton, and zooplankton in crumb rubber filter will be evaluated under in various design, operational, and water quality parameters. Filtration rate, run time, and filter backwash will also be evaluated. The ultimate goal of this proposed project is to provide design and operational criteria for a ballast water crumb rubber filter which could be used in a subsequent full-scale demonstration project. Our hypnosis is that a well designed crumb rubber filter, operated at 20-40 gpm/ft^2, can achieve an effective removal of invasive species.
Research Methods	The research will be conducted in three phases. Phase I consists of field pilot studies to evaluate the effects of crumb rubber size, filter media depth, filtration rate, and coagulation on the filter performance using water from a fresh water lake, Pinchot Lake in Gifford Pinchot State Park. Phase II consists of the development of design and operational criteria for an on-board crumb rubber filter. Phase III consists of field pilot studies to verify the design and operational criteria and investigate other factors (e.g., turbidity and salinity) which may affect the design and operation of an on-board crumb rubber filter.
Results	The success of the proposed project will result in design and operational criteria for a ballast water crumb rubber filtration system. Because of its higher water filtration rate, lighter weight, and longer filter run time, crumb rubber filtration is potentially an ideal treatment technique for ballast water treatment. As an in-vessel treatment facility in cargo ships or cruise ships, these crumb rubber filters could potentially be installed inside the ballast water tanks. The crumb rubber filters could also be mounted on a barge as a mobile treatment unit. For land based treatment facilities, using the crumb rubber filtration could significantly reduces the land requirements and the capital and operational cost of the ballast water treatment. This technology could also be developed for storm water and combined effluent treatment. The use of the crumb rubber will also minimize the waste tire piles and promote green technology concepts.

Appendix One: Template for Submissions to be Included in the Directory

This form is available as a Word document from *http://globallast.imo.org/research/*

Name of Project	
Treatment options researched	
Principal Researcher(s)	
Contact Details	
Host Institution(s)	
Location of Research	
Funding [US$]	
Funding Source(s)	
Timeframe of the Project	
Aims and objectives of the project	
Research Methods	
Results	

More Information?

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