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2012 ASSESSMENT OF THE EFFICACY, AVAILABILITY AND ENVIRONMENTAL IMPACTS OF BALLAST WATER TREATMENT SYSTEMS FOR USE IN CALIFORNIA WATERS

BACKGROUND:

California is in a unique biological and economic position in relation to the global problem of marine nonindigenous species. The State's natural resources contribute significantly to our coastal economy. In total, the tourism and recreation industries accounted for almost $15 billion of California's gross state product in 2009 (NOEP 2012). Invasive species pose a threat to these and other components of California's economy including fish hatcheries and aquaculture, recreational boating and marine transportation. The number of introduced invertebrates and algae in California exceeds that of most marine regions of the world, with the exception of the Mediterranean and the Hawaiian Islands (Ruiz et al. 2011). California has also been identified as the entry point for 79% of the nonindigenous and invasive marine species on the west coast of North America (Ruiz et al. 2011). Ballast water is a major pathway by which invasive species enter California waters (Fofonoff et al. 2003, see also Cohen and Carlton 1995 for San Francisco Bay), and is necessary to the safe and efficient operation of commercial vessels.

Vessels have multiple options for complying with California's performance standards. Over 80% of vessel arrivals to California waters do not discharge ballast water in State waters. In these cases, the standards are met because all ballast water is retained on board the vessel. Alternatively, vessels may discharge to a shoreside or barge-based ballast water reception facility. Finally, for vessels that cannot retain all ballast on board or discharge to a reception facility, shipboard ballast water treatment may be necessary to meet California's performance standards. The fields of treatment technology assessment and compliance verification continue to improve in large part because of California's protective performance standards.

Currently available methods for shipboard compliance evaluation can demonstrate that ballast water does not exceed California's discharge performance standards under shipboard conditions, except for the standards involving organisms within the 10 – 50 micron size range, and viruses and virus-like particles. Current testing methods for the 10-50 micron size class can show no organisms exist in treated ballast water, based on the volumes measured, to a level of sensitivity greater than the IMO standard, but the testing method cannot yet determine whether or not treated ballast water meets the California standard. However, this situation should not be confused with the ability or inability of a system to treat ballast water to California's standards.

Although available data continue to improve in quantity and quality, uncertainty regarding treatment system performance and evaluation still exists, and the utilization of an adaptive management approach will be essential at all stages of implementation in order to move forward and protect California's aquatic resources from the impacts of species introductions, while maintaining the integrity of the maritime industry.

PROPOSED REPORT:

Pursuant to Public Resources Code (PRC) Section 71205.3, Commission staff has prepared a report entitled "2012 Assessment of the efficacy, availability and environmental impacts of ballast water treatment systems for use in California waters" (Exhibit A; hereafter Report). This legislatively mandated Report is required to assess the state of ballast water treatment technologies and the ability of these technologies to treat water to California's statutory performance standards for the discharge of ballast water. The Report must also contain a discussion of the potential environmental impacts of ballast water treatment systems available for purchase and use. If technologies that can treat ballast water to California standards are found not to be available, then the Report must contain a discussion of why such systems are lacking.

This Report summarizes developments in ballast water treatment technologies for the upcoming January 1st, 2014, implementation date for existing vessels with a ballast water capacity of 1500 – 5000 metric tons. This vessel size class encompasses 8% of unique vessels visiting California ports from January 2000 to March 2012.

The determination of whether a ballast water treatment system can meet California's standards is based on the best available information reflected by data and conclusions reached from existing technologies for measuring organisms in ballast water. The conclusions that treatment systems can meet California standards is based on the data showing that the ballast water measured after treatment does not show exceedance of those standards.

Thirteen ballast water treatment systems showed the **potential** to treat ballast water to California's standards (eight systems met this criterion in 2010). This potential was determined by examining third-party treatment system testing data. If at least one test under shipboard or land-based testing conditions revealed that treated ballast water met or exceeded California's performance standards for ballast water discharges, that system was determined to have the **potential** to treat ballast water to California's standards. Data collected under shipboard testing conditions were given more weight in this analysis because the sampling conditions more closely reflect those of the practical limitations associated with onboard ship sampling and evaluation, where physical and operational constraints limit the volume of water that can be collected.

More rigorous evaluation criteria were applied to the thirteen systems that demonstrated the potential to treat ballast water to acceptable levels, in order to determine the proportion of tests that met or exceeded California's performance standards. **Six systems showed this potential at least 50% of the time in land-based or shipboard tests (only three systems fulfilled this more rigorous criterion in 2010). Three systems showed this potential in 100% of shipboard tests (one system met this criterion in 2010), and one additional system showed this potential in 100% of shipboard tests but did not conduct tests for total bacteria.**

These data indicate that there are ballast water treatment technologies available that have the potential to treat ballast water to California's performance standards for the discharge of ballast water. Even though the available data suggest that systems can meet the protective California standard for the 10-50 micron size class, staff's ability to make robust conclusions is limited by the availability of data sensitive enough to be applicable to California's standard for this size class.

In order to collect rigorous and standardized data associated with treatment system success for the 10-50 size class under real-world conditions, shipboard compliance assessment protocols are necessary; these compliance assessment protocols are currently under development by Commission staff.

Pursuant to Commission direction provided at its May 24, 2012 meeting, in recognition of the need for rigorous and standardized data collection on system performance under real-world conditions, Commission staff is currently developing compliance protocols, in consultation with and review by scientific experts. The proposed regulations for measuring performance will contain a provision indicating that ballast water performance standards not be enforced beyond IMO standards for all but the *Escherichia coli* and intestinal enterococci standards for two years while staff evaluates the compliance of vessels that have installed treatment systems. Under the protocols currently being developed, after two years, Commission staff would re-evaluate this non-enforcement provision and provide recommendations in subsequent reports to the Commission and Legislature based on the information in advance of the January 1, 2016 implementation date.

STATUTORY AND OTHER REGULATIONS:

A. Public Resources Code Section 71200 through 71271

OTHER PERTINENT INFORMATION:

1. The staff recommends that the Commission find that acceptance of the Report does not have a potential for resulting in either a direct or a reasonably

foreseeable indirect physical change in the environment, and is, therefore, not a project in accordance with the California Environmental Quality Act (CEQA).

Authority: Public Resources Code section 21065 and California Code of Regulations, Title 14, sections 15060, subdivision (c)(3) and 15378.

2. Adoption of the Report "2012 Assessment of the efficacy, availability and environmental impacts of ballast water treatment systems for use in California waters" does not affect small businesses as defined in Government Code Section 11342, subsection (h), because all affected businesses are transportation and warehousing businesses having annual gross receipts of more than $1,500,000, as specified under Government Code Section 11342, subsection (h)(2)(I)(vii).

   Authority: Public Resources Code Section 21065 and California Code of Regulations, Title 14, sections 15060(c)(3) and 15378.

EXHIBIT:

A. "2012 ASSESSMENT OF THE EFFICACY, AVAILABILITY AND ENVIRONMENTAL IMPACTS OF BALLAST WATER TREATMENT SYSTEMS FOR USE IN CALIFORNIA WATERS"

RECOMMENDED ACTION:

It is recommended that the Commission:

1. Find that acceptance of the Report is not subject to the requirements of CEQA pursuant to California Code of Regulations, Title 14, section 15060, subdivision (c)(3), because the activity is not a project as defined by Public Resources Code section 21065 and California Code of Regulations, Title 14, section 15378.

2. Accept the Report to the Legislature entitled "2012 Assessment Of The Efficacy, Availability And Environmental Impacts Of Ballast Water Treatment Systems For Use In California Waters", substantially in the form attached as Exhibit A.

3. Authorize the Commission Staff, prior to submission to the Legislature, to make such nonsubstantive changes in the Report as are necessary to correct errors or clarify the information presented.

4. Direct staff to submit the Report, substantially in the form attached as Exhibit A, to the Legislature in compliance with section 71205.3 of the Public Resources Code.

DRAFT

2012 Assessment of the Efficacy, Availability and Environmental Impacts of Ballast Water Treatment Systems for Use in California Waters

California State Lands Commission

July 2012

EXECUTIVE SUMMARY

Abstract

As part of addressing the threat of nonindigenous species (NIS) introductions to California waters, and as required by Public Resources Code (PRC) 71205.3(b), California State Lands Commission (Commission) staff must prepare a report on the efficacy, availability, and environmental impacts, including the effect on water quality, of currently available technologies for ballast water treatment. This report is submitted 18 months prior to each implementation date specified in PRC 71205.3 for ballast water discharge performance standards. This report summarizes developments in ballast water treatment technologies for the upcoming January 1st, 2014 implementation date for existing vessels with a ballast water capacity of 1500 – 5000 metric tons. This vessel size class encompasses 8% of unique vessels visiting California ports from January 2000 to March 2012.

Thirteen ballast water treatment systems showed the **potential** to treat ballast water to California's standards (there were eight systems that fit this category in 2010). Potential was determined by examining third-party treatment system testing data. If at least one test under shipboard or land-based testing conditions revealed that treated ballast water met or exceeded California's performance standards for ballast water discharges, that system was determined to have the potential to treat ballast water to California's standards. Data collected under shipboard testing conditions were given more weight in this analysis because the sampling conditions more closely reflect those of the practical limitations associated with onboard ship sampling and evaluation, where physical and operational constraints limit the volume of water that can be collected.

More rigorous evaluation criteria were applied to the thirteen systems that demonstrated the potential to treat ballast water to acceptable levels, in order to determine the proportion of tests that met or exceeded California's performance standards. **Six systems showed this potential at least 50% of the time in land-based or shipboard tests (three systems fulfilled this criterion in 2010). Three systems showed this potential in 100% of shipboard tests (one system fulfilled this criterion in 2010). One additional system demonstrated potential in 100% of shipboard tests but did not conduct tests for total bacteria.** These data indicate that there are ballast water treatment technologies available that have the potential to treat ballast water to California's performance standards for the discharge of ballast water. Even though the available data suggest that systems can meet the protective California standard for the 10-50 micron size class, staff's ability to make robust conclusions is limited by the availability of data sensitive enough to be applicable to California's standard for this size class. In order to collect rigorous and standardized data associated with treatment system success for the 10-50 size class under real-world conditions, shipboard compliance assessment protocols are necessary; these compliance assessment protocols are currently under development by Commission staff.

Pursuant to Commission direction provided at its May 24, 2012 meeting, in recognition of the need for rigorous and standardized data collection on system performance under real-world conditions, Commission staff is currently developing compliance protocols, in consultation with and review by scientific experts. The proposed regulations for measuring performance will contain a provision indicating that ballast water performance standards not be enforced beyond IMO standards for all but the *Escherichia coli* and intestinal enterococci standards for two years while staff evaluates the compliance of vessels that have installed treatment systems. Under the protocols currently being developed, after two years, Commission staff would re-evaluate this non-enforcement provision and provide recommendations in subsequent reports to the Commission and Legislature based on the information in advance of the January 1, 2016 implementation date.

Ballast water is a major pathway by which nonindigenous species enter California waters, which has resulted in human health risks, economic losses and environmental degradation. For this reason, State law charges the California State Lands Commission with implementation of existing statutory performance standards for ballast water discharges to California waters.

California's economy depends on marine resources. California had the second largest ocean-based Gross Domestic Product in the U.S. in 2009, and ranked number one for employment and second in wages. In total, the tourism and recreation industries accounted for almost $15 billion of California's gross state product in 2009. NIS threaten these and other components of California's ocean economy, including fish hatcheries and aquaculture, recreational boating, and marine transportation. Furthermore, the number of introduced invertebrates and algae in California exceeds that of most marine regions of the world. Ballast water is a significant ship-based introduction vector and is one of the primary routes by which NIS enter the coastal waters of California. Control measures cost millions of taxpayer dollars every year in California, and are ongoing because NIS are often impossible to remove once established. For these reasons, California is in a unique biological and economic position in relation to the global problem of NIS.

The Coastal Ecosystems Protection Act (Act) of 2006 (SB 497) charged the Commission to implement existing statutory performance standards for the discharge of ballast water that were adopted by the Legislature in 2006, and to prepare reports assessing the efficacy, availability and environmental impacts, including water quality, of currently available ballast water treatment technologies. The current report is required because of the upcoming implementation date of

January 1, 2014, for existing vessels that have a ballast water capacity of 1500-5000 metric tons (8% of vessel arrivals to California from date January 2000 through date March 2012).

Ballast water treatment technologies and management strategies continue to improve, though challenges still remain for future technology and compliance evaluation protocol development.

Over 80% of vessel arrivals to California waters do not involve the discharge of ballast water. In these cases, the standards are met because all ballast water is retained on board the vessel. For vessels that cannot retain all ballast on board or discharge to a reception facility, shipboard ballast water treatment may be necessary to meet California's statutory performance standards.

Progress continues to be made in the development and assessment of treatment systems. Both the quantity and the quality of the recently received data on system performance attest to this fact. Furthermore, the fields of treatment technology assessment and compliance verification continue to improve. All of these technological improvements continue to be made in large part because of California's protective performance standards. Commission staff is in the process of developing compliance verification protocols for ballast water discharges in consultation with and review by scientific experts who specialize in ballast water sampling and evaluation methods. Available methods for shipboard compliance evaluation can test to California's performance standards, with the exception of the standard for organisms within the 10 – 50 micron size range, viruses and virus-like particles.

Although available data continue to improve in quantity and quality, uncertainty regarding treatment system performance and evaluation still exists because of the absence of a significant worldwide effort to install and test treatment systems on multiple vessels and under all possible environmental scenarios. Continuing to wait for more information to emerge from outside California will only serve to delay progress, because other states and authorities as well as technology vendors are looking to California for guidance in development of their own testing protocols. In the meantime, utilization of an adaptive management approach will be essential at all stages of implementation in order to move forward and protect California's aquatic resources from the impacts of species introductions, while maintaining the integrity of the maritime industry..

Systems show sufficient potential to implement performance standards for existing vessels with ballast water capacity of 1500 – 5000 metric tons by January 1, 2014. The most uncertainty regarding system performance exists in available data that evaluate efficacy for California's 10 – 50 micron standard.

This report summarizes the advancement of ballast water treatment technology development and evaluation during 2011 and the first half of 2012 and discusses ongoing activities of the Commission's Marine Invasive Species Program regarding the implementation of California's statutory performance standards for the discharge of ballast water. Sufficient evidence exists to conclude that multiple systems show potential to meet California's discharge standards for all but organisms in the 10 – 50 micron size class, for which it is not yet possible to make robust conclusions. All available evidence suggests that systems can meet the 10 – 50 micron standard under shipboard conditions, but available data are not sensitive enough to either confirm or disprove these projections.

Commission staff should continue to gather information on treatment system efficacy, availability and environmental impacts as California's standards are implemented and additional vessels install treatment systems. To do this, the

Commission will require 1) implementation of ballast water discharge performance standards according to the schedule prescribed in PRC 71205.3 and 2) adoption of ballast water discharge testing protocols in regulation to assess whether ships with ballast water treatment systems are or are not meeting ballast water discharge performance standards, and to collect much-needed data on system performance in the 10-50 micron organism size class. Pursuant to Commission direction, staff will develop regulations that provide that the discharge performance standards that appear in PRC 71205.3 not be enforced beyond IMO for all but standards for *E. coli* and Enterococci (California standards for these two indicator bacteria are consistent with California's water contact standards established to protect public health) while California gathers relevant data. After a two year data collection period, Commission staff will re-evaluate the non-enforcement provision and provide recommendations in subsequent reports to the Commission and Legislature in advance of the January 1, 2016 implementation date.

Summary Table: Environmental and other approvals, pump rate capacities, and source information for 13 systems that demonstrate potential to comply with California's ballast water discharge standards. Blank cells indicate no information was available. Systems in **bold** have demonstrated the potential to comply with California standards in >50% of tests (land based OR shipboard). N/A = not applicable (e.g. UV systems do not produce residuals). * = treatment system demonstrated potential to treat ballast water to California's standards in 100% of shipboard tests. "TRC limits" refers to legal limits on total chlorine residuals set by the California State Water Board's 401 certification of the EPA Vessel General Permit (VGP). A "Y" in this category indicates that the system produces chlorine residuals and is therefore subject to TRC limits, while an "N" in this category indicates that the system does not produce chlorine residuals.

System Manufacturer	Max System Capacity (Pump Rate, m^3/hr.)	General Approvals (Non-California)	Environmental Approvals	TRC limits apply
Alfa Laval	2500	Type Approval (Norway)	IMO Basic and Final	N
Ecochlor*	**>13,000**	**Type Approval (Germany), USCG STEP, WA conditional**[1]	**IMO Basic and Final, USCG STEP**	**Y**
Hyde Marine	6000	USCG STEP, Type Approval (UK)	USCG STEP	N
JFE	3500	Type Approval (Japan)	IMO Basic and Final	Y
MAHLE*		**Type Approval (Germany)**	**N/A**	**N**
NK-03	8000	Type Approval (Korea)	IMO Basic and Final	N
OceanSaver	>6000	Type Approval (Norway)	IMO Basic and Final	Y
OptiMarin	3000	Type Approval (Norway)	N/A	Y
Quingdao*	**4500**	**Type Approval (China, DNS)**	**IMO Basic and Final**	**Y**
RWO	**2500**	**Type Approval (Germany)**	**IMO Basic and Final**	**N**
Severn Trent	**5000**	**USCG STEP, Type Approval (Germany)**	**IMO Basic and Final, USCG STEP**	**Y**
Techcross*	**>5000**	**Type Approval (Korea)**	**IMO Basic and Final**	**Y**
Wuxi Brightsky[2]		Type Approval (China)	N/A	N

[1] Washington State Conditional Approval and USCG STEP Approval require that systems demonstrate levels of efficacy and environmental acceptability. STEP is not a Type Approval process. Washington State Conditional Approval requires data from specific laboratory and effluent toxicity tests.
[2] Wuxi Brightsky provided third-party test data to MEPC 62, but Commission staff were not able to confirm success rate for potential compliance with California discharge standards.

TABLE OF CONTECTS

ABBREVIATIONS AND TERMS

Act	Coastal Ecosystems Protection Act
CCR	California Code of Regulations
CFR	Code of Federal Regulations
CFU	Colony-Forming Unit
CSLC/Commission	California State Lands Commission
Convention	International Convention for the Control and Management of Ships' Ballast Water and Sediments
CWA	Clean Water Act
EEZ	Exclusive Economic Zone
EPA	United States Environmental Protection Agency
ETV	Environmental Technology Verification Program
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
GESAMP-BWWG	Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection – Ballast Water Working Group
IMO	International Maritime Organization
MEPC	Marine Environment Protection Committee
Michigan DEQ	Michigan Department of Environmental Quality
ml	Milliliter
MPCA	Minnesota Pollution Control Agency
MT	Metric Ton
NIS	Nonindigenous Species
nm	Nautical Mile
NPDES	National Pollution Discharge Elimination System
NRL	Naval Research Laboratory
PRC	Public Resources Code
Staff	Commission staff
STEP	Shipboard Technology Evaluation Program
TRC	Total Residual Chlorine
µm	Micrometer or Micron (one millionth of a meter)
USCG	United States Coast Guard
UV	Ultraviolet Irradiation
VGP	Vessel General Permit for Discharges Incidental to the Normal Operation of Commercial Vessels and Large Recreational Vessels
Water Board	California State Water Resources Control Board
WDFW	Washington Department of Fish and Wildlife
WDNR	Wisconsin Department of Natural Resources

DISCLAIMER

This report provides information regarding the potential demonstrated by ballast water treatment systems to meet California's performance standards for the discharge of ballast water. This report does not constitute an endorsement or approval of any treatment system, system manufacturer or vendor by the Commission or its staff. Data are presented for informational purposes regarding the systems currently available on the market, but Commission staff strongly recommends that any party wishing to purchase a treatment system consult with treatment system vendors directly regarding system operational capabilities and third-party testing data. According to State law, any ballast water discharged in California waters must comply with California's performance standards for preventing species introductions as well as all other applicable laws, regulations and permits.

I. PURPOSE

This report was prepared for the California Legislature pursuant to Public Resources Code (PRC) Section 71205.3. Among its provisions, PRC Section 71205.3 requires the Commission to implement performance standards for the discharge of ballast water and to prepare and submit to the Legislature, "a review of the efficacy, availability, and environmental impacts, including the effect on water quality, of currently available technologies for ballast water treatment systems." California's regulations implementing Legislative performance standards for the discharge of ballast water were approved in 2007 by the Commission (see California Code of Regulations (CCR), Title 2, Division 3, Chapter 1, Article 4.7). The Commission completed an initial ballast water treatment technology assessment report in 2007 (see Dobroski et al. 2007) and revised reports in 2009 (see Dobroski et al. 2009a) and 2010 (see California State Lands Commission 2010). Additional reports are due to the California Legislature 18 months prior to each of the implementation dates for California's performance standards (see Tables III-1 and

III-2). This report is in response to the legislative mandate to assess the availability of ballast water treatment technologies prior to the January 1, 2014 implementation of California's performance standards for existing vessels (those built prior to January 1, 2010) with a ballast water capacity of 1500 - 5000 metric tons (MT). The report summarizes the Commission staff's conclusions on the advancement of ballast water treatment technology development, reviews industry efforts to retrofit existing vessels with ballast water treatment systems, and discusses progress by Commission staff in implementing California's performance standards for the discharge of ballast water.

II. INTRODUCTION

Nonindigenous species have negative economic, ecological, and public health impacts that are costly at the state, federal, and international levels

Nonindigenous species (also known as "introduced", "invasive", "non-native", "exotic", "alien", or "aquatic nuisance species") are organisms that have been transported by human activities to regions where they did not historically occur, and have established reproducing wild populations (Carlton 2001). Once established, nonindigenous species (NIS) can have serious human health, economic and environmental impacts in their new environment. Economic impacts from NIS may include property damages and declines in fishery yields and tourism. Costs also arise from efforts to control or eradicate NIS once they are established, and these efforts are often unsuccessful (Carlton 2001). Since 1956, for example, the US and Canada have each spent more than $16 million every year on control of sea lampreys alone in efforts to protect Great Lakes Fisheries (Lodge et al. 2006). For this reason, prevention of NIS introductions is considered more desirable than control. Cumulative costs in the United States related to NIS were estimated at $120 billion taxpayer dollars in 2005 (Pimentel et al. 2005).

NIS also create environmental problems where they are introduced. The comb jelly *Mnemiopsis leidyi*, for example, was introduced from North America to the Black Sea, where it feeds on plankton and fish eggs (Purcell et al. 2001), and has contributed to declines in locally important fish species. Worldwide, forty-two percent of the species listed as threatened or endangered in 2005 were listed in part because of negative interactions with NIS (e.g. competition) (Pimentel et al. 2005).

In addition, many human pathogens and contaminant indicator micro-organisms have been introduced to locations all over the world. These pathogens include human cholera (*Vibrio cholerae* O1 and O139) (Ruiz et al. 2000), toxic aquatic microbes that cause paralytic shellfish poisoning (Hallegraeff 1998), human intestinal parasites, and microbial indicators for fecal contamination (*Escherichia coli* and intestinal enterococci) (Reid et al. 2007). Larger NIS can also serve as intermediate hosts for human parasites (Brant et al. 2010).

Ballast water can transport nonindigenous species that are harmful to the economy, public health, and important native species in California

Commercial shipping is an important transport mechanism, or "vector," for nonindigenous species in marine, estuarine and freshwater environments, contributing up to an estimated 80% of invertebrate and algae introductions to North America (Fofonoff et al. 2003, see also Cohen and Carlton 1995 for San Francisco Bay). Ballast water is a possible vector for 69% of shipping introductions of NIS, with the remaining introductions attributed solely to biofouling. Therefore, ballast water is a significant ship-based introduction vector (Fofonoff et al. 2003) and is one of the primary routes, along with biofouling, by which nonindigenous species enter the coastal waters of California (Ruiz 2011). The number of introduced invertebrates and algae in California exceeds that of most marine regions of the world, with the exception of the Mediterranean and the Hawaiian Islands (Ruiz 2011), and includes three NIS recently identified by the California Department of Fish and Game that have not previously been observed in San Francisco Bay (CDFG 2011). Ballast water was cited as a possible mechanism for all three of these new introductions.

Ballast water is necessary for many functions relating to the trim, stability, maneuverability, and propulsion of large oceangoing vessels (National Research Council 1996). Vessels take on, discharge, and redistribute ballast water during cargo loading and unloading, during fuel loading and burning, in rough seas, or in transit through shallow coastal waterways. Typically, ships take on ballast water after cargo is unloaded in one port, and later discharge that water when cargo is loaded in another port. This transfer of ballast water from “source” to “destination” ports results in the movement of many organisms from one region to another. It is estimated that more than 7000 species are moved around the world every day in ballast water (Carlton 1999). In California, some of these ballast water-mediated introductions have had significant negative environmental and economic impacts.

One of the most infamous examples of a costly NIS in California, and the United States as a whole, is the zebra mussel (*Dreissena polymorpha*). This tiny mussel was introduced to the Great Lakes in the mid-1980s via ballast water from the Black Sea (Carlton 2008), and was later found in California in 2008 (CDFG 2008). Zebra mussels, and the closely related invasive quagga mussel (*Dreissena rostriformis bugensis*), attach to hard surfaces in dense aggregations that have clogged municipal water systems and electric generating plants, costing approximately $1 billion per year in damage and control for the Great Lakes (Pimentel et al. 2005). Zebra mussels have invaded San Justo Reservoir in San Benito County (California), and quagga mussels have invaded multiple locations in southern California (USGS 2011). Should quagga mussels spread to the Lake Tahoe region, they could create costs of up to $22 million per year (US Army Corps of Engineers 2009). Over $14 million has already been spent to control zebra and quagga mussels in California since the species were first found in 2007 (Norton, D., pers. comm. 2012). These costs represent only a fraction of the cumulative expenses related to NIS control over time, because such control is an unending process.

Ballast water introductions in California also present risks to public health. For example, the Japanese sea slug *Haminoea japonica* was introduced, likely via ballast water, to San Francisco Bay in 1999. This slug is a host for parasites that cause cercarial dermatitis, or “swimmer’s itch”, in humans. Since 2005, cases of swimmer’s itch at Robert Crown Memorial Beach in Alameda have occurred on an annual basis and are associated with high densities of *Haminoea japonica* (Brant et al. 2010). Ballast water has also been shown to transport viable human pathogens such as *Vibrio cholerae* (Ruiz et al. 2000), which remains a public health concern anywhere ballast water is discharged.

NIS also negatively impact native California species. The overbite clam (*Corbula amurensis*) has been linked in multiple studies to the decline of endangered delta smelt in the Sacramento-San Joaquin River Delta. It is believed that these clams reduce the plankton food base in this ecosystem and limit food availability for these endangered native fish species (Feyrer et al. 2003, Sommer et al. 2007, Mac Nally et al. 2010).

Open ocean exchange does not adequately address ballast water introductions

Due to safety and efficacy limitations of ballast water exchange, regulatory agencies and the commercial shipping industry have looked toward the establishment of ballast water performance standards and the development of ballast water treatment systems (BWTS). For regulators, such systems would provide nonindigenous species prevention, even under adverse conditions that would preclude exchange, and could provide a higher level of protection from nonindigenous species in general. For the shipping industry, the use of effective BWTS might allow voyages to proceed along the shortest available routes, without having to conduct exchange. For many vessels, this will mean safer conditions for crews, as well as savings in time and money.

For the vast majority of commercial vessels, ballast water exchange is currently the primary management technique to prevent or minimize the transfer of coastal, bay, and estuarine organisms. During exchange, the biologically rich water that was loaded when a vessel was in port or near the coast is exchanged with the comparatively species-poor waters of the mid-ocean (Zhang and Dickman 1999). Organisms adapted to coastal environments that were taken up with ballast water in port are flushed into the open ocean environment where they are not expected to survive and/or reproduce due to differences in biological factors (competition, predation, food availability) and oceanographic factors (turbidity, temperature, salinity, nutrient levels) (Cohen 1998). Any organisms taken up from mid-ocean environments are similarly not expected to survive or reproduce in coastal waters (Cohen 1998).

Ballast water exchange is generally considered to be an interim tool because of its variable efficacy and operational limitations. Studies indicate that ballast water exchange eliminates between 50-99% of organisms in ballast tanks (Cohen 1998, Parsons 1998, Zhang and Dickman 1999, USCG 2001, Wonham et al. 2001, MacIssac et al. 2002). Research demonstrates exchanging more ballast water does not necessarily improve its biological efficacy. Additionally, vessels routed on short voyages or that remain within 50 nautical miles (nm) of shore may have to delay or divert from the most direct course available to perform a proper exchange. A delay or deviation in a ship's route can extend travel distance, increase costs for personnel time and fuel consumption, and lead to increased air emissions.

Occasionally, ballast water exchange cannot be performed because it would compromise crew or vessel safety. Vessels that encounter adverse weather or experience equipment failure may be unable to conduct exchange safely. Unmanned barges are incapable of conducting exchange without extensive engineering modifications, unless personnel are transferred onboard. Personnel transfer to a barge presents unacceptable safety risks if performed in the open ocean. State and federal ballast water regulations allow vessels to forego exchange should the master or other person in charge determine that it would place a vessel, its crew, or its passengers at risk. This provision is primarily invoked by unmanned barges, and the vessels that use it do sometimes discharge unexchanged ballast into state waters, which elevates the risk of nonindigenous species introduction.

Statutory performance standards place California at the forefront of national efforts to prevent the introduction of nonindigenous species through ballast water discharge

California's coastal waters have been the entry point for 79% of known invertebrate and algal invasions by nonindigenous species on the west coast of the United States (including Alaska) and Canada , due in part to the high frequency of marine commerce and large variety of habitats present in San Francisco Bay (Ruiz 2011). This fact places California in a unique position regarding management and prevention of NIS. California took the U.S. lead in the prevention of marine NIS introductions in 1999 by being the first state to adopt mandatory ballast water management requirements (Ballast Water Management for Control of

Nonindigenous Species Act, Chapter 849, Statutes of 1999). In 2006, California cemented its leadership role by adopting statutory performance standards for ballast water discharge (Coastal Ecosystems Protection Act, Chapter 292, Statutes of 2006, Public Resources Code (PRC) Section 71205.3), which are being implemented via regulations adopted in October 2007 (see Title 2, California Code of Regulations (CCR), Section 2291 *et seq.*). Many states and the federal government have since followed suit and have adopted or are in the process of developing performance standards for ballast water discharge (see Section III. Regulatory Overview for more details).

California's legislatively adopted performance standards set benchmarks for levels of organism discharge from vessels. The absence of such benchmarks was identified by shipping industry representatives, ballast water technology developers and investors as a major impediment to the development of treatment technologies (MEPC 2003). California's protective ballast water treatment standards were designed in part to encourage the development of innovative and effective ballast water treatment technologies, and new systems have emerged rapidly since 2006. New systems and new data on existing systems continue to emerge, and are the focus of this technology assessment report.

III. REGULATORY AND PROGRAMMATIC OVERVIEW

The regulatory framework and context of performance standards development for ballast water discharges has influenced the advent of new ballast water treatment technologies. For this reason, a thorough review of the implementation of performance standards in California and the technologies available to treat ballast water must include an overview of regulatory activities at the state, national and international level. Currently, there are no formally adopted and implemented international, federal or state programs that include all three of the following:

1) performance standards,

2) guidelines or protocols to verify the performance of treatment technologies, and

3) methods to sample and analyze discharged ballast water for compliance purposes.

California, other U.S. states, the federal government, and the international community have recently made great strides towards the development of standardized approaches for the management of discharged ballast water. However, existing legislation, standards and guidelines still vary by jurisdiction. The following is a summary of current performance standards-related laws, regulations and permits by jurisdiction, and a review of current and proposed processes for treatment system evaluation and compliance verification.

International Maritime Organization

In February 2005, after several years of development and negotiation, International Maritime Organization (IMO) Member States adopted the International Convention for the Control and Management of Ships' Ballast Water and Sediments (Convention) (see IMO 2005). Among its provisions, the Convention includes performance standards for the discharge of ballast water (Regulation D-2) with an associated implementation schedule based on vessel ballast water capacity and date of construction (Tables III-1 and III-2).

The Convention as proposed would enter into force 12 months after ratification by 30 countries representing 35% of the world's commercial shipping tonnage (IMO 2005). As of July 2012, 35 countries representing 28% of the world's shipping tonnage have signed the convention (IMO 2012). Once 35% of the world's shipping tonnage is represented by ratifying countries, the Convention will enter into force. The Convention cannot be enforced upon any ship until it is ratified and enters into force (IMO 2007). Because the Convention was not ratified in time to enter into force before the first performance standards implementation date in 2009, the IMO General Assembly adopted Resolution A.1005(25) (IMO 2007). The resolution delays the date by which new vessels built in 2009 with a ballast water capacity of less than 5000 MT are proposed to comply with Regulation D-2 from 2009 until the vessel's second annual survey, but no later than December 31, 2011 (IMO 2007). In September 2009, another draft resolution was put forth to encourage the installation of ballast water treatment systems on new build ships based on the existing implementation dates even though the Convention has not yet been ratified (MEPC 2009j). That resolution was adopted at the 60th meeting of the Marine Environment Protection Committee (MEPC) in March, 2010. However, since the conditions of the resolution are not mandatory, the implementation dates for all other vessel size classes and construction dates remain the same as originally proposed (Table III-2).

Table III-1. Ballast Water Treatment Performance Standards

Organism Size Class	IMO D-2[1]/U.S. Federal	California[1,2]
Organisms greater than 50 µm[3] in minimum dimension	< 10 viable organisms per cubic meter	No detectable living organisms
Organisms 10 – 50 µm in minimum dimension	< 10 viable organisms per ml[4]	< 0.01 living organisms per ml
Living organisms less than 10 µm in minimum dimension		< 10^3 bacteria/100 ml < 10^4 viruses/100 ml
Escherichia coli	< 250 cfu[5]/100 ml	< 126 cfu/100 ml
Intestinal enterococci	< 100 cfu/100 ml	< 33 cfu/100 ml
Toxicogenic *Vibrio cholerae* (O1 & O139)	< 1 cfu/100 ml or < 1 cfu/gram wet weight zooplankton samples	< 1 cfu/100 ml or < 1 cfu/gram wet weight zoological samples

[1] See Table III-2 below for dates by which vessels must meet California's adopted standards and IMO proposed Ballast Water Performance Standards.

[2] Final discharge standard for California, beginning January 1, 2020, is zero detectable living organisms for all organism size classes.

[3] Micrometer = one-millionth of a meter

[4] Milliliter = one-thousandth of a liter

[5] Colony-forming unit (CFU) is a standard measure of viable bacterial numbers

Table III-2. Implementation Schedule for Performance Standards

Ballast Water Capacity of Vessel	Standards apply to new vessels in this size class constructed on or after	Standards apply to all other vessels in this size class beginning in[1]
< 1500 metric tons	2009 (IMO)[2] /2010 (CA)	2016
1500 – 5000 metric tons	2009 (IMO)[2] /2010 (CA)	2014
> 5000 metric tons	2012	2016

[1] In California, the standards apply to vessels in this size class as of January 1 of the year of compliance. The IMO Convention would apply to vessels in this size class no later than the first intermediate or renewal survey, whichever occurs first, after the anniversary date of delivery of the ship in the year of compliance (IMO 2005).

[2] IMO pushed back the initial implementation of the performance standards for vessels constructed in 2009 in this size class until the vessel's second annual survey, but no later than December 31, 2011 (IMO 2007).

In order to ensure globally uniform application of the requirements of the Convention, the IMO MEPC has adopted 14 implementation guidelines (Everett, R., pers. comm. 2012). Most relevant to this report, Guideline G8, "Guidelines for Approval of Ballast Water Management Systems" (MEPC 2008), and Guideline G9, "Procedure for Approval of Ballast Water Management Systems That Make Use of Active Substances" (MEPC 2008), work together to create a framework for the evaluation of treatment systems by the MEPC and Flag State Administration (the country or flag under which a vessel operates) (Figure III-1). Flag States (not the IMO) are authorized under this Convention to grant approval (also known as "Type Approval") to treatment systems that are in compliance with the Convention's Regulation D-2 performance standards based upon recommended procedures detailed in Guideline G8 for full-scale land-based and shipboard testing. A treatment system may not be used by a vessel party to the Convention to meet the D-2 standards unless that system is Type Approved by a representative Flag State.

In addition to receiving Type Approval from the Flag State, ballast water treatment systems using "active substances" must first be approved by the IMO MEPC based upon procedures developed by the organization (IMO 2005). An active substance is defined by IMO as, "…a substance or organism, including a virus or a fungus, that has a general or specific action on or against Harmful Aquatic Organisms and Pathogens" (IMO 2005). For all intents and purposes, an active substance is a chemical or reagent (e.g. chlorine, ozone) that kills organisms in ballast water. For this reason, the MEPC has decided that ultraviolet radiation (UV) does not classify as an active substance. The IMO approval pathway for treatment systems that use active substances is more rigorous than the evaluation process for technologies that do not. As required by Guideline G9, technologies utilizing active substances must go through a two-step "Basic" and "Final" approval process. Active substance systems that apply for Basic and Final Approval are reviewed for environmental, ship, and personnel safety by the IMO Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) – Ballast Water Working Group (BWWG) in accordance with the procedures detailed in Guideline G9. The MEPC may grant Basic or Final Approval based upon the recommendation of the GESAMP-BWWG.

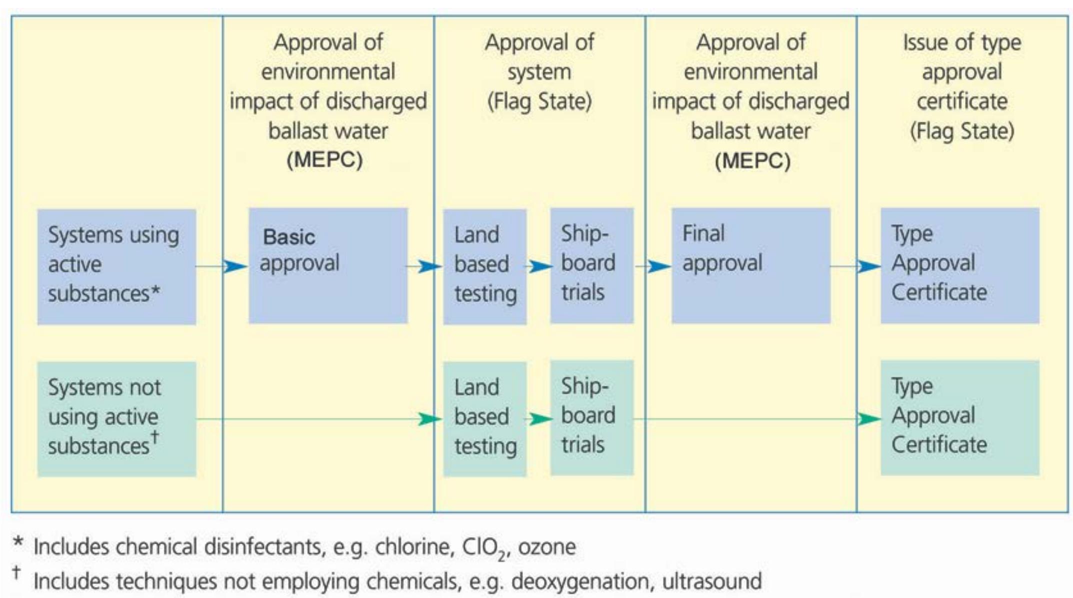

Figure III-1. Summary of IMO approval pathway for ballast water treatment systems. (Modified from Lloyd's Register (2007))

The entire IMO evaluation process, including approval for systems using active substances may take two or more years to complete depending on the time lag for GESAMP-BWWG review and the number of systems attempting to gain Type Approval from any one Flag State at one time. Once a ballast water treatment system has acquired Type Approval (and the Convention is ratified and in force), the system is deemed acceptable by parties to the Convention for use in compliance with Regulation D-2.

Because the U.S. has not signed on to the Convention, the U.S. has neither reviewed nor submitted applications to IMO on behalf of any U.S. treatment technology vendors. Unless and until the Convention is both signed by the U.S. and enters into force through international ratification, no U.S. federal agency has the authority (unless otherwise authorized by Congress) to manage a program to review treatment technologies and submit applications on their behalf to IMO. United States treatment vendors may approach IMO through association with other IMO Member States, and several have or are in the process of doing so. However, unless the U.S. signs on to the Convention, and the Convention is ratified and enters into force, the U.S. is not party to the Convention requirements. Hence, vessels calling on U.S. ports cannot rely on treatment systems approved solely through the IMO Type Approval process to meet U.S. ballast water management requirements. Vessels calling on U.S. ports must also ensure that their systems meet and are approved under the USCG Type Approval process (discussed below).

U.S. Federal Legislation and Programs

Ballast water discharges in the United States are regulated by both the United States Coast Guard (USCG) and the United States Environmental Protection Agency (EPA). Prior to February 6, 2009, ballast water was regulated solely by the USCG through regulations developed under authority of the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990, which was revised and reauthorized as the National Invasive Species Act of 1996. EPA began regulating ballast water in 2009 after a court decision required ballast water and other discharges incidental to the normal operation of vessels to be regulated under the Clean Water Act. The USCG and EPA regulations and permits do not relieve vessel owners/operators of the responsibility of complying with applicable state laws and/or regulations. Vessels thus face a challenging environment for the management of ballast water discharges marked by the need to navigate regulation by two federal agencies as well as the states. Recent efforts by both USCG and EPA, described below, have included working collaboratively to develop a strong federal program for ballast water management while reducing confusion amongst the regulated industry.

USCG

The USCG currently regulates ballast water under regulations found in Title 33 of the Code of Federal Regulation (CFR) Part 151. The regulations include requirements for vessels arriving from outside of the U.S. Exclusive Economic Zone (EEZ) to conduct ballast water exchange prior to discharge in U.S. waters. On March 23, 2012 the USCG published regulations in the Federal Register to establish federal performance standards for living organisms in ships' ballast water discharged in US waters. This rule became effective on June 21, 2012.

The USCG standards are the same as those established by the IMO Ballast Water Convention (see Table III-1) and will be implemented upon delivery for new build vessels constructed on or after December 1, 2013. Existing vessels (i.e. vessels constructed before December 1, 2013) must meet the standards as of the first scheduled dry docking after January 1, 2014 or 2016, depending on vessel ballast water capacity. The USCG rule provides exemptions for vessels that operate exclusively within the Great Lakes, exclusively within one Captain of the Port Zone, and for those vessels less than 1600 gross registered tons (GRT) in size that operate solely within the U.S. EEZ. Furthermore, vessel owners may request an extension of the implementation date if, despite all best efforts, the vessel will not be able to comply with the standards.

In addition to establishing performance standards, the USCG rule amends requirements for engineering equipment and establishes procedures for the USCG to Type Approve ballast water treatment systems for use in U.S. waters. The Type Approval process includes requirements for land-based and shipboard evaluation of ballast water treatment system performance. Land-based testing must be conducted in accordance with the EPA's Environmental Technology Verification (ETV) protocols for the verification of ballast water treatment technologies (see below for more information on the ETV protocols). The USCG rule also requires vessels to install ballast water sampling ports to facilitate enforcement, although no specific compliance assessment procedures are established by the rule.

The USCG continues to operate the Shipboard Technology Evaluation Program (STEP). STEP is intended to facilitate the development of ballast water treatment technologies. Vessel owners and operators accepted into STEP may install and operate specific experimental ballast water treatment systems on their vessels for use in U.S. waters. In order to be accepted, treatment technology developers must assess the efficacy of systems for removing biological organisms, residual concentrations of treatment chemicals, and water quality parameters of the discharged ballast water (USCG 2004). Vessels accepted into the program are authorized to operate the system to comply with existing USCG ballast water management requirements and will be grandfathered for operation under future ballast water discharge standards for the life of the vessel or the treatment system, whichever is shorter. As of June 2012, five vessels had been accepted into STEP (USCG 2012). The lengthy STEP review process and recent uncertainties regarding requirements for biological testing on STEP vessels have delayed significant testing of treatment systems on STEP vessels. The USCG has, however, made efforts to streamline the review process for future applicants. USCG plans to continue STEP even after the implementation of performance standards, as the STEP will serve to facilitate system shipboard testing for USCG approval, and will continue to promote vessel access for the research and development of promising experimental technologies (Moore, B., pers. comm. 2010; Everett, R., pers. comm. 2010).

EPA

On February 6, 2009, the EPA joined USCG in the regulation of ballast water in U.S. waters. The EPA regulates ballast water, and other discharges incidental to normal vessel operations, through the Clean Water Act (CWA). This requirement stems from a 2003 lawsuit filed by Northwest Environmental Advocates et al. against the EPA in U.S. District Court, Northern District of California, challenging a regulation originally promulgated under the CWA (Nw. Envtl. Advocates v. U.S. EPA, No. C 03-05760 SI, 2006 U.S. Dist. LEXIS 69476 (N.D. Cal. Sept. 18, 2006)). The regulation at issue, 40 CFR Section 122.3(a), exempted effluent discharges "incidental to the normal operations of a vessel," including ballast water, from regulation under the National Pollution Discharge Elimination System (NPDES). The plaintiffs sought to have the regulation declared *ultra vires,* or beyond the authority of the EPA, under the CWA. On March 31, 2005, the District Court granted judgment in favor of Northwest Environmental Advocates et al., and on September 18, 2006 the Court issued an order revoking the exemptive regulation (40 CFR Section 122.3(a)) as of September 30, 2008. EPA filed an appeal with the Ninth Circuit U.S. Court of Appeals but was denied in July 2008 (Nw. Envtl. Advocates v. U.S. EPA, No. 03-74795, 2008 U.S. App. LEXIS 15576 (9th Cir. Cal. July 23, 2008)).

In June 2008, EPA released for public comment the draft NPDES "Vessel General Permit for Discharges Incidental to the Normal Operation of Commercial Vessels and Large Recreation Vessels" (VGP). In September 2008, the District Court granted a motion to delay the vacature of the 122.3(a) regulation from September 30 to December 19, 2008. The implementation of the permit was later delayed to February 6, 2009 to provide the regulated community with additional time to comply. The VGP regulates 26 discharges incidental to the normal operation of vessels, including ballast water and hull husbandry discharges. In large part, the VGP maintains the regulation of ballast water discharges by the USCG under 33 CFR Part 151 and does not include performance standards for the discharge of ballast water. The current version of the VGP expires on December 18, 2013.

In 2009, the State of Michigan and environmental groups filed suit against EPA charging that the VGP violates the Clean Water Act because it does not adequately protect U.S. waters from invasive species and could lead to violation of water quality standards. In March 2011, plaintiffs and the EPA reached a settlement in the case. The settlement required EPA to release a draft revised Vessel General Permit by November 30, 2011 that includes numeric effluent limits for the concentration of living organisms in discharged ballast water (i.e. performance standards). Additionally, EPA agreed to provide additional time to states to review the draft permit and add state-specific provisions under the Section 401 certification process. Lastly, the permit must be finalized by November 30, 2012, a full year before it goes into effect on December 19, 2013, in order to provide time for the regulated industry to comply.

EPA released the draft 2013 Vessel General Permit on November 30, 2011, in compliance with the terms of the settlement. The draft 2013 VGP would require vessels to meet performance standards for the discharge of ballast water equivalent to the standards set forth by the IMO Ballast Water Convention (and the USCG final rule on standards for living organisms discharged in ships' ballast water).Vessels may comply with the performance standards set forth in the permit through the use of ballast water treatment technologies, potable water, the onshore treatment of ballast, or retention of all ballast on board. The implementation schedule is similar to that established by the USCG final rule. Vessels constructed on or after January 1, 2012, must meet the standards upon delivery of the vessel (and implementation of the permit – which takes place on December 19, 2013). Existing vessels constructed before January 1, 2012, must meet the standards as of the first scheduled dry dock after January 1, 2014 or 2016, depending on the vessel's ballast water capacity. Like the USCG rule, the draft 2013 VGP exempts from performance standards requirements vessels operating exclusively on the Great Lakes, unmanned, unpowered barges, and vessels operating within one USCG Captain of the Port Zone.

The draft 2013 VGP does require vessels to conduct biological monitoring of select bacteria species (*E. coli*, intestinal enterococci, and heterotrophic bacteria), yearly monitoring of sensors and control equipment, and frequent monitoring for residual biocides. These results must be reported to EPA in yearly monitoring reports.
The draft 2013 VGP was open to public comment between December 8, 2011 and February 21, 2012. EPA hosted multiple public meetings and information sessions during that time to answer questions about the proposed permit. States had until the end of June, 2012 to issue their 401 Certification of the draft 2013 Vessel General Permit. EPA is scheduled to release the final permit by November 2012 to provide the regulated community with time to comply by the permit implementation date of December 19, 2013.

EPA/USCG Collaborative Activities

EPA and USCG have been working collaboratively to develop performance standards and programs to evaluate ballast water treatment system performance. One such program, the EPA Environmental Technology Verification (ETV) program, is an effort to accelerate the development and marketing of environmental technologies. In 2001, the USCG and the EPA established a formal agreement to implement an ETV program focused on ballast water management. Under this agreement, the ETV program developed a draft protocol in 2004 for verification of the performance of ballast water treatment technologies. Subsequently, the USCG established an agreement with the Naval Research Laboratory (NRL) to evaluate, refine, and validate this protocol and the test facility design required for its use. This validation project resulted in the construction of a model ETV Ballast Water Treatment System Test Facility at the NRL Corrosion Science and Engineering facility in Key West, Florida. The innovative research conducted at the NRL facility is intended to result in technical procedures for testing ballast water treatment systems for the purpose of approval and certification. Based on the information collected during the evaluation of the 2004 draft protocol, ETV staff, in consultation with an advisory panel (of which Commission staff is a member), revised the protocol. In September 2010, the EPA released the "Generic Protocol for the Verification of Ballast Water Treatment Technology" (see EPA 2010). The protocol established specific methods and procedures for verifying ballast water treatment system performance at land-based testing facilities. In 2012, USCG incorporated the ETV protocol into its final rule as part of the testing process to approve ballast water treatment technologies. EPA and USCG are currently pursuing the development of an ETV shipboard protocol to verify treatment system performance. Commission staff has been invited to participate in this process.

In 2010, EPA and USCG also worked together to commission two scientific studies to better inform understanding of ballast water performance standards and treatment technologies. The goals of the studies were to evaluate: 1) the risk of species introduction given certain living organism concentrations in ballast water discharges, and 2) the efficacy and availability of ballast water treatment technologies. The National Academy of Sciences' National Research Council (NRC) was charged with evaluating the organism concentration question, and the EPA Office of Water requested the Science Advisory Board's (SAB) Ecological Processes and Effects Committee, augmented with experts in ballast water issues, to address the efficacy/availability question. The outcome of these two studies guided the development of the USCG final rule on living organisms discharged in ships' ballast water and the EPA draft 2013 Vessel General Permit.

On June 2, 2011, the NRC released the report "Assessing the Relationship Between Propagule Pressure and Invasion Risk in Ballast Water" (see NRC 2011). The goal of the report was to "inform the regulation of ballast water by helping EPA and the USCG better understand the relationship between the concentration of living organisms in ballast water discharges and the probability of nonindigenous organisms successfully establishing populations in U.S. waters." The report concluded that there is currently insufficient information to determine the probability of invasion associated with any particular discharge standard. The report recommends establishing a benchmark discharge standard (such as the IMO D-2 standard) followed by the selection of a risk-based model to guide the collection of experimental and field-based data for further analysis to inform the selection of science-based standards in the future.

The SAB report, "Efficacy of Ballast Water Treatment Systems: a Report by the EPA Science Advisory Board," was finalized in July 2011 (see SAB 2011). The panel examined 51 ballast water treatment technologies, of which only nine systems were deemed to have reliable data (defined by the SAB as including, at a minimum, methods and results from land-based or shipboard testing) that allowed for scientifically credible assessment of performance. The SAB evaluated the ability of those nine systems, condensed into five operational types (e.g. filtration + electrochlorination), to meet various existing and proposed performance standards, ranging from the IMO D2 standard to a standard 1,000 times more stringent than IMO. California's full standards were not included in the analysis.

Some argue that California's standard should be considered roughly 1,000 times more stringent than IMO. However, out of California's seven different organism size class standards (see Table III-1), only one (the 10 - 50 micrometer size class) is specifically 1,000 times more stringent than the IMO standard; the California standard for organisms greater than 50 micrometers in minimum dimension is "no detectable living organisms" which cannot be directly compared to the IMO standard of 10 organisms per cubic meter. California's remaining standards for organisms less than 10 micrometers in size either have no comparison to the IMO standards (e.g. total bacteria and viruses) or are only 2-3 times more stringent than IMO (e.g. human health indicator species).

Commission staff does not believe that the SAB report's conclusions are entirely applicable to the situation in California. The five reasons that Commission staff remains skeptical of the SAB report's applicability to ballast water regulations and laws in California are:

1) The SAB report was focused on evaluating data from a Type Approval perspective. This accurately reflects the needs of USCG which will Type Approve systems, but does not accurately reflect the needs of the Commission, which is mandated to assess discharges under shipboard conditions. While this report also uses data from tests for Type Approval

2) California's standards were not completely or accurately represented in the analysis or conclusions of the report. The SAB report provided results for standards 10X, 100X, and 1,000X stricter than IMO standards.

3) The SAB report routinely misinterprets the fact that testing designs did not allow for evaluation of more protective standards with a system's actual ability to meet those standards. This is not a trivial point, the inability of the chosen methods to detect strict standards does not equate with a system's failure to meet strict standards.

4) For reasons unexplained, the SAB report did not include many systems for which Commission staff was able to obtain third-party testing data. This makes the SAB report more limited in scope than this report, and hints that the SAB report might not present a complete picture of the current state of ballast water treatment technologies.

5) The SAB report was not supported in its final draft by all of the scientists on the Science Advisory Board. In fact, a letter of dissenting opinion was signed by 13 scientists on the Board. Among the concerns listed in this letter was the assertion that the findings of the SAB Panel have been misrepresented. This situation alone warrants that the Commission and its staff scientists evaluate the conclusions of the SAB with additional care.

The SAB report concluded that the nine systems could meet the IMO D-2 standard, but that the current limits of testing methods precluded a statistically valid analysis of whether or not the systems could meet more stringent standards (including standards 100 and 1,000 times more stringent than the IMO D-2 standard). Despite this inability to statistically analyze more protective standards, the panel did not believe that systems can currently meet standards more stringent than IMO D-2. The panel also concluded that reasonable changes to existing systems could result in the achievement of standards roughly 10 times more stringent than IMO, but that novel treatment techniques would likely be required to meet more stringent standards. In addition to the review of available treatment technologies, the panel advocated for the use of risk management systems approaches to reduce species introductions from vessels, including, for example, modifications to vessel operations and ship design and options for shore or barge-based ballast water reception facilities.

Impacts of Federal Actions in California

The EPA VGP and the USCG regulations do not relieve vessel owners/operators (permittees) of the responsibility of complying with applicable state laws and/or regulations. Many states with authority to implement the CWA have added specific provisions, including performance standards for vessel discharges in state waters, to the EPA's general permit through the CWA Section 401 certification process. There is not expected to be any impact from the implementation of the NPDES permit on individual states' ability to implement performance standards for the discharge of ballast water in state waters, including California. Since vessels will have to comply with both state and federal regulations for ballast water management under the VGP and the USCG regulations, until such time that ballast water treatment systems are type approved by the USCG or the 2013 VGP goes into effect, this may result in vessels having to exchange ballast water to comply with federal management requirements and also treat ballast water to comply with state regulations.

Recently proposed legislation could change the way the EPA/USCG and states regulate ballast water. Title 7 of The Coast Guard and Maritime Transportation Act of 2011 (H.R. 2838), contains language that would set the federal ballast water discharge standard to the proposed IMO standard, and would preempt any state from adopting ballast water discharge standards that are more protective than those proposed in H.R. 2838 unless the state's Governor submits a petition to the Coast Guard. This bill was passed by the U.S. House of Representatives in 2011, and as passed, could also preempt states from adopting any standards or management practices related to any discharge incidental to the normal operation of commercial vessels. As introduced to the Senate, H.R. 2838 (see S. 1665) no longer contains Title 7, nor any language that preempts states from adopting more protective standards for vessel discharges than those at the federal level. Should S. 1665 pass the Senate, the bill may be referred to a conference committee, at which time Title 7 could be re-introduced. Commission staff is continuing to follow this bill's progress in Congress.

A bill with similar implications has been introduced in the US Senate (S. 3332) to establish uniform federal standards for vessel discharges. This bill could also preempt states from adopting more protective standards for vessel discharges (including ballast water) than those adopted at the federal level. As of 16 July 2012, S. 3332 has been referred to the Senate Committee on Commerce, Science, and Transportation.

In the meantime, Commission staff is carefully reviewing the final USCG rulemaking and the draft 2013 revisions to the Vessel General Permit. As the draft 2013 VGP is not finalized yet, and states have yet to add their state-specific provisions through the Section 401 certification process, it is hard to predict exactly how the USCG rule and the 2013 VGP will complement one another and how they will be enforced. The National Invasive Species Act and the Clean Water Act allow states to implement more stringent standards, therefore federal actions should not directly impact the Commission's efforts to implement California's performance standards, unless H.R. 2838/S. 1665 passes with the federal discharge standards intact, or S. 3332 passes. Commission staff is working closely with stakeholders to ensure that vessels clearly understand California's ballast water management requirements.

U.S. State Legislation and Programs

States have taken two approaches to the implementation of ballast water management requirements, and specifically performance standards for the discharge of ballast water. Some states have authority granted by state statute to establish performance standards through regulation or by permit. Other states exercise authority to establish standards under the federal Clean Water Act through the Section 401 certification process for the Vessel General Permit. The following is a summary of ballast water performance standards by state and how each has approached implementation.

CWA Section 401 Certifications Under the Vessel General Permit (VGP)

Section 401 of the Clean Water Act requires states to approve federal permits and allows states to add conditions, if necessary, above and beyond those present in the federal permit. A number of states established ballast water management programs and/or requirements in 2009 through the VGP. States that specifically included the establishment of performance standards in their 401 certification include: Illinois, Indiana, Ohio, and Pennsylvania. Illinois, Indiana and Ohio require vessels to comply with the IMO D-2 standard (see Table III-1) by 2012 for newly built vessels or 2016 for existing vessels. Pennsylvania originally established a two-phase discharge standard, but deleted those conditions from their 401 certification in December 2010.

The New York 401 Certification of the VGP requires all vessels to install treatment systems that meet a standard roughly equivalent to 100 times the IMO D-2 standard by 2012. Vessels constructed on or after 2013 must install systems that meet California's performance standards. However, due to a shortage in the supply of available technologies to meet the New York 401 conditions, the New York Department of Environmental Conservation issued a letter on February 16, 2012 extending the date by which vessels must comply with the standards until December 19, 2013, the end of the current VGP term.

Non-VGP State Ballast Water Programs that Include Performance Standards

Michigan

Michigan passed legislation in June 2005 (Act 33, Public Acts of 2005) requiring a permit for oceangoing vessels engaging in port operations in Michigan beginning

January 2007. Through the general permit (Permit No. MIG140000) developed by the Michigan Department of Environmental Quality (DEQ), any ballast water discharged must first be treated by one of four methods (hypochlorite, chlorine dioxide, ultraviolet radiation preceded by suspended solids removal, or deoxygenation) that have been deemed environmentally sound and effective in preventing the discharge of NIS or a vessel must certify no discharge of ballast water. In state waters, vessels must use treatment technologies in compliance with applicable requirements and conditions of use as specified by Michigan DEQ. Vessels using technologies not listed under the Michigan general permit may apply for individual permits if the treatment technology used is deemed, "environmentally sound and its treatment effectiveness is equal to or better at preventing the discharge of aquatic nuisance species as the ballast water treatment methods contained in [the general] permit," (Michigan DEQ 2006).

Minnesota

Effective July 1, 2008, Minnesota state law (S.F. 3056) requires vessels operating in state waters to have both a ballast water record book and a ballast water management plan onboard that has been approved by the Minnesota Pollution Control Agency (MPCA) (MPCA 2008). Additionally, based on the authority in Minn. Stat. 115.07, Minn. R. 7001.0020, subp. D, and Minn. R. 7001.0210, and to implement the recently enacted legislation, the MPCA approved a State Disposal System general permit for ballast water discharges into Lake Superior and associated waterways in September 2008 (MPCA 2008). Under the permit, all vessels (oceangoing and lakes-only) transiting Minnesota waters must comply with approved best management practices. No later than January 1, 2012, new vessels are required to comply with the IMO D-2 performance standards for the discharge of ballast water (see Table III-1), and existing vessels will be required to comply with those standards no later than January 1, 2016 (MPCA 2008).

Wisconsin

As of February 1, 2010, vessels that discharge ballast in Wisconsin waters must comply with the General Permit to Discharge under the Wisconsin Pollutant Discharge Elimination System. The permit was established by the Wisconsin Department of Natural Resources (WDNR) under authority provided by Chapter 283, Wisconsin Statutes. Among its provisions, the permit sets ballast water performance standards equivalent to the IMO D-2 standard. Vessels constructed on or after 2012 must meet the standard set forth in the permit. Existing vessels have until 2014 to comply.

California Legislation and the Implementation of Performance Standards

Review of Legislation

California's Marine Invasive Species Act of 2003 directed the Commission to recommend performance standards for the discharge of ballast water to the State Legislature in consultation with the State Water Resources Control Board (Water Board), the USCG and a technical advisory panel (see PRC Section 71204.9). The legislation directed that standards should be selected based on the best available technology economically achievable, and should be designed to protect the beneficial uses of the waters of the State.

In 2005, Commission staff convened a cross-interest, multi-disciplinary panel consisting of regulators, research scientists, industry representatives and environmental organizations and facilitated discussions over the selection of performance standards. Many sources of information were used to guide the performance standards selection including: biological data on organism concentrations in exchanged and un-exchanged ballast water, theories on coastal invasion rates, standards considered or adopted by other regulatory bodies, and available information on the efficacy and costs of experimental treatment technologies. Though all sources and panel members provided some level of insight, none could provide solid guidance for the selection of a specific set of standards that would reduce or eliminate the introduction and establishment of NIS. At a minimum, it was determined that reductions achieved by the selected performance standards should improve upon the status quo and decrease the discharge of viable ballast organisms to a level below quantities observed following legal ballast water exchange. Additionally, the technologies used to achieve these standards should function without introducing chemical or physical constituents to the treated ballast water that may result in adverse impacts to receiving waters. Beyond these general criteria, however, there was no concrete support for the selection of a specific set of standards. This stems from the key knowledge gap that invasion risk cannot be predicted for a particular quantity of organisms discharged in ballast water (MEPC 2003), with the exception that zero organism discharge equates to zero risk.

The Commission ultimately put forward performance standards recommended by the majority of the Panel because they encompassed several desirable characteristics: 1) A significant improvement upon ballast water exchange; 2) Representative of the best professional judgment of scientific experts that participated in the development of the IMO Convention; and 3) Approached a protective zero discharge standard. The proposed interim standards were based on organism size classes (Table III-1). The standards for the two largest size classes of organisms (greater than 50 microns in minimum dimension and 10 – 50 microns in minimum dimension) were significantly more protective than those proposed by the IMO Convention. The majority of the Panel also recommended standards for organisms less than 10 µm including human health indicator species and total counts of living bacteria and viruses. The recommended bacterial standards for human health indicator species, *Escherichia coli* and intestinal enterococci, are identical to those adopted by the EPA in 1986 for recreational use and human health safety (EPA 1986). The implementation schedule proposed for the interim standards was similar to the IMO Convention (Table III-2). A final discharge standard of zero detectable organisms was recommended by the majority of the Panel. The Commission included an implementation deadline of 2020 for this final discharge standard.

The Commission submitted the recommended standards and information on the rationale behind its selection in a report to the State Legislature in January of 2006 (see Falkner et al. 2006). By the fall of that same year, the Legislature passed the Coastal Ecosystems Protection Act (Chapter 292, Statutes of 2006) directing the Commission to adopt the recommended standards and implementation schedule through the California rulemaking process by January 1, 2008. The Commission completed that rulemaking in October, 2007 (see 2 CCR § 2291 *et seq*.).

In anticipation of the implementation of the interim performance standards, the Coastal Ecosystems Protection Act (Chapter 292, Statutes of 2006) also directed the Commission to review the efficacy, availability and environmental impacts of currently available ballast water treatment systems by January 1, 2008. The review and resultant report was approved by the Commission in December, 2007 (see Dobroski et al. 2007). Additional reviews are completed 18 months prior to the implementation dates for all other vessel classes and 18 months before the implementation of the final discharge standard on January 1, 2020 (see Table III-2 for full implementation schedule). During any of these reviews, if it is determined that existing technologies are unable to meet the discharge standards; the report is to describe why they are not available.

The first technology assessment report (Dobroski et al. 2007) determined that technologies would not be available to meet California's discharge standards for new vessels with a ballast water capacity of less than or equal to 5000 MT by the original 2009 implementation date. In response, the Legislature passed Senate Bill

1781 in 2008 (Chapter 696, Statutes of 2008). Senate Bill 1781 amended PRC Section 71205.3(a)(2) and delayed the implementation of the interim performance standards for new vessels with a ballast water capacity of less than or equal to 5000 MT for one year from January 1, 2009 to January 1, 2010. Senate Bill 1781 also required an additional assessment of available ballast water treatment technologies by January 1, 2009 (see Dobroski et al. 2009a) prior to the new 2010 implementation date. Dobroski et al. (2009a) determined that technologies that demonstrated the potential to meet California's performance standards were available. The report recommended that the Commission proceed with the initial implementation of the performance standards for new build vessels with a ballast water capacity of less than or equal to 5000 MT for January 1, 2010.

In August 2010, the Commission completed another report examining the availability of ballast water treatment systems for new build vessels (those constructed on or after January 1, 2012) with a ballast water capacity greater than 5000 MT (see California State Lands Commission 2010). The report concluded that ballast water treatment systems had demonstrated the potential to meet California's standards, and thus the Commission proceeded with implementation for this size class of vessels on January 1, 2012.

The current report reviews the availability of ballast water treatment systems for existing vessels, those constructed before January 1, 2010, with a ballast water capacity between 1500 and 5000 MT.

Implementing California's Performance Standards

Pursuant to PRC Section 71205.3, as of January 1, 2012, all newly built vessels (i.e. vessels constructed on or after January 1, 2010 with a ballast water capacity less than or equal to 5000 MT and vessels constructed on or after January 1, 2012 with a ballast water capacity greater than 5000 MT) that discharge ballast in California waters must comply with California's performance standards. Vessel construction often takes a year or more, and Commission staff has only recently seen newly built vessels arrive to California's waters that are subject to the performance standards. Thus far, no newly built vessel has discharged ballast in California, so there has been no need to take ballast water samples and assess compliance with the performance standards. Commission staff has consulted with vendors and manufacturers to determine if treatment systems have been or will be purchased for newly built vessels that will operate in California. Commission staff is aware of several vessels that have purchased systems to comply with the standards. Many other vessels in the midst of construction are leaving dedicated space for a ballast water treatment system so it may be installed at the last possible moment to ensure that the system purchased is the most current available.

The Commission does not have the practical ability to test and approve ballast water treatment systems for use in California waters. Commission staff has encouraged the shipping industry to collaborate with treatment vendors and third party testing organizations to conduct performance verification testing and determine the best treatment solution for each vessel based on the vessel's configuration and regular routes. Commission staff will focus on dockside inspection of vessels for verification of compliance with the performance standards (in accordance with PRC Section 71206). Vessel inspections will consist of both an administrative review of applicable ballast water management plans and reporting documents as well as the collection of ballast water samples for analysis and assessment of compliance with the standards.

Vessels must currently keep an up-to-date ballast water management plan on board as well as copies of all ballast water reporting forms submitted to the Commission within the past two years. The Commission's Report to the Legislature in 2009 (Dobroski et al. 2009a) recommended that additional authority be granted to the Commission to allow for the collection of specific information about the installation, use, and maintenance of ballast water treatment systems on vessels operating in California waters. This information is necessary to monitor the effective implementation of California's performance standards. In response to the recommendation in Dobroski et al. (2009a), Assembly Bill 248 (Chapter 317, Statutes of 2009) was passed in the fall of 2009, which provides the Commission with the authority to request the aforementioned information on forms developed by the Commission. Those forms, the "Ballast Water Treatment Technology Annual Reporting Form" and the "Ballast Water Treatment Supplemental Reporting Form" were adopted via regulation in November, 2010 (see 2 CCR § 2297.1).

Once Commission staff has reviewed applicable vessel paperwork, a ballast water sample will be drawn from vessels intending to discharge in California waters. California's performance standards are a discharge standard, and thus samples must be drawn from the vessel's ballast water discharge piping. Most existing vessels do not have the equipment (ports) to allow samples of ballast water to be taken from the discharge line. Therefore, the Commission developed regulations in the fall of 2009 that require vessels to install sampling ports (i.e. sampling facilities) as near to the point of discharge as practicable (2 CCR § 2297). Vessels must install the sampling ports by the same year that they must comply with California's performance standards.

The Commission is currently in the process of developing regulations for the collection and analysis of ballast water samples in order to assess compliance with the performance standards regulations. Currently no government agency or entity in the world has developed a comprehensive suite of compliance assessment protocols. Commission staff is developing these draft regulations in consultation with a technical advisory panel of state, federal and international experts in ballast water treatment system evaluation and analysis in order to adopt protocols based on the best available scientific techniques to assess viable organism concentration for each of California's standards.

One issue of public and industry concern has been the development of sampling methods and procedures that will assess vessel compliance with an acceptable level of scientific, statistical, and legal confidence (see King and Tamburri 2009). The bulk of these concerns are aimed at performance standards for the greater than 50 µm organism size class, specifically for standards that are defined as a given number of live organisms per cubic meter (e.g. IMO, USCG, EPA standards). While sampling large volumes of ballast water (i.e. many cubic meters) are necessary to attain adequate statistical confidence to verify a given number of viable organisms are indeed present in each cubic meter, this approach is not necessarily appropriate for California's performance standards. California's performance standard for the greater than 50 µm organism size class is defined as "no detectable living organisms" and is not bound by any volumetric units or the confidence limits associated with those units. Therefore Commission staff believes it is appropriate to sample as large a volume as is scientifically appropriate and logistically feasible for shipboard inspection (whether that is 50 liters, 500 liters, 5000 liters, or any volume in-between) in order to verify compliance with California's unit-less performance standard.

Keeping in mind the goals of achieving (and balancing) scientific rigor, statistical confidence, and logistical feasibility, Commission staff convened the compliance protocol technical advisory panel four times in 2011 – June, August, October and November. During the first three meetings, Staff met solely with scientists and engineers involved in technology evaluation and sample analysis. During the last meeting in November, Staff convened the larger advisory panel which included industry representatives, environmental organizations, and state and federal regulators, in addition to the scientists and engineers. An initial draft of the compliance protocol regulations was discussed at the November meeting, and copies of the notes from all meetings can be requested from Commission staff. Based on the outcome of these meetings, Commission staff drafted a rulemaking package which was submitted to the California Office of Administrative Law for publication in the Notice Register to begin the public rulemaking process. The proposed rulemaking was open for public comment from February 24 through April 17, and a public hearing was held on April 17 to discuss the draft regulations.

California's compliance assessment regulations will not only define and implement protocols so that Commission staff can assess vessel compliance with California's standards, but by establishing the protocols in regulation, they will be available as a resource for system manufacturers and vessel owners/operators so they can verify that their treatment technologies will meet California standards using the same methods that will be used by Commission personnel to assess compliance. As the precision of sampling equipment and analytical techniques improve, Commission staff will update the sampling protocols and work with the regulated community to ensure that all treatment systems in use in California are working effectively to meet California's performance standards and protect California's waters from non-native species introductions.

IV. TREATMENT TECHNOLOGY ASSESSMENT PROCESS

Public Resources Code (PRC) Section 71205.3 directs the Commission to prepare "a review of the efficacy, availability, and environmental impacts, including the effect on water quality, of currently available technologies for ballast water treatment systems" 18 months prior to each of the implementation dates, as indicated in Table III-2. In accordance with the Marine Invasive Species Act, the Commission has consulted with, "the State Water Resources Control Board, the United States Coast Guard, and the stakeholder advisory panel described in subdivision (b) of PRC Section 71204.9." This stakeholder panel also provided guidance in the development of the 2006 performance standards report to the California Legislature (Falkner et al. 2006).

As with previous legislatively mandated treatment technology assessment reports (see Dobroski et al. 2007, 2009a, California State Lands Commission 2010), Commission staff conducted an exhaustive literature search to prepare this report. Staff focused its review on recently available scientific articles, performance verification reports, and water quality impact analyses from independent testing organizations. Staff also contacted treatment technology vendors in order to gather the most up-to-date information about system development, testing, and approvals.

Due to rapid increases in the availability of new data on treatment system performance in recent years, and a desire by industry to receive updated information on the latest technology developments, Commission staff has also conducted two interim assessments of available treatment technologies. The first interim update was completed in October 2009 (Dobroski et al. 2009b) and the second update was completed in September 2011 (Dobroski et al. 2011). These interim technology updates were not legislatively mandated and were not reviewed by the technical advisory panel. Updates were intended as a resource for the Commission and stakeholders interested in ballast water treatment systems for use in California waters. Technology updates also provide Commission staff with an opportunity to begin identifying and focusing on issues of concern for the full, legislatively-mandated technology assessment reports due 18 months prior to each of the implementation dates for California's performance standards for ballast water discharge.

For the preparation of this report, Commission staff compiled available data to develop a treatment system matrix (Table V-1). This 2012 report addresses the availability of BWTS for existing vessels (those built before January 1, 2010) with a ballast water capacity between 1500 - 5000 MT, and the retrofit capability on these vessels. As with previous reports, data were summarized relative to the ballast water capacities and pump flow rates of the vessel fleet operating in California waters in order to determine if systems both meet California's performance standards and are available for this size class of vessels. Commission staff also gathered the latest available data on environmental impacts, including effects on water quality, and the economics of treatment system installation and operation. Upon completion of the data analysis, Commission staff drafted a preliminary report for review by the Commission's stakeholder advisory panel (see Appendix C for list of panel members and meeting notes), the Water Board, and USCG.

Commission staff assessed BWTS efficacy as the **potential** for a BWTS to meet California's performance standards for the discharge of ballast water. This potential was determined by reviewing the results of relevant third-party efficacy tests as provided by technology vendors, consultants, and research organizations. To demonstrate such potential, a system needed to produce results consistent with California's standards for each organism size class in one land-based or shipboard test (averaged across replicates). While this criterion is lenient in determining the availability of BWTS that can meet California standards, Commission staff pair this preliminary analysis with a more critical look at system consistency over multiple tests (see Table VI-3, California State Lands Commission 2010). In addition, shipboard tests were given more weight than land-based tests in determining system efficacy, as California's standards are discharge standards that can only practically be evaluated via shipboard sampling. In other words, shipboard test conditions more accurately reflect conditions under which any compliance evaluation in California would take place than do land-based tests. The relevant differences between shipboard and land-based testing are as follows:

1) In land-based trials, ballast water taken up is “spiked” with concentrations of organisms specified by IMO protocols that are not necessarily going to be encountered by vessels operating under normal conditions. This is reflective of the highly rigorous sampling required for Type Approval of a system, which is not comparable to onboard sampling for compliance with a discharge standard such as California’s. Public Resources Code 71205.3 specifies oceanic conditions to be avoided during ballast water uptake in order to reduce the risk of taking up high concentrations of organisms entrained in ballast water.

2) Sample volumes in land-based testing can represent entire ballast tanks, whereas shipboard verification (as for California’s performance standards) can only represent a snapshot of total discharge volumes. The results of shipboard assessments by testing facilities are therefore the most comparable to any results that California inspectors would glean from shipboard verification of discharge standards.

By assessing efficacy as the **potential** to meet California discharge standards, this report provides two useful perspectives on BWTS and their use on vessels. Commission staff has created:

1) An inclusive list of promising technologies by including any and all technologies that have demonstrated potential to treat ballast water to California’s standards, and

2) A detailed account of BWTS success rate at demonstrating potential to meet California standards. Creating an inclusive list of promising technologies ensures that this report presents the cutting edge of BWTS technology development.

Reporting the number of tests during which a system met California standards is anticipated to assist the regulated community in selecting a BWTS suited to their vessel's unique needs. This report provides no *a priori* guarantee that a system will meet California's standards once installed on a vessel, as all vessels operate on different routes and under different biological, chemical and physical conditions that may influence ballast water treatment system operation. California law requires that vessel owners/operators, who know the particulars of their vessels, ensure that vessel discharges comply with California's performance standards for the discharge of ballast water and applicable water quality laws, regulations and permits.

Treatment systems were also assessed regarding their environmental impacts and retrofit capabilities. Commission staff assessed environmental impacts by summarizing whether a system utilizes active substances to kill or remove organisms, the type(s) of active substance(s) used, and whether the system has received relevant approvals for pollutant discharges from the IMO. Staff also determined whether available BWTS conformed to the standards for pollutant discharges set out by the USEPA Vessel General Permit and conditions established by the California Section 401 certification of that permit. To assess retrofit capability, Commission staff developed and distributed a questionnaire for BWTS vendors and selected marine engineers that included questions regarding the space and power requirements of the BWTS, and whether the vendor had yet received or completed any retrofit orders. A copy of this questionnaire is provided in Appendix B, and the responses to these questions are summarized in Table VI-4.

V. TREATMENT TECHNOLOGIES

The goal of ballast water treatment is to remove or kill organisms in ballast water

Ballast water treatment systems must be capable of eradicating a wide variety of organisms in order to prevent species introductions. Organisms in unmanaged ballast water that must be removed or killed include viruses, bacteria, free-swimming plankton (microscopic plants and animals), as well as larger species. The wide variety of vessel types, shipping routes, and port geographies has further complicated the development of treatment technologies. Shipping routes and port geographies, for example, influence the water quality, sediment loads, and organisms that a ship might take up with ballast water.

Wastewater treatment technologies have been in use for many years, but transferring the necessary equipment to mobile, space- and energy-limited vessels has proven challenging. Species compositions are also different in ballast water than in municipal wastewater. A shipboard ballast water treatment system must be effective under a wide range of environmental conditions, including variable temperature, salinity, nutrient concentrations, and suspended solids. It must also function under difficult operational constraints including high flow-rates of ballast water pumps, large water volumes, and variable retention times (time ballast water is held in a ballast tank).

Shoreside ballast water treatment could be an emerging alternative to shipboard treatment

Two general platform types have been explored for the development of ballast water treatment technologies: Shoreside treatment facilities and shipboard treatment systems. Shoreside treatment facilities include barge- or land-based facilities that treat ballast water after it has been transferred from a vessel. Shipboard treatment occurs on a vessel through the use of technologies integrated into the ballasting system. Shipboard treatment systems are broadly applicable because they allow flexibility to manage ballast water during normal operations, while shoreside treatment might be a good option for vessels with small ballast water capacities and/or dedicated port calls.

Shoreside treatment of ballast water is an appealing option, particularly from a regulatory perspective. Permitting and inspection of a fixed shoreside facility is significantly easier than the regulation of discharges from mobile point sources such as vessels. Shoreside treatment also provides an option for treatment technologies and methods that are not feasible onboard vessels due to space and/or energy constraints, such as reverse osmosis. Instead of ships' crew, who may not be specifically trained in the operation and maintenance of water treatment facilities, shoreside facilities could be operated by specially trained wastewater engineers. Additionally, if ballast water exchange is prevented by ocean conditions or a shipboard treatment system fails, shoreside or barge-mounted treatment facilities could provide an important back-up location where unmanaged ballast water could be held or treated. Shoreside treatment facilities could also be equipped to allow vessels to exchange untreated ballast water for treated, "clean" ballast water. This would require treatment facilities to be present at ports (Tsolaki and Diamadopoulos 2010).

However, shore side treatment poses several challenges. Vessels must have the appropriate piping or attachment mechanism to establish a connection with a shoreside facility. An international standard would be useful to design these connections to ensure that ships could connect to shoreside facilities all over the world, and the cost of these retrofits could be prohibitive (CAPA 2000). Additionally, vessels must be able to discharge ballast at a rate that prevents vessel delays.

If existing municipal facilities are to be used for the purposes of ballast water treatment, they will need to be modified. Wastewater treatment plants are not designed to treat saline water (Water Board 2002, Moore, S. pers. comm. 2012). Furthermore, a new extensive network of piping and associated pumps would be required to distribute ballast water from vessels at berth to the treatment plants. The establishment of new piping and facilities dedicated to ballast water treatment, while technically feasible, would require the acquisition of land for facility construction. New land acquisition would be difficult and costly in California's densely populated coastal and port areas. Additionally, shoreside treatment is not feasible for vessels that must take on or discharge ballast water while underway. For example, some vessels need to adjust ballast water to navigate through shallow channels or under bridges.

To date, limited studies have been conducted regarding the feasibility of shoreside ballast water treatment (see references in Falkner et al. 2006, USEPA SAB 2011). A study by McMullin et al. (2008) assessed the feasibility of shoreside treatment at the Port of Milwaukee. The authors concluded that shoreside treatment is a feasible alternative to shipboard treatment, but only under certain conditions. In addition to a universal standard for retrofitted ballast water piping connections to shoreside pumps, procedures would need to be developed for each vessel to maintain its stability and ensure safe deballasting rates during cargo loading. The authors caution against extrapolation of the report's conclusions to port areas outside Milwaukee, however, as each region presents unique sets of challenges.

In California, shoreside treatment might be an appropriate option for unique terminals such as those with limited but regular vessel calls (e.g. cruise ships and barges), though one study specific to cruise ships indicated that because cruise ships rarely deballast in California there is little demand for shoreside treatment except in emergencies (Bluewater Network 2006). Additional studies are necessary to determine the feasibility of and demand for shoreside facilities for other vessel types and across California as a whole. These might include assessments by those involved in the wastewater treatment sector on whether existing technologies could meet California's performance standards.

Prior to the completion of the 2010 ballast water treatment technology assessment report (see California State Lands Commission 2010), Commission staff was contacted by a company interested in developing a barge-based reception facility for use in California and along the west coast. This company was contacted again prior to the 2012 report, and has ceased development of this type of facility. As of the writing of this report, no barge- or land-based facilities are yet available in California.

The vast majority of time, money, and effort in the development of ballast water treatment technologies during recent years have been focused on shipboard treatment systems. For this reason, we focus on shipboard treatment systems for the remainder of this report.

Shipboard treatment systems utilize mechanical, chemical, physical, biological, and combination technologies to remove and/or kill organisms in ballast water

At the root of many ballast water treatment systems are technologies already in use to some degree by the wastewater treatment industry. A preliminary discussion of these treatment technologies follows and forms the basis of a more detailed analysis and discussion of treatment systems. The diverse array of methods currently under development for use in the treatment of ballast water fall into four general categories: mechanical, chemical, physical, and biological treatments. These methods are typically combined in some manner to maximize system efficacy.

Mechanical Treatment

Mechanical treatments are those that trap and remove mid- to large-sized particles from ballast water. Mechanical treatment typically takes place upon ballast water uptake in order to limit the organisms and sediment that enters ballast tanks. Filtration and hydrocyclonic separation are the two most common mechanical treatment methods.

Filtration captures organisms and particles as water passes through a porous screen or filtration medium, such as sand or gravel. The size of organisms trapped by the filter depends on the mesh size (for screen or disk filters), or on the size of the interstitial space for filtration media. Screen and disk filters are more commonly used than filtration media, though there has been some research on the use of crumb rubber as a filtration medium in recent studies (Tang et al. 2006, 2009). Typical mesh sizes for ballast water filters range from 25 to 100 micrometers (μm) (Parsons and Hawkins 2002, Parsons 2003). Most filtration-based technologies also use a backwash process that removes organisms and sediments that can clog filters. Backwash systems can discharge particles and organisms at the port of origin before the vessel is underway. Filter efficiency is a function not only of initial mesh size, but also of water flow rate and backwashing frequency. Some technology developers utilize proprietary technology to clean filters without backwashing (American Bureau of Shipping, 2011).

Hydrocyclonic separation, also known as centrifugation, relies on density differences to separate organisms and sediment from ballast water. Hydrocyclones create a vortex that causes heavier particles to move toward the outer edges of the cyclonic flow where they are trapped in a weir-like device and can be discharged before entering the ballast tanks (Parsons and Harkins 2002). Hydrocyclones used in ballast water treatment generally trap particles in the 50 to 100 μm range (Parsons and Harkins 2002). One challenge associated with hydrocyclone use, however, is that many small aquatic organisms have a density similar to seawater and are thus difficult to separate.

Chemical Treatment

A variety of chemicals (i.e. active substances) are available to kill organisms in ballast water. While the vast majority of chemicals are biocides, some chemicals function to clump or coagulate organisms in order to assist with their mechanical removal. Chemical treatment can take place during ballast uptake, vessel transit, or discharge. Chemicals can be stored onboard in liquid or gas form, or they can be generated on demand through electrochemical processes.

Chemicals used in ballast water treatment are either oxidizing or non-oxidizing. Oxidizing agents (e.g. chlorine, chlorine dioxide, bromine, hydrogen peroxide, peroxyacetic acid, ozone) are commonly used in the wastewater treatment sector and work by destroying cell membranes and other organic structures (National Research Council 1996, Faimali et al. 2006). Electrochemical oxidation combines electrical currents with naturally occurring reactants in seawater and/or air (e.g. salt, oxygen) to produce killing agents. For example, electrochemical oxidation can produce products such as hydroxyl radicals, ozone or sodium hypochlorite that are capable of damaging cell membranes. Non-oxidizing biocides, including Acrolein ®, gluteraldehyde, and menadione (Vitamin K3), are reported to work like pesticides by interfering with an organism's neural, reproductive, or metabolic processes (National Research Council 1996, Faimali et al. 2006).

Ultimately, chemicals used in ballast water treatment should maximize organism mortality while minimizing environmental impact. Environmental concerns surrounding chemical use in ballast water focus on the impacts of residuals or byproducts in treated discharge on receiving waters. The effective use of chemicals in ballast water treatment requires a balance between the amount of time required to achieve an inactivation of organisms, with the time needed for those chemicals and residuals to degrade or be neutralized to environmentally acceptable levels. Both of these times vary as a function of ballast water temperature, salinity, organic content, and sediment load. As a result, certain chemicals might be more effective than others depending on ballast volume, voyage length, and water quality conditions. Additional concerns about chemical use specific to shipboard operation include corrosion of metals, personnel and ship safety, and vessel design limitations that impact the availability of space onboard for both chemical storage and equipment for dosing.

Physical Treatment

Physical treatment methods include a range of non-chemical means to kill organisms in ballast water. Like chemical treatment, physical treatment can occur on ballast uptake, during vessel transit, or during discharge. Heat, UV, ultrasound, cavitation, and deoxygenation are all physical treatment methods used in current ballast water treatment technologies.

Rigby et al. (1999, 2004) discuss the use of waste heat from the ship's main engine as a mechanism to heat ballast water and kill unwanted organisms during vessel transit. However, it would be difficult to heat ballast water to a sufficient temperature to kill all bacterial species due to lack of sufficient energy/heat available on a vessel (Rigby et al. 1999, 2004). An alternative involves the use of microwaves, though as of 2010 such a treatment would be prohibitively expensive (up to \$2.55/m^3). Additional research and development could reduce costs to acceptable levels (Balasubramadian et al. 2008, Boldor et al. 2008).

Ultraviolet (UV) irradiation is another physical method of sterilization that is commonly used in waste water management. UV damages genetic material and proteins, disrupting reproductive and physiological processes, and can be highly effective against pathogens (Wright et al. 2006). Both low-pressure and medium-pressure UV systems have been used to treat ballast water on vessels. The pairing of UV light and a catalyst (e.g. titanium dioxide) results in an advanced oxidative process that generates hydroxyl radicals – an effective killing agent.

Ultrasound (or ultrasonic treatment) kills through high frequency vibration that creates microscopic bubbles. These bubbles rupture cell membranes (Viitasalo et al. 2005). The efficacy of ultrasound varies based on the intensity of vibration and length of exposure. Cavitation is another physical treatment method that uses mechanical forces to generate and collapse microscopic bubbles that crush or implode organisms in ballast water. Deoxygenation involves the displacement or "stripping" of oxygen with another inert gas such as nitrogen or carbon dioxide. This process is primarily physical in nature, although the addition of carbon dioxide might trigger a chemical response that would reduce ballast water pH (Tamburri et al. 2006).

Biological Treatment

The least common method of ballast water treatment involves the use of organisms to directly kill or produce conditions that will kill potential NIS present in ballast water. These treatment organisms are considered an "active substance" according to the IMO definition (IMO 2005). One example of biological treatment is the use of yeast to produce low-oxygen (hypoxic) conditions in ballast tanks. Yeast cells extract the available oxygen in the ballast water tank during cell replication (Bilkovski, R. pers. comm. 2008). The resultant hypoxic environment is toxic to many of the remaining organisms in the ballast tank, though some organisms are resistant to hypoxic conditions. Vendors of biological treatment systems will likely need to address how systems will meet the performance standards as the organisms responsible for producing the desired killing effect on NIS could trigger non-compliance if detected at sufficient levels in the discharged ballast. This is because yeast cells used by such systems could themselves become invasive if released in ballast water discharges.

Combination of Treatment Methods

The vast majority of ballast water treatment technologies kill organisms by combining mechanical, chemical, physical, and/or biological treatment methods. Any single treatment method might not be sufficient to treat ballast water to required standards, but in combination the methods produce the desired result. For example, while filtration is rarely sufficient to remove organisms of all size classes from ballast water, and UV irradiation might be insufficient to deactivate dense clusters of organisms, paired together they could be an effective method of ballast water treatment. The most common combined treatment methods pair mechanical removal with physical or chemical processes.

Commission staff reviewed sixty-three BWTS for this report, most of which utilize a combination of treatment methods

For this report, Commission staff compiled and reviewed information on 63 shipboard ballast water treatment systems (Table III-1, Figure V-1). In the 5 years since the first Commission ballast water treatment technology assessment report (see Dobroski et al. 2007), staff has seen more than a doubling of the number of treatment systems under development (from 28 in 2007 to 63 in 2012). Over the same time period, the number of these treatment systems that have received Type Approval according to the IMO G8 Guidelines has jumped from 1 in 2007 to 22 in 2012 (see Figure V-1).

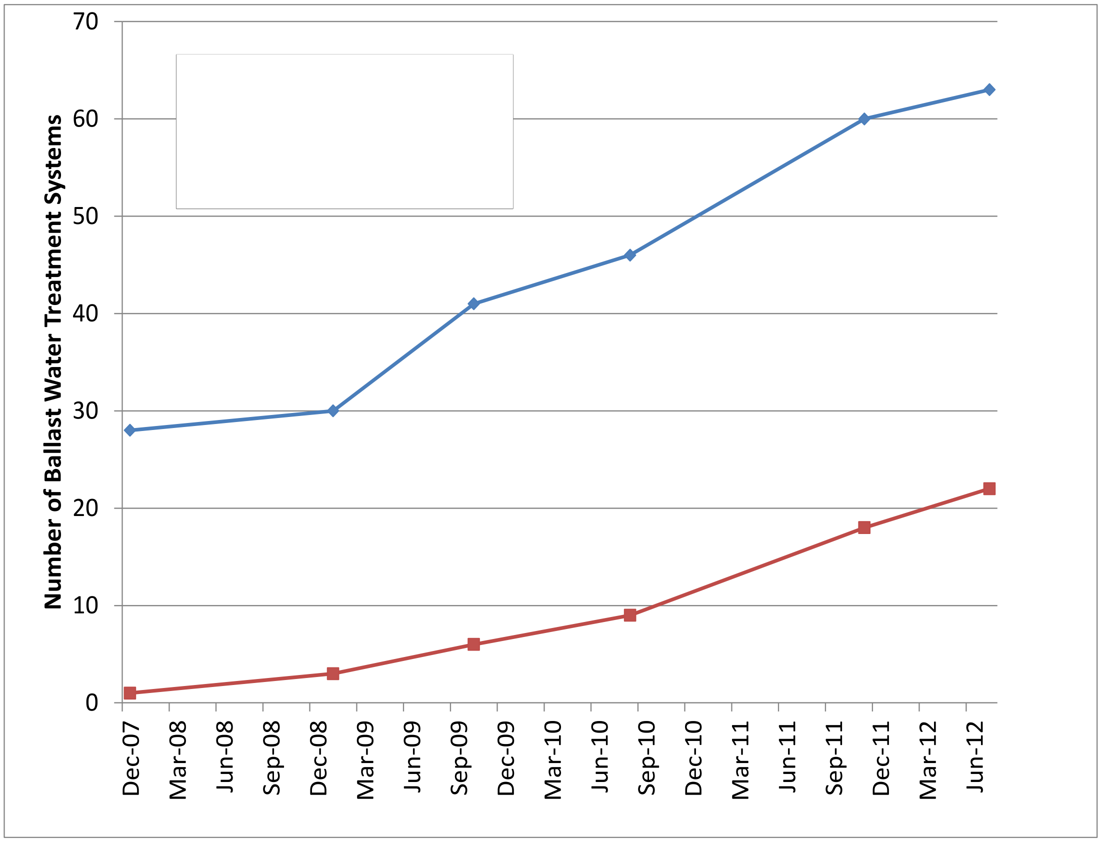

Figure V-1. The number of treatment systems reviewed by Commission staff during each of the Commission's treatment technology assessment reports and updates. The number of systems with Type Approval (IMO) is also shown.

Over 75% (=48) of the treatment systems reviewed here utilize a combination of treatment methods, the majority of which combine mechanical treatment with another treatment method(s). Aside from mechanical separation, the most common method used in ballast water treatment systems is chemical. Of the 63 systems reviewed, 41 use an active substance in the treatment process (Table V-1). Specifically:

- 18 systems use electrolysis which may generate an array of oxidants including bromine, chlorine, and/or hydroxyl radicals
- 6 systems use the electrochemical generation of sodium hypochlorite
- 6 systems use ozone
- 2 systems use Peraclean Ocean

- 2 use chlorine (not electrically generated)
- 1 system uses chlorine dioxide
- 1 system uses ferrate
- 5 systems use other chemicals including a coagulant or biocides not identified at this time

All of the systems that use active substances require IMO Basic and Final Approval prior to operating in compliance with the IMO Convention. These systems must also comply with all applicable requirements of the EPA Vessel General Permit and California Section 401 Certification of the VGP.

The next most commonly used method of ballast water treatment amongst the systems reviewed is UV irradiation. Eighteen (18) treatment systems use UV as a means to kill or deactivate organisms found in ballast water. All of these systems combine UV treatment with filtration and/or hydrocyclonic mechanical separation methods. Five of these systems have an additional treatment step involving another physical or chemical process.

Only five systems use deoxygenation as a treatment method. Other approaches to ballast water treatment include a heat treatment technology and one that uses electrical pulses to kill organisms (Table V-1).

Table V-1. Ballast Water Treatment Systems Reviewed by Commission Staff

Manufacturer	***Country***	***System Name***	***Technology Type***	***Technology Description***	***Approvals***
21st Century Shipbuilding Co. Ltd.	Korea	ARA Ballast	combination	filtration + plasma + UV	IMO Basic and Final
Alfa Laval	Sweden	PureBallast 2.0/2.0 Ex	combination	filtration + advanced oxidation technology (UV + TiO_2)	IMO Basic and Final, Type Approval (Norway)
AQUA Eng. Co. Ltd.	Korea	AquaStar™ BWMS	combination	filtration + electrolysis + neutralization (sodium thiosulfate)	IMO Basic and Final
Aquaworx ATC GmbH	Germany	AquaTriComb™	combination	filtration + ultrasound + UV	IMO Basic
ATLAS-DANMARK	Denmark	ABWS	combination	filtration + electrolysis (ANOLYTE + CATHOLYTE)	
Auramarine Ltd.	Finland	CrystalBallast	combination	filtration + UV	
Brillyant Marine, LLC	USA	BrillyantSea™	physical	electric pulse	
Coldharbour Marine Ltd.	United Kingdom	Coldharbour BWTS	physical	deoxygenation	
China Ocean Shipping Company (COSCO)	China	Blue Ocean Shield	combination	hydrocyclone + filtration + UV	IMO Basic[2], Type Approval (China)
Dalian Maritime University Environment Engineering Institute (DMU-EEI)	China	DMU ·OH BWMS	combination	filtration + active oxygen radicals and ions + neutralization (sodium thiosulfate)	IMO Basic

Table V-1. Ballast Water Treatment Systems Reviewed by Commission Staff

Manufacturer	***Country***	***System Name***	***Technology Type***	***Technology Description***	***Approvals***
DESMI Ocean Guard A/S	Denmark	DESMI Ocean Guard BWTS	combination	filtration + ozone + UV	IMO Basic
Ecochlor	USA	Ecochlor® BWTS	combination	filtration + biocide (chlorine dioxide)	IMO Basic and Final, STEP[1], Type Approved (Germany)
EcologiQ	USA/Canada	BallaClean	biological	deoxygenation	
Electrichlor	USA	Model EL 1-3 B	chemical	electrolytic generation of sodium hypochlorite	
Environmental Technologies Inc.	USA	BWDTS	combination	ozone + sonic energy	
Envirotech and Consultancy Pte. Ltd.	Singapore	BlueSeas BWMS	combination	filtration + electrolysis + neutralization (sodium thiosulfate)	IMO Basic
Envirotech and Consultancy Pte. Ltd.	Singapore	BlueWorld BWMS	combination	filtration + electrolysis + neutralization (sodium thiosulfate)	IMO Basic
ERMA FIRST ESK Engineering Solutions S.A.	Greece	ERMA FIRST BWTS	combination	filtration + hydrocyclone + electrolysis + neutralization (sodium bisulfite)	IMO Basic and Final
Ferrate Treatment Technologies LLC	USA	Ferrator	chemical	biocide (ferrate)	

Table V-1. Ballast Water Treatment Systems Reviewed by Commission Staff

Manufacturer	***Country***	***System Name***	***Technology Type***	***Technology Description***	***Approvals***
GEA Westfalia Separator Group GmbH	Germany	BallastMaster BWMS	combination	filtration + electrolysis + neutralization (sodium thiosulphate)	IMO Basic
Hamworthy Water Systems Ltd.	Netherlands	AQUARIUS™ -EC BWMS	combination	filtration + electrolysis + neutratlization (sodium bisulfite)	
Hamworthy Water Systems Ltd.	Netherlands	AQUARIUS™ UV	combination	filtration + UV	
Hanla IMS Co., Ltd.	Korea	EcoGuardian™	combination	filtration + electrochlorination + neutralization (sodium thiosulfate)	IMO Basic
Hi Tech Marine	Australia	SeaSafe-3	physical	heat treatment	New South Wales EPA
JFE Engineering Corp.	Japan	JFE BallastAce	combination	filtration + biocide (sodium hypochlorite)[2] + cavitation + neutralizing agent (sodium sulfite)	IMO Basic and Final, Type Approval (Japan)
Katayama Chemical Inc.	Japan	SKY-SYSTEM	chemical	biocide (Peraclean® Ocean) + neutralization (sodium sulfite)	IMO Basic
KT Marine Co., Ltd.	Korea	KTM-BWMS	combination	cavitation + electrolysis + neutralization (sodium thiosulfate)	

Table V-1. Ballast Water Treatment Systems Reviewed by Commission Staff

Manufacturer	***Country***	***System Name***	***Technology Type***	***Technology Description***	***Approvals***
Kuraray Co. Ltd.	Japan	MICROFADE™ BWMS (formerly Kuraray BWMS)	combination	filtration + biocide (calcium hypochlorite) +neutralizing agent (sodium sulfite)	IMO Basic and Final
Kwang San Co. Ltd.	Korea	En-Ballast	combination	filtration + electrolysis + neutralizing agent (sodium thiosulfate)	IMO Basic
MARENCO Tech. Gr.	USA	MARENCO BWTS	combination	filtration + UV	
Maritime Solutions Inc.	USA	MSI BWTS	combination	filtration + UV	
Mexel Industries	France	Mexel®	chemical	non-oxidizing biocide	
MH Systems	USA	MH BWT System	combination	deoxygenation (inert gas + CO_2)	
Mitsui Engineering and Shipbuilding	Japan	SPO-SYSTEM	combination	filtration + mechanical treatment + biocide (Peraclean Ocean)	IMO Basic (from Peraclean MEPC 54)
Mitsui Engineering and Shipbuilding	Japan	FineBallast MF	physical	pre-filtration + microfiltration (membrane)	
Mitsui Engineering and Shipbuilding	Japan	FineBallast® OZ (formerly SP-Hybrid BWMS Ozone)	combination	filtration + mechanical treatment + ozone + neutralization	IMO Basic and Final, Type Approval (Japan)
NEI	USA	Venturi Oxygen Stripping (VOS)	combination	deoxygenation + cavitation	Type Approval (Liberia, Malta, Marshall Islands, Panama), STEP[1]

Table V-1. Ballast Water Treatment Systems Reviewed by Commission Staff

Manufacturer	***Country***	***System Name***	***Technology Type***	***Technology Description***	***Approvals***
Ntorreiro	Spain	Ballastmar	combination	filtration + electrochlorination + neutralization (sodium metabisulphite)	
OptiMarin	Norway	OptiMarin Ballast System	combination	filtration + UV	Type Approval (Norway)
Pinnacle Ozone Solutions	USA	Aquatic enhancement system	combination	filtration + ozone + UV	
RWO Marine Water Technology	Germany	CleanBallast	combination	filtration + electrolysis + neutralization (sodium thiosulfate)	IMO Basic and Final, Type Approval (Ger.)
Samsung Heavy Industries Co., Ltd.	Korea	Purimar™ BWMS	combination	filtration + electrolysis + neutralization (sodium thiosulfate)	IMO Basic and Final, Type Approval (Korea)

Table V-1. Ballast Water Treatment Systems Reviewed by Commission Staff

Manufacturer	***Country***	***System Name***	***Technology Type***	***Technology Description***	***Approvals***
Samsung Heavy Industries Co. Ltd.	Korea	Neo-Purimar™ BWMS	combination	filtration + electrolysis + neutralization (sodium thiosulfate)	IMO Basic and Final
Sea Knight	USA	INSITU BWMS	combination	deoxygenation + biological augmentation	
Severn Trent De Nora	USA	BALPURE®	chemical	filtration + electrochlorination + neutralizing agent (sodium bisulfite)	IMO Basic and Final, STEP[1], Type Approval (Ger.)
Siemens	Germany	SiCure™	combination	filtration + electrochlorination	IMO Basic and Final
STX Metal Co. Ltd.	Korea	Smart Ballast	chemical	electrolysis + neutralization (sodium thiosulfate)	IMO Basic
Sumitomo Electric Industries, Ltd.	Japan	SEI-Ballast System	combination	filtration + UV	
Sunrui Marine Environment Eng. Co.	China	BalClor™ BWMS	combination	filtration + electrochlorination + neutralizing agent (sodium thiosulfate)	IMO Basic and Final, Type Approval (China)
Techcross Co. Ltd.	Korea	Electro-Cleen™ System	chemical	electrolysis + neutralizing agent (sodium thiosulfate)	IMO Basic and Final, Type Approval (Korea)
Wärtsilä Corporation	Finland	Wartsila BWTS	combination	filtration + UV	

Table V-1. Ballast Water Treatment Systems Reviewed by Commission Staff

Manufacturer	***Country***	***System Name***	***Technology Type***	***Technology Description***	***Approvals***

[1] STEP is a USCG experimental use approval that applies to the combination of one vessel and one treatment system. While STEP enrollment includes a rigorous technical and environmental screening it is not a type approval process.

[2] Based on MEPC 59/24 – administrations may determine if BWMS that make use of UV light produce Active Substances. China does not believe this system uses Active Substances, so Final Approval is not necessary.

VI. ASSESSMENT OF TREATMENT SYSTEMS

The California Coastal Ecosystems Protection Act required the adoption of regulations to implement performance standards for the discharge of ballast water. The Act does not, however, prescribe how these standards are to be met. Vessel owners and operators understand the unique needs and capabilities of their ships, and can select from a variety of ballast water management strategies to ensure that all ballast water discharged is compliant with California's performance standards. One option is to retain all ballast onboard while in California waters. Over 80% of voyages to California ports report that they do not discharge ballast into California waters (Takata et al. 2011). Vessels that do discharge but use nontraditional sources for ballast water (such as freshwater from a municipal source) will likely meet the discharge standards without needing to use ballast water treatment systems (BWTS). Alternatively, vessels may discharge to barge- or land-based reception and treatment facilities, where available. Vessels that utilize riverine, estuarine, coastal or ocean water as ballast and discharge that ballast into California waters, however, will likely require ballast treatment prior to discharge. For vessels that will require a BWTS, an assessment of treatment system efficacy, availability and environmental impacts (as required by PRC Section 71205.3(b)) is necessary to summarize the biological and environmental aspects of available and developing systems.

Efficacy

Treatment system performance, or efficacy, is defined for purposes of this report as the extent to which a system removes or kills organisms in ballast water. Commission staff focused on the ability of available treatment systems to meet or exceed California's performance standards for the discharge of ballast water (see Table III-1 for performance standards), which will apply to all new and existing vessels that utilize ballast water in shipboard operations as of January 1, 2016. This report specifically targets existing vessels with a 1500-5000 metric ton ballast water capacity which will be required to comply with the California discharge standards as of January 1, 2014.

Since the first technology assessment report was submitted to the California Legislature in 2007, Commission staff has seen rapid growth in the availability and quality of performance verification data gathered by independent, scientific testing organizations. These independent reports generally provide the most robust and comprehensive review of system performance and environmental acceptability. Commission staff continues to work with vendors and testing organizations to encourage further standardization of data analysis and presentation.

In the current report, Commission staff provides the California Legislature and interested stakeholders with all available sources of information on treatment technology development and operation. Unless otherwise indicated, third-party data from all testing scales and locations (land-based and shipboard) are presented in the main report. To determine the success rates with which systems can treat ballast water to California's standards, only third-party data were used. Vendor provided laboratory data are provided in Appendix A, along with a more detailed account of third-party test results. In all instances, citations are provided for the original data sources. This information is provided so that interested parties can review and evaluate all of the available data and data sources in order to make an informed decision about whether a treatment system may or may not be sufficient for their needs.

Due to the limitations of available data, and the variable conditions present in the "real world," this report presents whether or not systems have demonstrated the **potential** to comply with California's performance standards. The Commission and its staff do not have the practical ability to test and approve treatment systems for operation in California waters, nor the legal authority to do so. Positive assessment for the purpose of this report does not guarantee system compliance during operation in California, nor does the report suggest or imply system approval. Vessel owners and operators are ultimately responsible for complying with California's performance standards for the discharge of ballast water.

Commission staff was able to collect efficacy data for 34 of the 63 treatment systems reviewed in this report (Tables V-1, Appendix A). With the exception of the evaluation of system performance for inactivating *Vibrio cholerae*, laboratory data were not used for evaluation purposes in this report because of the large difference in scale between the laboratory, land-based, and shipboard investigations. As in the Commission's 2011 technology update (Dobroski et al. 2011), this report differentiates between data collected for research and development (R&D) and data collected by third-parties for Type Approval purposes. Third-party data appear in the body of this report, though some vendors also provided data collected for R&D purposes (these data are included in Appendix A). Third-party efficacy data are given more weight in this report in part because they represent the performance of a finalized system design available for sale. The EPA SAB report (SAB 2011) notes that not all data can be considered "reliable", and defines reliable data as consisting of both methods and results from land-based and shipboard tests. Commission staff agree with this definition, and thus for this report only consider systems that can provide methods and results of third-party tests gathered as part of the Type Approval process when evaluating system success rates. Tables that do include vendor-collected data are indicated as such. Many systems demonstrated potential to treat ballast water to California's standards, defined as a system meeting these discharge standards during at least one efficacy test (averaged across replicates). These data are summarized in Table VI-1.

In the particular case of California's standard of 0.01 living organisms per milliliter for organisms in the 10 – 50 micron size category, Commission staff recognizes that detection limits of the best available methods cannot yet reliably attain the required level of accuracy. Therefore, while Commission staff does report when systems show a potential to meet this standard, the level of uncertainty that accompanies this potential is such that more data conducted using more sensitive methods and design are necessary for a more appropriate evaluation of this standard.

Table VI-1. Systems with potential to treat ballast water at levels that meet or exceed each of California's statutory performance standards, separated by size class. This table includes ALL systems that met or exceeded California standards in one test (third party or vendor-collected) averaged across replicates. Organisms in the bacteria category were examined using culturable heterotrophic bacteria as a proxy for total bacteria. This table is provided to allow assessment of which size classes present the greatest challenges to treatment system developers.

	Organism size class					
	>50 microns	**10 - 50 microns**	**Bacteria (<10 microns)**	***E. coli***	**Intestinal enterococci**	***Vibrio cholerae***
Total # systems with data available	32	31	28	32	31	31
# systems with potential to meet standard	26	21	19	31	30	28

As of March 2012, Commission staff confirmed that 13 systems available on the market have demonstrated the potential to comply with California's ballast water discharge standards for all organism size classes (Table VI-2). As in the Commission's 2010 technology assessment report (see California State Lands Commission 2010), systems with at least one test (averaged across replicates) at either land-based or shipboard scale in compliance with California's performance standards are scored with a "Y." Systems with no tests demonstrating potential compliance are scored with an "N." Systems that presented data for a given size class in metrics not comparable to California standards are classified as "Unknown." Cells with hashing indicate that data were not available. The source(s) of the data for each system can be found in the Literature Cited section. See Appendix A for all laboratory data and for specifics about the land-based and shipboard testing data, including the number of tests and replicates performed for each system. Table VI-2 is provided as a summary, and does not reflect system success rates that will appear in Table VI-3.

Table VI-2. Systems that show **potential** to comply with California standards for each size class of organisms in ballast water. Blank cells indicate that no data were available. Where manufacturers also provided information on BWTS efficacy in freshwater trials, this is indicated in the table. A positive "Y" indication for an organism size class reflects that at least one land-based or shipboard test (averaged across replicates), met California's performance standards for discharge of ballast water. References are listed in the Literature Cited section. An asterisk (*) indicates that some information on this system was collected by system developers for research and development purposes. All other system data were collected by third-party testing organizations or vetted through the IMO MEPC.

Manufacturer	> 50 µm	10 µm - 50 µm	<10 µm Bacteria	*E. coli*	Enterococci	*V. cholerae*	References
21 Century Shipbuilding	Y	N		Y[1]	Y[1]	Y[1]	148
AQUA Eng. Co. Ltd.	N	Y		Y[1]	Y[1]	Y[1]	149, 150
Alfa Laval - freshwater	N	N	N	Y	Y		61, 170, 173, 176
Alfa Laval - land 2.0	Y	Y	N	Y	Y	Y[1]	61, 170, 173, 176
Alfa Laval - ship 1.0	Y	Y	Y	Y[1]	Y[1]	Y[1]	61, 170, 173, 176
Auramarine Ltd. – land	N	Y	Y	Y[1]	Y	Y[1]	177
COSCO				Y	Y	Y	124, 153
DESMI - land	Y	N	Y	Y	Y	Y	29, 133
DESMI - ship	Y						29, 133
Ecochlor - land	Y	Y	Y	Y	Y	Y[2]	54, 116, 162
Ecochlor - ship	Y	Y		Y	Y	Y[1]	54, 116, 162
ERMA FIRST - land	Y	Y	N	Y[1]	Y		55, 56, 166
ERMA First - ship	N				Y		55, 56,166
ETI*		N	N				91, 92, 93, 94
Hi Tech Marine*	N		Y	Y			66
Hyundai Hvy. Ind. EcoBall.	Y	Y		Y[1]	Y[1]	Y[1]	134, 139
Kwang San Co. Ltd.	N	N	Y	Y	Y	Y[1]	136, 140
Maritime Solutions Inc.	N	N	Y	Y	Y	Y[1]	98, 146
MAHLE Industriefiltration - land	Y	Y	Y	Y	Y		52, 165

Table VI-2 continued. Systems that show **potential** to comply with California standards for each size class of organisms in ballast water. Blank cells indicate that no data were available. Where manufacturers also provided information on BWTS efficacy in freshwater trials, this is indicated in the table. A positive "Y" indication for an organism size class reflects that at least one land-based or shipboard test (averaged across replicates), met California's performance standards for discharge of ballast water. References are listed in the Literature Cited section. An asterisk (*) indicates that some information on this system was collected by system developers for research and development purposes. All other system data were collected by third-party testing organizations or vetted through the IMO MEPC.

Manufacturer	> 50 µm	10 µm - 50 µm	<10 µm Bacteria	*E. coli*	Enterococci	*V. cholerae*	References
MAHLE Industriefiltration - ship	Y	Y	Y	Y	Y	Y	52, 165
MARENCO - land	Y	N	Y				83, 84, 229
Mitsui Eng. SP Hybrid*	N						72, 74, 75
Mitsui Eng. FineBallast*	Y				Y		72, 74, 75
Qingdao Headway Tech. - land	Y	Y	Y	Y[1]	Y[1]	Y[1]	141, 175
Qingdao Headway Tech. - ship	Y	Y	Y	Y[1]	Y[1]	Y[1]	141, 175
Hamworthy Aquarius UV, Land	N	Y	Y	Y	Y	Y	57, 58
Hyde Marine - land	Y	N	Y	Y[1]	Y[1]		163, 231
Hyde Marine - ship	Y	Y	Y	Y[1]	Y[1]	Y[1]	163, 231
JFE Eng.Corp. - ship	Y	Y		Y	Y	Y[1]	49
NEI – land	Y	N	N	N	N		208, 210
NEI – ship	Y		N	Y[1]		Y[1]	208, 210
NK-03 – ship	Y	Y	Y	Y	Y[1]	Y[1]	81
Nutech 03 Inc. - land	N	N	Y				65
Nutech 03 Inc. - ship	Y	N	Y	Y[1]	Y[1]	Y[1]	234
OceanSaver - land	Y	Y	Y	Y[1]	Y[1]	Y[1]	114, 171
OceanSaver - ship	Y			Y[1]	Y[1]	Y[1]	114, 171
OptiMarin - land	Y	Y	Y	Y[1]	Y[1]	Y[1]	168, 172

Table VI-2 continued. Systems that show **potential** to comply with California standards for each size class of organisms in ballast water. Blank cells indicate that no data were available. Where manufacturers also provided information on BWTS efficacy in freshwater trials, this is indicated in the table. A positive "Y" indication for an organism size class reflects that at least one land-based or shipboard test (averaged across replicates), met California's performance standards for discharge of ballast water. References are listed in the Literature Cited section. An asterisk (*) indicates that some information on this system was collected by system developers for research and development purposes. All other system data were collected by third-party testing organizations or vetted through the IMO MEPC.

Manufacturer	> 50 µm	10 µm - 50 µm	<10 µm Bacteria	*E. coli*	Enterococci	*V. cholerae*	References
OptiMarin - ship	N	Y		Y[1]	Y[1]	Y[1]	168, 172
Panasia - land	Y	Y		Y	Y	Y	80, 82
Panasia - ship	N	Y		Y	Y	Y	80, 82
RWO – land	Y	Y	Y	Y[1]	Y[1]	Y[1]	53, 178
RWO – ship	Y	Y		Y[1]	Y	Y[1]	53, 178
Severn Trent - land	Y	Y	Y	Y[1]	Y	Y[1]	64, 142, 164
Severn Trent - ship	Y	N		Y	Y	Y[1]	64, 142, 164
Siemens - MERC	N	Y	N	Y	Y	Y[1]	155
Siemens - GSI	N	Y	N	Y	Y	Y[1]	60
STX Metal - lab	Y	Y		Y	Y	Y	151
Sunrui	Y	Y		Y	Y	Y	138
Techcross - land	Y	Y	Y	Y	Y	Y	78, 79
Techcross - ship	Y	Y	Y	Y	Y	Y	78, 79
Wuxi Brightsky - land	Y	Y	Y	Y	Y	Y	154
Wuxi Brightsky - ship	Y	Y	Y	Y	Y	Y	154

[1] Concentration at intake was zero, non-detectable or unknown.

[2] *Vibrio* testing conducted on live cultures in a lab.

A more detailed assessment of system success rate is provided in Table VI-3. For this table, the total number of tests performed on a system under land-based or shipboard test conditions is given as a denominator. The number of land-based or shipboard tests for which a system demonstrated potential to meet California's discharge standards is given in the numerator. Six systems demonstrated potential to meet California's discharge standards in more than 50% of land-based or shipboard tests, and of these six, three systems demonstrated this potential in 100% of shipboard tests. One system also demonstrated potential to meet discharge standards in 100% of shipboard efficacy tests, but did not conduct tests for bacterial concentrations applicable to California's statutory performance standard.

Shipboard tests were given additional weight in the consideration of this report's conclusions as shipboard test conditions more accurately reflect the only practical way to assess discharge standards such as California's. Some systems failed to demonstrate the same potential compliance rates in land-based tests as in shipboard tests. This should be of interest both in light of any Type Approvals that will occur at the federal level, and in informing the discussions between vendors and anyone wishing to purchase a treatment system. Commission staff included land-based testing results in this success-rate table for these reasons.

Table VI-3. Systems with reliable third-party collected land-based or shipboard test results from Type Approval or other third-party testing, for which success rates could be generated. The number of tests, averaged across replicates, that demonstrated potential compliance with California's standards is presented in the numerator, and the total number of tests performed is presented in the denominator. Systems in bold conducted at least 3 tests and demonstrated the potential to meet California's standards at least 50% of the time at either land-based or shipboard scales.

Manufacturer	**>50 µm**		**10 – 50 µm**		**<10 µm (bacteria)**		***E. coli***		**Enterococci**		***Vibrio***		**Literature Cited[2]**
	Land	**Ship**	**Land**	**Ship**	**Land**	**Ship**	**Land**	**Ship**	**Land**	**Ship**	**Land**	**Ship**	
Alfa Laval[1]	4/10	1/4	3/10	1/4	0/8	2/2	10*/10	4*/4	10*/10	4*/4	10*/10	4*/4	61, 170, 173, 176
Auramarine	0/11	-	5/11	-	10*/11	-	11*/11	-	11*/11	-	11*/11	-	177
Ecochlor	**8/15**	**3/3**	**9/11**	**3/3**	**8/11**	**-**	**10/10**	**3/3**	**11/11**	**3/3**	**1/1 (lab)**	**3*/3**	**54, 116, 162**
ERMA First	5/12	0/2	9/12	2/2	0/Unk[3]	-	10*/10	2*/2	10/10	2/2	-	2*/2	55, 56, 166
DESMI	5/11	4/5	0/11	-	11/11	-	11/11	-	11/11	-	11/11	-	29, 133
Hamworthy	-	0/2	-	2/2		2/2	-	2/2	-	2/2	-	2/2	57, 58
Hyde	1/10	3/3	4/10	1/3	5/10	3/3	10*/10	3*/3	10*/10	3*/3	-	3*/3	163, 231
JFE	6/11	3/6	11/11	5/6	3/11	-	11*/11	6/6	11/11	6/6	11*/11	6*/6	49
MAHLE	**1/11**	**4/4**	**4/11**	**4/4**	**11/11**	**4/4**	**11/11**	**4/4**	**11/11**	**4/4**	**-**	**4/4**	**52, 163**
Marenco	3/4	-	0/1	-	2/3	-	-	-	-	-	-	-	83, 84, 229
MSI	0/5	-	0/5	-	3/5	-	5/5	-	5/5	-	5*/5	-	98, 146
NEI	1/5	1/2	0/1	Unk	0/2	0/2	0/1	2*/2	0/1	Unk	-	2*/2	208, 210
NK-03		1/1		1/1		1/1		1/1		1/1		1/1	81
Nutech	0/3	2/3	0/2	0/3	3/3	2/2	-	3*/3	-	3*/3	-	3*/3	65, 234
OceanSaver	2/25	1/3	5/25	1/3	16/16	-	14*/14	3*/3	20*/25	3*/3	25*/25	3/3	114, 171
OptiMarin	8/14	0/8	6/12	2/8	2/12	-	12*/12	8*/8	12*/12	8*/8	12*/12	8*/8	168, 172
Panasia	4/10	0/3	6/10	2/3	-	-	9/10	3/3	10/10	3/3	10/10	3/3	80, 82
Qingdao	**4/13**	**3/3**	**8/13**	**3/3**	**9/13**	**3/3**	**13*/13**	**3*/3**	**13*/13**	**3*/3**	**13*/13**	**3*/3**	**141, 175**
RWO	**6/13**	**4/5**		**5/5**	**7/13**	**5/5**	**13*/13**	**5*/5**	**13*/13**	**5/5**	**13*/13**	**5*/5**	**53, 178**
Severn Trent	**7/11**	**2/4**	**7/11**	**0/4**	**10/11**	**4/4**	**11*/11**	**4/4**	**11/11**	**4/4**	**-**	**38*/38**	**64, 142, 164**

Table VI-3. Systems with reliable land-based or shipboard test results from Type Approval or other third-party testing, for which success rates could be generated. The number of tests, averaged across replicates, that demonstrated potential compliance with California's standards is presented in the numerator, and the total number of tests performed is presented in the denominator. Systems in bold conducted at least 3 tests and demonstrated the potential to meet California's standards at least 50% of the time at either land-based or shipboard scales.

Manufacturer	**>50**		**10 - 50**		**<10 (bacteria)**		***E. coli***		**Enterococci**		***V. cholorae***		**Literature Cited[2]**
	Land	**Ship**	**Land**	**Ship**	**Land**	**Ship**	**Land**	**Ship**	**Land**	**Ship**	**Land**	**Ship**	
Siemens	0/2	-	1/2	-	2/2	-	2/2		2/2	-	2*/2	-	155, 60
Techcross		**3/3**		**3/3**		**3/3**	**10/10**	**3/3**	**11/11**	**3/3**	**11*/11**	**3*/3**	**78, 79**

[*] Concentration at intake was zero, non-detectable or unknown.

[1] These data include land-based testing of system v. 2.0 and shipboard testing of system v. 1.0. DNV did not require shipboard testing of v. 2.0.

[2] Numbered references can be found in the Literature Cited section.

[3] Unknown, minimum and maximum values provided but not the total number of tests.

No available dataset on treatment system performance can represent a system's efficacy on all vessel types under all possible voyage conditions. Many systems have not yet undergone full-scale shipboard testing (see Appendix A for detailed account of data by type of testing facility). The number of tests performed varies from system to system, and those that have been tested on vessels may have only been assessed on one ship or under limited testing scenarios. Water condition variables, such as salinity, turbidity, and temperature can affect the ability of a system to kill organisms. Some systems require minimum ballast water "holding times" for optimal performance, while others perform best on shorter voyages. The density or diversity (types) of organisms found at the ballast uptake location can also affect system performance. In essence, a system that fails to meet California's standards under one scenario (e.g. short voyage duration) might meet the standards or exceed them under a different scenario (e.g. longer voyage duration).

Recent discussions over the implementation of the IMO and proposed federal standards have focused on whether or not methods and/or protocols exist to assess compliance with more stringent standards – such as those in California. Specific concerns have focused on the volume of water necessary to assess compliance with the standards for organisms greater than 50 µm in size. California's standards for organisms greater than 50 µm is defined as "no detectable living organisms," and does not define a specific volumetric concentration. Many outside parties have reasoned that the volumes of ballast water required to determine compliance with this standard are too large to be practical for shipboard compliance verification. It is important to note, however, that unlike the IMO standard for the same size class, the standard for California is unitless. Whereas IMO defines its standard for organisms greater than 50 µm as less than 10 per cubic meter, California's standard does not set forth a volume requirement. Therefore, compliance and performance testing for this size class could occur with any volume of water that is feasible under shipboard testing conditions. Commission staff is developing protocols to assess vessel compliance with California's standards, and is in the process of a rulemaking action to make them transparent to the shipping industry. These protocols would address ballast water sample volumes and take into account both scientific rigor and practicality for shipboard inspections.

California's standard for organisms in the 10 – 50 micron size class (≤0.01 living organisms per milliliter) is another area of concern in terms of the appropriateness of available data. Although some systems do demonstrate potential to comply with this 10 – 50 micron size class standard, the volumes typically sampled for Type Approval are too small for this potential to be referred to with the same confidence as for the other size classes. This should not be confused with the inability of a treatment system to treat ballast water to California's standards, but does mean that more relevant data will be useful to determining whether systems can or cannot treat to these standards with a higher level of confidence.

The bacteria and virus standards present unique challenges to compliance monitoring. Methods do exist to quantify bacteria, viruses, and virus-like particles in a sample of ballast water, but no appropriate techniques are readily available to assess the viability of all bacteria and viruses, as required by California's performance standards (see Dobroski et al. 2009a, Appendix A1 for discussions on this topic). To assess compliance with the bacterial standard, Commission staff used a representative group of organisms (culturable, aerobic, heterotrophic bacteria – hereafter culturable heterotrophic bacteria) to quantify potential compliance with the bacterial standard. Culturable heterotrophic bacteria were selected as a representative for the total bacterial concentration because, unlike total bacteria, there are reliable, widely-accepted standard methods to both enumerate and assess viability of these organisms (See CSLC 2010 for detailed discussion of culturable heterotrophic bacteria).

Analysis of viruses remains challenging at this time. While several representative organisms exist for viruses, their relationship to the greater population of all viral species is more tenuous than for bacteria (confer Culley and Suttle 2007). For the purposes of this analysis, Commission staff believes that no widely accepted technique is available to quantify or reliably estimate virus concentrations, and thus systems were not evaluated for compliance with the viral standard. Staff will continue to monitor the development of new assessment techniques for all organism size classes and incorporate them into future technology assessment reports.

Availability

Many factors play into system availability including industry demand (i.e. how many ships need to buy systems) and commercial availability (i.e. are there enough systems being manufactured/sold to meet industry demand and are resources available to install these technologies on new and existing vessels). Of the 13 systems that demonstrated the potential to meet California's standards, all are commercially available at this time (see Lloyd's Register 2011). Existing vessels with a ballast water capacity between 1500 – 5000 metric tons will be required to meet California's ballast water discharge standards as of January 1, 2014. New builds in this size class had to meet discharge standards as of January 1, 2012. This vessel size class represents about 8% of the fleet arriving to California ports between January 2000 and March 2012 (Figure VI-1). While commercial availability and industry demand are two important components of this assessment of availability, the specific purpose of this report is to assess the availability of retrofit-capable BWTS for existing vessels with a ballast water capacity between 1500-5000 metric tons.

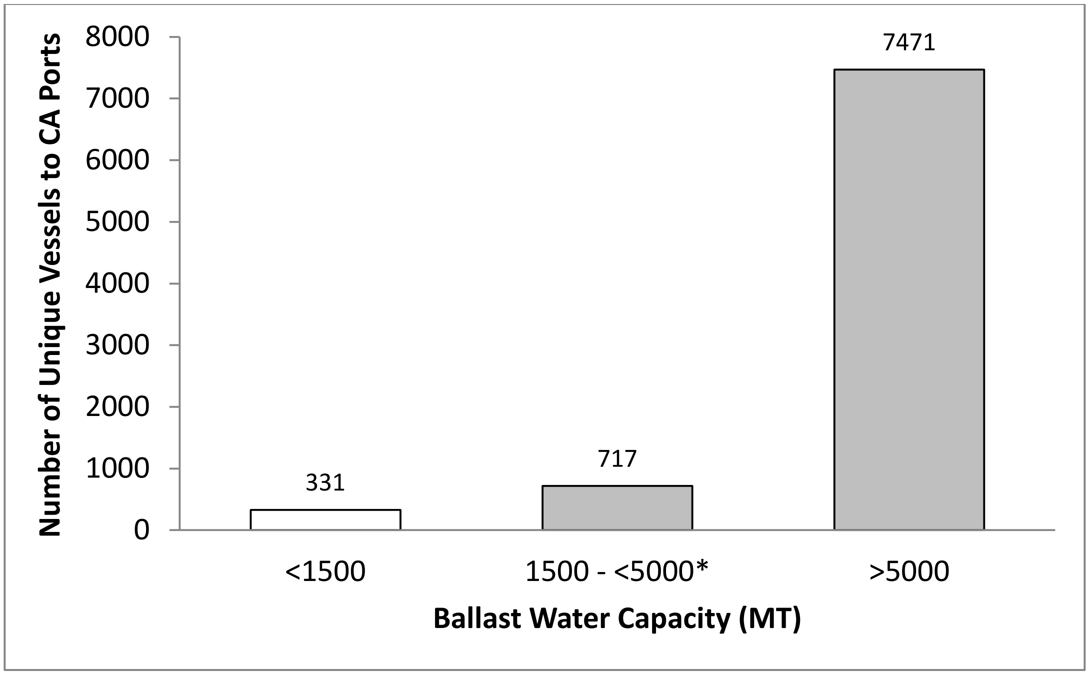

Figure VI-1. Vessels arriving to California ports between January 2000 and March 2012. Vessels are categorized by ballast water capacity in metric tons (MT). * = Existing vessels in this size class will be required to comply with ballast water discharge standards as of January 1, 2014.

Between January 2000 and March 2012, 717 unique vessels with a ballast water capacity between 1500 – 5000 metric tons arrived at California ports (Figure VI-1). As less than 20% of voyages, on average, discharge ballast in California waters (Takata et al. 2011) these vessels will not always have to discharge ballast. This could result in only 144 vessels requiring retrofits by January 1, 2014. It is important to note that any one vessel might need to discharge ballast water on a single voyage due to safety or operational concerns, in which case the vessel may need to have a treatment system installed. This number is still likely to be conservative, as it represents data from every vessel that has called on California since 2000.

Caution should be taken in interpreting these estimates, as the number of vessels visiting California waters may vary based on economic conditions, and not all treatment systems are equally appropriate for all vessels. Distributed among the thirteen treatment systems that have demonstrated the potential to comply with California’s performance standards and are commercially available, the estimate of 144 vessels requiring retrofits equates to about 11 system retrofits per vendor. It is not yet clear whether vendors will be able to meet this demand, but one vendor has plans to retrofit 101 vessels with its ballast water treatment system in the next one to two years.

As part of assessing the availability of treatment systems for this report, Commission staff compiled data regarding the retrofit capability of BWTS by contacting vendors directly and asking them to complete a retrofit questionnaire (see Appendix B for copy of questionnaire). This questionnaire was developed by Commission staff to address engineering concerns regarding system retrofits on vessels with a variety of space, power, and schedule constraints. Commission staff also contacted select marine engineers to discuss challenges encountered during retrofitting existing vessels. Fifteen treatment system manufacturers returned the retrofit questionnaire, ten of which produce systems that have demonstrated the potential to meet California’s discharge standards (Table VI-4).

Table VI-4. Summary of BWTS vendor responses to retrofit questionnaire supplied by Commission staff in March 2012. "Max flow rate retrofit" refers only to the maximum flow rate system that has been previously retrofit on a vessel. Vessel types are abbreviated as follows: a = auto, b = bulker, c = container, g = general, p = passenger, t = tanker, ba = barges. Blank cells indicate that no information was available. Systems in bold demonstrated potential to meet California standards during >50% of efficacy tests.

Manufacturer	System Name	Retrofits Completed (#)	Retrofit Orders (#)	Vessel Types Retrofit	Potential to Meet CA Standards	Max Flow Rate Retrofit (m3/h)	Max Power (kW)	Drydock Required	Explosion Hazard Protections[2]
Alfa Laval	PureBallast	14	13	t, p, c, g, p	Y	1000	37 - 433	no	yes
Auramarine	CrystalBallast	2	0	b, p		1000	38 - 462	no	in develop.
Ecochlor	**Ecochlor BWTS**	**2**	**0**	**c, b**	**Y**	**1250**	**7 - 43**	**case specific**	
Hamworthy	Aquarius[1]	2		t, p	N			case specific	In develop.
Hyde Marine	Hyde Guardian	12	6	p, g, o, c	Y	1000	15 - 114	no	yes
MAHLE	**Ocean Protection Sys.**	**3**	**0**	**p, c, a**	**Y**		**varies**	**no**	**no**
N.E.I.	Venturi Oxygen Stripping Sys.	9		b	N	4400			
NK-03	NK-03 System	2	101	c, t	Y	2200	725.4	no	
OceanSaver	OceanSaver BWTS	1	9	a	Y	500		case specific	
OptiMarin	Optimarin Ballast Sys.	3	6		Y		varies	case specific	no

Table VI-4 continued. Summary of BWTS vendor responses to retrofit questionnaire supplied by Commission staff in March 2012. "Max flow rate retrofit" refers only to the maximum flow rate system that has been previously retrofit on a vessel. Vessel types are abbreviated as follows: a = auto, b = bulker, c = container, g = general, p = passenger, t = tanker, ba = barges. Blank cells indicate that no information was available. Systems in bold demonstrated potential to meet California standards during >50% of efficacy tests.

Manufacturer	System Name	Retrofits Completed (#)	Retrofit Orders (#)	Vessel Types Retrofit	Potential to Meet CA Standards	Max Flow Rate Retrofit (m3/h)	Max Power (kW)	Drydock Required	Explosion Hazard Protections[2]
RWO	**CleanBallast**	**1**	**0**	**c**	**Y**	**500**	**salinity depend**	**no**	**no**
SunRui	BalClor	1	5	b	N	1000	300	no	
Severn Trent	**BalPure**	**1**	**1**	**t**	**Y**	**1500**	**varies**	**case specific**	
Wartsila/Trojan Marinex	Trojan BWTS	1	1	c		500		no	
Techcross	**Electro-Cleen**	**5**	**0**	**c, b**	**Y**		**salinity depend**	**case specific**	**yes**

[1] Hamworthy produces two Aquarius systems, Aquarius UV and Aquarius EC.
[2] Explosion hazard protections are primarily of concern for retrofits onboard tankers.

Systems must be able to treat all ballast on a vessel prior to discharge. For systems that treat on uptake and/or discharge, the total volumetric capacity of the vessel is not the determining factor. Instead, the treatment system must be able to keep pace with the flow rate of the vessel's ballast water pumps. Commission staff analyzed data on the number of ballast water pumps and the maximum pump rates for the fleet of vessels that call on California ports. It is difficult to pinpoint an average system treatment rate necessary for these vessels because, depending on a vessel's piping configuration, a vessel may need one system per pump or one system to treat water coming in or out from all pumps. The pump rate capacities of treatment systems are of particular relevance to oil tankers, which must load and discharge cargo rapidly.

Figure VI-2 illustrates the range of ballast water pump rates on vessels that operate in California waters. The figures include both vessels that have discharged and have not discharged ballast in California waters, because all vessels have the potential to discharge ballast at some point either due to cargo operations or safety concerns. Figure VI-2 also shows the maximum single pump rate per vessel, and the average maximum combined pump rate per vessel. Average maximum flow rates for vessels between 1500-5000 metric tons ballast capacity fall within the pump rate capacity of available BWTS that have been retrofit on vessels in Table VI-4, though some vessels may have to slow ballasting/deballasting operations under some circumstances. Figures VI-3 and VI-4 provide a more detailed summary of the pump rates of unique vessel that arrived to California ports between January 2000-March 2012. Figure VI-3 summarizes the average maximum ballast pump rates, and Figure VI-4 summarizes single maximum ballast pump rates. Most unique vessels that arrived to California during this time have a combined and/or single pump rate maximum of below 2000 m^3/hr., and thus fall within the pump rate capacity of available BWTS. It is important to note that treatment system pump rates can vary based on the age of system components as well as the quality of water to be treated.

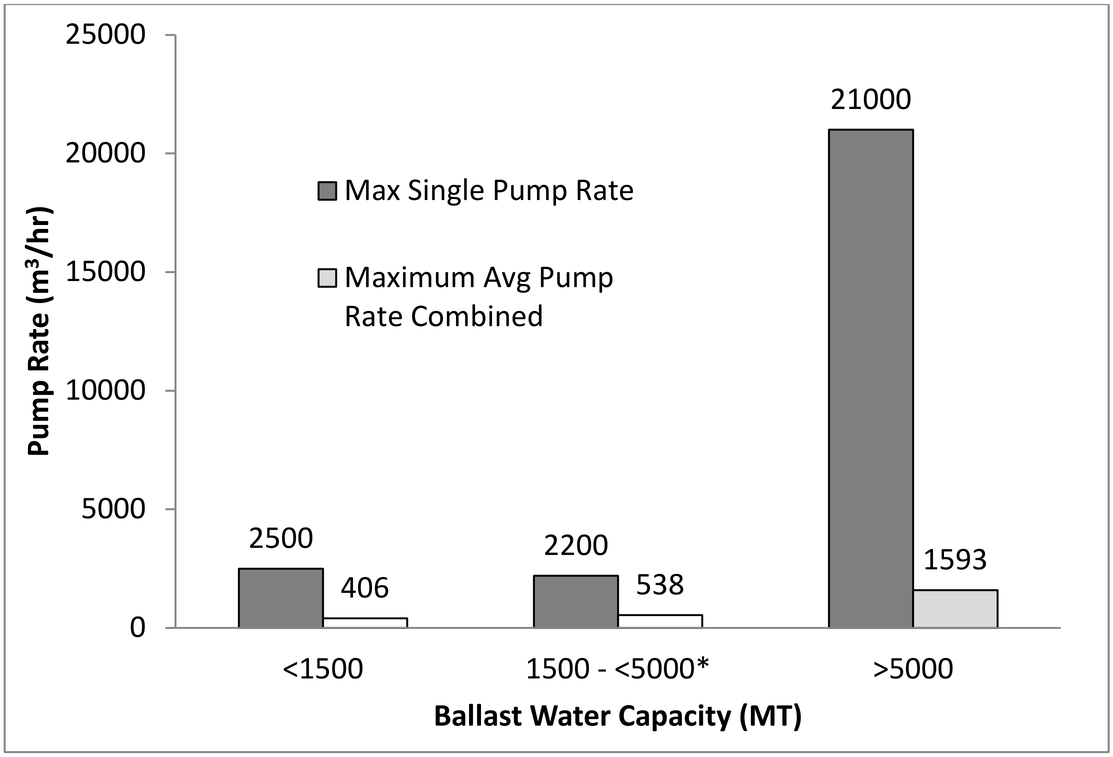

Figure VI-2. Vessels that have visited California ports and their average maximum single and average maximum combined ballast water pump rates (m^3/h). Data were collected from January, 2000 – March 2012. * = existing ships with this ballast water capacity will be subject to the 2014 implementation date for California's performance standards.

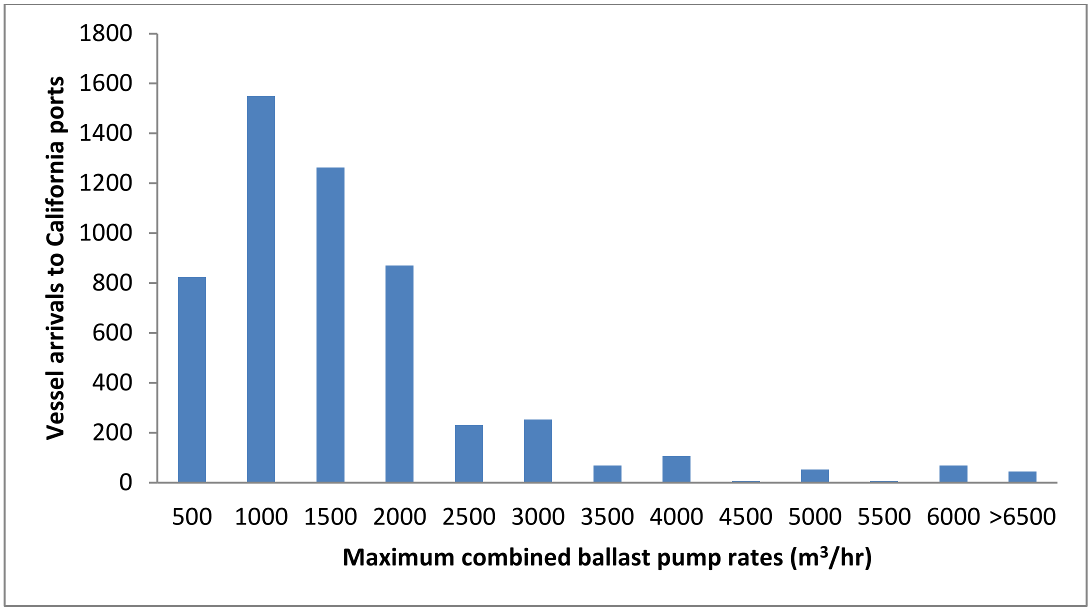

Figure VI-3. Frequency distribution vessel combined pump rate capacities for vessels that arrived to California ports from January 2000-March 2012.

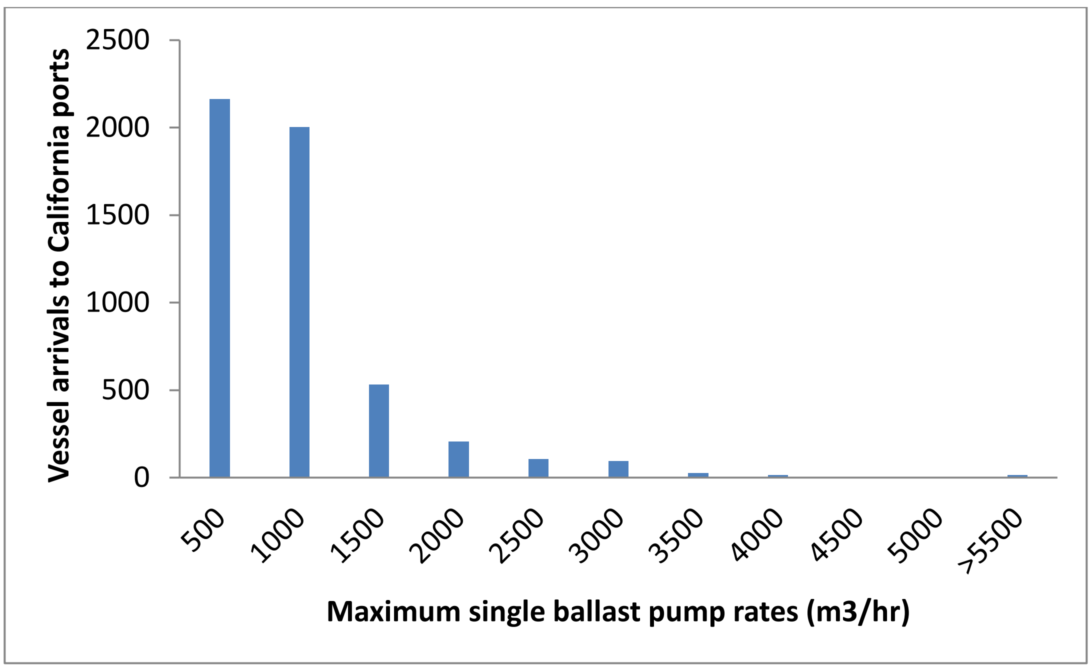

Figure VI-4. Frequency distribution of single ballast pump rate capacities for vessel arrivals from January 2000-March 2012.

System support is as important as commercial availability. Following installation, system developers will need to have personnel and infrastructure in place to troubleshoot and fix problems that arise during system operation. Maritime trade is a global industry, and vessel operators will need to have global support for onboard machinery. Larger companies established in the maritime logistics or equipment industries may already be prepared to respond to technological challenges and emergencies as they arise, but smaller ballast water treatment vendors may face an initial period to ramp-up service and access to replacement parts. Vendors claim that service will be available worldwide. Only time will tell, how support networks can deal with this influx of new machinery, and if system support services will be adequate as California's performance standards are implemented for existing vessels with a ballast water capacity between 1500-5000 metric tons in 2014.

Environmental Regulation and Impact Assessment

An effective ballast water treatment system must comply with both performance standards for the discharge of living organisms in ballast water and with applicable environmental safety and water quality laws, regulations and permits. The discharge of treated ballast water should not impair water quality such that it impacts the beneficial uses of the State's receiving waters. The IMO, federal government, and state governments have developed specific limits for discharge constituents and/or whole effluent toxicity evaluation procedures in order to protect the beneficial uses of waterways from harmful contaminants. Commission staff has drawn on the environmental review of ballast water treatment systems and active substance constituents from all levels of government (state, federal, international) in the assessment of environmental risk for the 63 treatment systems reviewed in this report.

International

As discussed in Section III (Regulatory Overview), the IMO has established an approval process through the Guideline G9 for treatment technologies using active substances (i.e. chemicals) to insure that systems are safe for the environment, ship, and personnel. The IMO two-step approval process is comprised of an initial "Basic Approval" utilizing laboratory test results to demonstrate basic environmental safety, followed by "Final Approval" based upon evaluation of the environmental integrity of the full-scale system. Guideline G9 of the Convention requires applicants to provide information identifying: 1) Chemical structure and description of the active substance and relevant chemical byproducts; 2) Results of testing for persistence (environmental half-life), bioaccumulation, and acute and chronic aquatic toxicity effects of the active substance on aquatic plants, invertebrates, fish, and mammals; and 3) An assessment report that addresses the quality of the test results and a characterization of risk (MEPC 2008f). Systems that apply for Basic and Final Approval are reviewed by the IMO Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) – Ballast Water Working Group (BWWG) in accordance with the procedures detailed in Guideline G9. The Guideline does not address system efficacy, only environmental safety (MEPC 2008f) and is a voluntary guideline for the Convention which has not yet gone into effect.

Federal

USCG will Type Approve ballast water treatment systems based on biological efficacy, and has signed a Memorandum of Understanding with the US EPA to share data relevant to implementation of the Vessel General Permit (VGP) and to cooperate regarding enforcement measures. The USCG also approves systems for use in the Shipboard Technology Evaluation Program (STEP), and in doing so and must consider potential environmental impact under the National Environmental Policy Act (NEPA). Vessels that participate in the STEP must comply with the US EPA's Vessel General Permit (VGP) and additionally conform to the environmental compliance requirements associated with STEP participation, including: 1) Compliance with the NEPA process; 2) Due diligence by the applicant in providing requested biological and ecological information and obtaining necessary permits from regulatory agencies; and 3) A provision that systems found to have an adverse impact on the environment or present a risk to the vessel or human health will be withdrawn from the program (USCG 2006).

The current 2008 VGP contains requirements for total residual chlorine (TRC; instantaneous maximum = 100 micrograms/l) levels in effluents from vessel operations, and the draft 2013 VGP currently contains requirements for TRC and five other chemical residuals (ozone, chlorine dioxide, hydrogen peroxide, peracetic acid). The effluent limits and best management practices described in the VGP are specific to those treatment systems that make use of biocides. Under the permit, all biocides that meet the definition of a "pesticide" under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA; 7 U.S. Code 136 *et seq*.) must be registered for use with the EPA. Biocides generated onboard a vessel solely through the use of a "device" (as defined under FIFRA) do not require registration. Systems that use biocides or produce derivatives which lack applicable EPA Water Quality Criteria must conduct Whole Effluent Toxicity testing to determine chronic toxicity levels. Systems that do not meet the Water Quality Criteria or chronic toxicity limits may be required to cease discharging and must apply for coverage under an individual NPDES permit.

The draft 2013 VGP requires monitoring of ballast water treatment system discharges for chemical residuals. Numeric limits are included in the draft VGP for TRC (100 µg/l), chlorine dioxide (200 µ/l), ozone (100 µg/l, detected as total residual oxidizers or TRO), peracetic acid (500 µg/l), and hydrogen peroxide (1000 µg/l). For systems that utilize or generate other residuals, acceptable levels in ballast water discharges would be equivalent to values discussed in the EPA 1986 Quality Criteria for Water (the Gold Book) and subsequent updates to these levels. The Gold Book and its updates can be accessed at http://water.epa.gov/scitech/swguidance/standards/criteria/library_index.cfm.

States

As discussed in Section III, several states established ballast water management programs and performance standards requirements through Section 401 certification of the VGP. This certification also provides states a mechanism to set water quality criteria for ballast water discharges. Chlorine was a toxicant of concern for many states, particularly those located on the Great Lakes. Several states chose to establish limits for Total Residual Chlorine (TRC) in ballast discharges that were substantially more stringent than the limit established by the VGP (= 100 microns/l). Massachusetts for example, set a TRC limit of 10 microns/l in discharges from experimental treatment systems. Several states also established conditions requiring evaluation of acute and chronic impacts from treated discharges. States have until June 30, 2012 to issue their Section 401 certifications of the draft 2013 Vessel General Permit.

Washington State

The State of Washington's evaluation of environmental impacts from the discharge of treated ballast water has proven an invaluable resource. The Washington State Department of Ecology developed a framework for "Establishing the Environmental Safety of Ballast Water Biocides" in 2003, and revised it in 2008 to be included as Appendix H in the Laboratory Guidance and Whole Effluent Toxicity Test Review Criteria manual (Washington State Department of Ecology 2008, available at http://www.ecy.wa.gov/pubs/9580.pdf). Two systems have completed toxicity testing in accordance with Washington requirements (Table VI-5).

California

California does not have a formal environmental impact evaluation process for the discharge of treated ballast water. Vessels that discharge in California waters must comply with the applicable provisions of the EPA's VGP including any California-specific conditions added by the State Water Resources Control Board (Water Board) through the Section 401 certification process. California's Section 401 certification requires that vessel discharges contain no hazardous wastes as defined in California law or hazardous substances as listed in the 401 certification letter (see Water Board 2009). Discharges may not contain an oily sheen or noxious liquid substance residues, and detergents may not be used to disperse hydrocarbon sheens. More information is available at http://www.swrcb.ca.gov/water_issues/programs/index.shtml. A section on vessel discharges under the clean beaches/ocean programs is listed at this website.

Environmental Assessment of Treatment Systems

Staff has compiled environmental assessment reports and water quality data reported to the IMO, as well as information made available to the State of Washington and Commission staff, to assess available treatment systems for potential environmental impacts to California waters. The IMO active substance approval documents, in particular, have proved to be a valuable resource to assess a treatment system's broad-scale environmental safety prior to comparison of specific system effluent constituents to the VGP and California water quality objectives.

Of the 63 treatment systems evaluated for this report, 35 have received either IMO Basic or IMO Basic and Final approvals as of March 2012. Forty-three systems utilize active substances, including ozone gas, free radicals generated by system operation, sulfur-based reducing compounds, and chlorinated and brominated compounds. Of systems that utilize or generate active substances, 34 provided information to Commission staff for this report on toxicity testing. Active substances, approvals, and federal VGP compliance with limits for TRC residuals for these active-substance systems are summarized in Table VI-5. An assessment of all of the potential impacts from all possible chemicals and residuals associated with the use of these treatment technologies is beyond the scope of this report and is the purview of the California Water Board and the EPA.

Table VI-5. Environmental testing and approvals for 63 ballast water treatment systems reviewed by Commission staff. Blank cells indicate that data were not available. Total residual chlorine may not exceed 60 µg/l for discharges to Ocean waters, and may not exceed 20 µg/l for discharges to enclosed bays and inland waters. N/A = not applicable, Insufficient data = TRC data were received, are not sufficient to determine whether VGP TRC limits were met.

Manufacturer	Active Substance	Toxicity Testing Conducted	Environmental Related Approvals	VGP TRC 60 µg/l compliant?	VGP TRC 20 µg/l compliant?	Source
21st Century Shipbuilding	ozone, atomic oxygen, nitric oxide, superoxide radicals produced during disinfection	Y	IMO Basic and Final			147
Alfa Laval	free radicals	Y	IMO Basic and Final	Y	N	61, 170, 173, 176
AQUA Eng. Co. Ltd.	sodium hypochlorite	Y	IMO Basic and Final	Insufficient data	Insufficient data	149, 150
Aquaworx ATC Gmbh	n/a (UV, cavitation bubble)	Y	IMO Basic	n/a	n/a	129
ATLAS-DANMARK	hyplochlorous acid, ozone, hydrogen peroxide, chlorine dioxide, hydrogen, sodium hydroxide					150
Auramarine Ltd.	n/a (UV)	Y		n/a	n/a	3
Brillyant Marine LLC						
Coldharbour Marine	n/a (deoxygenation)			n/a	n/a	
COSCO/Tsinghua Univ.	n/a (UV)	Y	IMO Basic	n/a	n/a	153
Dalian Maritime University Environment Engineering Institute (DMU-EEI)	DMU -OH BWMS	Y	IMO Basic			
DESMI Ocean Guard A/S	hydroxyl radical, ozone	Y	IMO Basic	Y	N	29, 133

Table VI-5 continued. Environmental testing and approvals for 63 ballast water treatment systems reviewed by Commission staff. Blank cells indicate that data were not available. Total residual chlorine may not exceed 60 µg/l for discharges to Ocean waters, and may not exceed 20 µg/l for discharges to enclosed bays and inland waters. N/A = not applicable. N/A = not applicable, Insufficient data = TRC data were received, are not sufficient to determine whether VGP TRC limits were met.

Manufacturer	Active Substance	Toxicity Testing Conducted	Environmental Related Approvals	VGP TRC 60 µg/l compliant?	VGP TRC 20 µg/l compliant?	Source
Ecochlor	chlorine dioxide	Y	IMO Basic and Final, USCG STEP, Rec WA Cond.[1]	Y	Y	116
Electrichlor	sodium hypochlorite					
ETI	ozone	Y				94
Envirotech and Consultancy Pte. Ltd.	sodium hypochlorite	Y	IMO Basic			
Envirotech and Consultancy Pte. Ltd.	sodium hypochlorite	Y	IMO Basic			
ERMA First ESK Engineering Solutions SA		Y	IMO Basic and Final			
Ferrate Treatment Tech.	ferrate					
GEA Westfalia	OXIDAT	Y	IMO Basic			
Hamworthy Aquarius UV	n/a UV			n/a	n/a	
Hamworthy Aquarius EC	sodium hypochlorite					
Hanla IMS Co., Ltd.	sodium hypochlorite	Y	IMO Basic			
Hi Tech Marine	n/a (heat)		New South Wales EPA	n/a	n/a	96
Hitachi/Mitsubishi	triiron tetraoxide, poly aluminum chloride, poly acrylamide sodium acrylate	Y	IMO Basic and Final			107, 126

[1] WA Dept. of Ecology Water Quality Program has recommended Conditional Approval of the system to WA Dept. Fish and Wildlife. As of the writing of this report, approval has not been granted.

Table VI-5 continued. Environmental testing and approvals for 63 ballast water treatment systems reviewed by Commission staff. Blank cells indicate that data were not available. Total residual chlorine may not exceed 60 µg/l for discharges to Ocean waters, and may not exceed 20 µg/l for discharges to enclosed bays and inland waters. N/A = not applicable, Insufficient data = TRC data were received, are not sufficient to determine whether VGP TRC limits were met.

Manufacturer	Active Substance	Toxicity Testing Conducted	Environmental Related Approvals	VGP 60 µg/l compliant?	VGP 20 µg/l compliant?	Source
HWASEUNG R&A Co., Ltd.	sodium hypochlorite	Y				
Hyde Marine	n/a (UV)	Y	UCSG STEP	n/a	n/a	
Hyundai Heavy Ind. (1) EcoBallast	n/a (UV)	Y	IMO Basic and Final	n/a	n/a	107,114
Hyundai Heavy Ind. (2) HiBallast	chlorine, bromine, sodium hypochlorite, sodium hypobromite, hypochlorous acid, hypobromous acid	Y	IMO Basic and Final	Detection limit of tests above EPA std.	Detection limit of tests above EPA std.	134, 139
JFE Eng. Corp./TG Group (1)	sodium hypochlorite	Y	IMO Basic and Final	Insufficient data	Insufficient data	49, 135, 174
	sodium hypochlorite (granular)	Y	IMO Basic			
Katayama Chemical Inc.	Peraclean Ocean	Y	IMO Basic			
KT Marine Co., Ltd.	sodium hypochlorite					
Kuraray	calcium hypochlorite	Y	IMO Basic and Final			
Kwang San Co. Ltd.	Cl_2, hypochlorous acid, hypobromous acid, sodium hypochlorite, sodium hypobromite	Y	IMO Basic		Detection limit of tests above EPA std.	136
MAHLE Ind. GmbH	n/a (UV)			n/a	n/a	

Table VI-5 continued. Environmental testing and approvals for 63 ballast water treatment systems reviewed by Commission staff. Blank cells indicate that data were not available. Total residual chlorine may not exceed 60 µg/l for discharges to Ocean waters, and may not exceed 20 µg/l for discharges to enclosed bays and inland waters. N/A = not applicable, Insufficient data = TRC data were received, are not sufficient to determine whether VGP TRC limits were met.

Manufacturer	Active Substance	Toxicity Testing Conducted	Environmental Related Approvals	VGP 60 µg/l compliant?	VGP 20 µg/l compliant?	Source
MARENCO	n/a (UV)		WA Conditional[1]	n/a	n/a	
Maritime Solutions Inc.	n/a (UV)			n/a	n/a	
Mexel Industries	yes, unknown					
MH Systems	n/a (deoxygenation)			n/a	n/a	
Mitsui Engineering	Peraclean Ocean	Y	IMO Basic			
Mitsui Engineering	filtration					
Mitsui Engineering	ozone	Y	IMO Basic and Final	N	N	103
NEI	n/a (deoxygenation)	Y	USCG STEP	n/a	n/a	208, 210
NK Co. Ltd.	ozone, total residual oxidant	Y	IMO Basic and Final	Y	Y	117
ntorreiro	yes, unknown					
Nutech 03 Inc.	ozone	Y		N	N	65, 234
OceanSaver	free and total residual oxidant	Y	IMO Basic and Final	Y	Y	114,171,184
OptiMarin	n/a (UV)	Y		n/a	n/a	168
Panasia Co.	n/a (UV)	Y	IMO Basic and Final	n/a	n/a	80, 82
Pinnacle Ozone Solutions	ozone					

[1] WA Dept. of Ecology Water Quality Program has recommended Conditional Approval of the system to WA Dept. Fish and Wildlife. As of the writing of this report, approval has not been granted.

Table VI-5 continued. Environmental testing and approvals for 63 ballast water treatment systems reviewed by Commission staff. Blank cells indicate that data were not available. Total residual chlorine may not exceed 60 µg/l for discharges to Ocean waters, and may not exceed 20 µg/l for discharges to enclosed bays and inland waters. N/A = not applicable, Insufficient data = TRC data were received, are not sufficient to determine whether VGP TRC limits were met.

Manufacturer	Active Substance	Toxicity Testing Conducted	Environmental Related Approvals	VGP 60 µg/l compliant?	VGP 20 µg/l compliant?	Source
Qingdao Headway Tech	hydroxyl radical, hypochlorous acid, hypochlorite, hydrogen peroxide	Y	IMO Basic and Final	Y	Y	141, 175
RWO Marine Water Tech.	hydroxyl radicals, free active chlorine	Y	IMO Basic and Final	Insufficient data	Insufficient data	53, 104, 122, 178
Samsung Heavy Industries, Co., Ltd.	sodium hypochlorite	Y	IMO Basic and Final			
Sea Knight						
Severn Trent De Nora	sulfur-based reducing compounds	Y	IMO Basic and Final, USCG STEP	Y	Y	104,122
Siemens	sodium hypochlorite, sodium hypobromite, oxygenated species, oxygen, hydrogen	Y	IMO Basic and Final	Y	Y	97, 155
STX Metal Co., Ltd.	hypochlorite	Y	IMO Basic			151
Sumitomo Electric Industries, Ltd.	hypochlorite					
Sunrui	hypochlorite, hypobromite, chloramines, bromamines	Y	IMO Basic and Final			138

Table VI-5 continued. Environmental testing and approvals for 63 ballast water treatment systems reviewed by Commission staff. Blank cells indicate that data were not available. Total residual chlorine may not exceed 60 µg/l for discharges to Ocean waters, and may not exceed 20 µg/l for discharges to enclosed bays and inland waters. N/A = not applicable, Insufficient data = TRC data were received, are not sufficient to determine whether VGP TRC limits were met.

Manufacturer	Active Substance	Toxicity Testing Conducted	Environmental Related Approvals	VGP 60 µg/l compliant?	VGP 20 µg/l compliant?	Source
Techcross Inc.	hypochlorite, hypobromite, ozone, hydroxyl radicals, hydrogen peroxide	Y	IMO Basic and Final	Insufficient data	Insufficient data	102,115
Wartsila Corporation	n/a (UV)			n/a	n/a	
Wuxi Brightsky Electronic Co. Ltd.	n/a (UV)			n/a	n/a	154

The EPA's VGP specifies a Total Residual Chlorine (TRC) limit of 100 µg/l (micrograms per liter) for ballast water, and of the systems outlined in this report, 26 utilize or generate chlorine or chlorinated compounds. Systems subject to VGP TRC limits are summarized in table VI-5. Currently, regulation of TRC in ballast water discharges in California occurs through the VGP and the Water Board's Section 401 Certification. The Water Board is in the process of adopting amendments to the California Ocean Plan that will bring current state law for vessel discharges under the purview of the Ocean Plan. Total residual chlorine would not be allowed to exceed 60 µg/l in ocean waters (or 20 µg/l in freshwater or in enclosed bays such as San Francisco Bay) by the letter of the California certification of the VGP. All vessels that discharge ballast in California waters must comply with the conditions of California's 401 certification of the EPA VGP, which contains limits for TRC. Vendors and vessel owners/operators must consult with the Water Board and EPA to ensure that vessel discharges comply with all other applicable effluent requirements.

Of the 13 systems with the potential to meet California standards for organism levels in discharged ballast water (see *Efficacy* section above), seven provided data demonstrating that TRC (sometimes measured as TRO = Total Residual Oxidants) was neutralized by an adaptable and automated neutralization step. One system produced chlorinated compounds but was not compliant with federal VGP TRC limits, and four systems utilized technologies to kill organisms in ballast water that do not include the addition or generation of chlorine or chlorine compounds.

Other biocides used for ballast water treatment may fall under the "pesticide" registration requirement under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). FIFRA does not, however, apply to chemicals that are generated and used onboard a vessel. Most treatment systems using biocides generate that chemical through onboard electrochemical processes, and thus will not be subjected to FIFRA registration. This exception provides significant leeway for systems to operate in U.S. waters without any kind of federal biocide regulation except as provided by the VGP. The EPA and USCG have signed a Memorandum of Understanding that provides for data sharing and collaboration regarding informal enforcement documents for the VGP such as notices to ship operators of deficiencies.

Economic Impacts

An assessment of the economic impacts associated with the implementation of performance standards and the use of treatment technologies requires consideration of the costs of NIS introductions to California and the U.S. if performance standards are not met. As discussed in the Introduction (Section II), California has suffered major economic losses as a result of attempts to control and eradicate NIS (aquatic and terrestrial; Carlton 2001, Lovell and Stone 2005, Pimentel et al. 2005), and these costs are projected to increase. California was also the entry point for 79% of existing NIS on the west coast of North America (Ruiz et al. 2011), impacting the economies of California's regional and international partners, requiring control and eradication of NIS that arrived first to California.

Vector control (i.e. controlling the pathways by which NIS enter California waters) is the most effective solution to the problem of NIS (Crooks and Soule 1999, Carlton et al. 2005, Davidson et al. 2008). For each NIS that has established in California and caused harm to California's economy, environment and public health, California spends thousands to tens of millions of dollars per year (Cardno-Entrix and Cohen 2011). Taken together, this means that NIS are severely impacting the California economy.

Once established, NIS can cause direct economic losses by reducing yield (i.e. aquaculture and fisheries), reducing the value of commodities, increasing health care costs, or by reducing tourism-based revenues. For example, evidence strongly indicates that a toxigenic strain of *Vibrio cholerae* was transported via ships from South America to the U.S. Gulf coast in 1991, resulting in the closure of Mobile Bay (Alabama) shellfish beds. Economic damages for the short-term localized closure are estimated at over $700,000 (Lovell and Drake 2009). Prince Edward Island oyster operations in Canada lose approximately $1.5 million annually due to mortality caused by the nonindigenous seaweed *Codium fragile* (Colautti et al. 2006). The rate of new introductions is increasing (Cohen and Carlton 1998, Ruiz and Carlton 2003), which suggests that economic impacts will likely increase as well.

California had the second largest ocean-based GDP in the U.S. in 2009, and ranked number one for employment and second in wages (NOEP 2012). California's natural resources contribute significantly to the coastal economy. For example, in 2010 total landings of fish were almost 438 million pounds, valued at more than $176 million (NOEP 2012). Squid, the top revenue-generating species in 2010, brought in more than $71 million (NOEP 2012). Millions of people visit California's coasts and estuaries each year, spending money on recreational activities that are directly related to the health of the ecosystem. Annually, over 150 million visits are made to California's beaches: approximately 20 million for recreational fishing, over 65 million for wildlife viewing, and over 5 million for snorkeling or scuba diving (Pendleton 2009). Direct expenditures for recreational beach activities alone likely exceed $3 billion each year (Kildow and Pendleton 2006). In total, the tourism and recreation industries accounted for almost $15 billion of California's gross state product in 2009 (NOEP 2012). NIS pose a threat to these and other components of California's ocean economy including fish hatcheries and aquaculture, recreational boating, and marine transportation.

The use of ballast water treatment technologies to combat NIS introductions will involve economic investment on the part of ship owners. This investment reflects not only initial capital costs for the equipment and installation, but also the continuing operating costs for replacement parts, equipment service and shipboard energy usage. Cost estimates are strongly linked to vessel-specific characteristics including ballast water capacity, ballast pump rates and available space. Additionally, the retrofit of vessels already in operation (existing vessels) with ballast water treatment technologies may cost significantly more than installation costs for newly built vessels due to: 1) The necessity to rework existing installations (plumbing, electric circuitry); 2) Non-optimal arrangement of equipment that may require equipment modules that can be mounted individually; 3) Relocation of displaced equipment; and 4) Time associated with lay-up (Reynolds, K., pers. comm. 2007). Nonetheless, the use of these treatment technologies will help minimize or prevent future introductions of NIS and relieve some of the future economic impacts associated with new introductions.

Many treatment technology vendors are hesitant to release costs because system prices still represent research and development costs and do not reflect the presumably lower costs that would apply once systems are in mass production. In the 2010 Lloyd's Register report, the most recent report available with system cost information, only 22 of 41 technologies profiled provided estimates of system capital expenditures (equipment and installation) and half (20) provided estimates of system operating expenditures (parts, service, and energy usage; Table VI-6). Commission staff has also acquired some data on capital and operating costs. Capital expenditure costs are dependent on system size. A 200 cubic meters per hour (m^3/h) capacity system may require an initial capital expenditure between \$20,000 and \$630,000 with an average cost of \$291,000 (Lloyd's Register 2007, Lloyd's Register 2010, Commission data from technology vendors 2007-2008) – down \$96,500 from 2009 (see Dobroski et al. 2009a). A 2000 m^3/h capacity system ranges from $50,000 to $2,000,000 with an average cost of $892,500 per system (Lloyd's Register 2007, Lloyd's Register 2010, Commission data from technology vendors 2007-2008). The average cost of the large capacity systems has not changed since Dobroski et al. (2009a). Operating costs range from negligible, assuming waste heat is utilized, to $1.50 per m^3 with an average of $0.07 per m^3 (Lloyd's Register 2007, Lloyd's Register 2010, Commission data from technology vendors 2007-2008) – down $0.06 per m^3 since 2009 (when it was $0.13 per m^3) (see Dobroski et al. 2009a). Staff has not been able to update these numbers, as Lloyd's (2010) is still the best and most complete reference for cost data. As more systems are sold, costs will likely decrease.

Treatment systems will likely increase the cost of a new vessel by 1-2%. For example, a new 8200 TEU (twenty-foot equivalent unit) container ship built by Hyundai Samho Heavy Industries costs approximately $120 million per vessel (Pacific Maritime 2010). Installation of the most expensive treatment system currently available at $2.0 million (as indicated in Table VI-6) would increase the cost of that vessel by 1.7%. Many treatment technology developers claim that their systems will last the life of the vessel, so the capital costs for treatment systems should be a one-time investment per vessel.

While the economic investment by the shipping industry in ballast water treatment technologies will be significant, when compared to the major costs to control and/or eradicate NIS, the costs to treat ballast water may be negligible. Control efforts are multi-year and represent tens of millions of dollars already spent by the State of California. Managing ballast water with treatment technologies will help to prevent further introductions and lower future costs for control and eradication. Additional studies will be necessary to obtain actual economic impacts associated with treating ballast water.

Table VI-6. Summary of capital and operating cost data for select treatment systems. Unless otherwise noted, source of data is Lloyd's Register (2010).

Manufacturer	Capital Expenditure *(Equipment & Installation)* 200 m^3/h *($ in thousands)*	2000 m^3/h *($ in thousands)*	Other *($ in thousands)*	Operating Expenditure *($ /m^3)*
21st Century Shipbuilding				
Alfa Laval				0.015[1]
Aquaworx ATC				
atg UV Technology				
ATLAS-DANMARK	180	850		
Auramarine Ltd.				0.040
Brillyant Marine LLC	300	2000		
Coldharbour Marine				
COSCO/Tsinghua Univ.				
DESMI Ocean Guard				
Ecochlor	500	800		0.080
EcologiQ			<50[1]	1 - 1.50[1]
Electrichlor	350			.019
ETI		500		cost of power
Hamworthy Aquarius UV				
Hi Tech Marine	150	1600	16.5 – 300[1] *(equipment)*	nil[2]
Hitachi/Mitsubishi		400		
Hyde Marine	250	1200	174 – 503[1]	<.020
Hyundai Heavy Industries (1) – Ecoballast				
Hyundai Heavy Industries (2) – HiBallast				

[1] Source: Communications with technology vendors (2007-2008).
[2] Assumes waste heat utilized

Table VI-6. Summary of capital and operating cost data for select treatment systems. Unless otherwise noted, source of data is Lloyd's Register (2010).

Manufacturer	Capital Expenditure *(Equipment & Installation)* 200 m^3/h *($ in thousands)*	2000 m^3/h *($ in thousands)*	Other *($ in thousands)*	Operating Expenditure *($ /m^3)*
JFE Eng. Corp./TG Corp.				0.053
Kwang San Co. Ltd.				
MAHLE				
MARENCO	145	175		0.0006 - 0.001
Maritime Solutions Inc.				
Mexel Industries	20	50		
MH Systems	500	1500		0.06
Mitsui Engineering			100[1] *(installation)*	0.15[3]
NEI	249	670		0.13
NK Co. Ltd.	250	1000		0.007
Ntorreiro				
Nutech 03 Inc.	250	450		0.32
OceanSaver	288	1600		0.06[3]
OptiMarin	290	1280		
Panasia Co. Ltd.				
Pinnacle Ozone Solutions	200	500		0.013
Qingdao Headway Tech.				0.0018
Resource Ballast Tech.	275	700		
RWO Marine Water Tech.				
Severn Trent De Nora	630	975		0.020
Siemens	500	1000		0.0085 - 0.010
Sunrui CFCC				
Techcross Inc.	200	600		0.003
Wartsila				

[3] Source: Lloyd's Register (2007)

VII. DISCUSSION AND CONCLUSIONS

Efficacy and Availability

Sixty-three (63) systems were reviewed by Commission staff. Of these, reliable efficacy data were available for thirty-four (34) systems. Thirteen (13) systems demonstrated potential to comply with California ballast water discharge standards In this case, potential was defined as one test (averaged across replicates) in compliance with each of the California standards (see Table V!-2 and Appendix A). All of these systems are available for purchase. Six (6) systems demonstrated potential to comply with California's standards in over 50% of land-based or shipboard tests.

Three (3) systems demonstrated potential compliance with California standards in 100% of shipboard tests. One (1) additional system also demonstrated potential to comply in 100% of shipboard tests, but did not conduct testing for bacteria. High system success rates in shipboard tests were not always reflected under more rigorous land-based testing conditions. As California's performance standards are discharge standards that can only be sampled via discharge lines, Commission staff determined that shipboard trials most accurately reflect the scenarios under which compliance evaluation would take place. Protocols have been proposed for compliance evaluation, and resemble those used for shipboard tests during testing for Type Approval with modifications for shipboard compliance testing conditions. Thus, in assessing whether systems were available to treat ballast water to the standards specified in existing California law, shipboard trials were considered more indicative of a system's ability to treat to California's discharge standards.

Although in this report, systems show potential to treat to California's standards for the 10 – 50 micron organism size class, given the volumes sampled it will be desirable to have data gathered by Commission staff using protocols developed for compliance assessment. This size class is of particular importance because it is the one standard of California's seven adopted performance standards that is exactly

1000X more protective than the un-ratified IMO standards. Sampling protocols for compliance assessment are currently going through a public rulemaking process under the Administrative Procedures Act (APA), and will be useful for data collection. Pursuant to Commission direction, these compliance assessment protocols could be made non-enforceable beyond IMO standards and California standards for bacterial concentrations while data are compiled.

Environmental impacts

Forty-one (41) systems of the sixty-three (63) considered for this report provided some sort of environmental testing/compliance information. Of the thirteen (13) systems that demonstrated potential to comply with California standards, seven (7) demonstrated compliance with the EPA's Vessel General Permit limits for total residual chlorine (TRC; 100 µg/l), and have a flexible mechanism for neutralizing residual chlorine. Five (5) of the thirteen systems that demonstrated potential to comply with Cailfornia standards utilize technologies other than chlorine or chlorinated compounds to treat ballast water (e.g. UV light), and are thus not covered under the Vessel General Permit. Of the six (6) systems that met or exceeded CA standards in >50% efficacy tests, all have received IMO Basic and Final Approvals for active substances or do not require these approvals. Of the four (4) systems that demonstrated potential to comply with California standards in 100% of shipboard tests (this number includes the one (1) system that did not conduct tests for total heterotrophic bacteria), three (3) provided data sufficient to demonstrate that treated water can neutralized by the system to comply with California's most stringent limits for total residual chlorine (TRC/TRO; freshwater limit = 20 µg/l, Ocean water limit = 60 µg/l).

Any system that utilizes chlorine or chlorine compounds will need to comply with California's 401 certification of the EPA's Vessel General Permit, which contains special conditions for chlorine residuals in effluents. The California State Water

Board administers this certification, and anyone wishing to purchase a system for operation in California waters is advised to discuss whether any chlorine residuals produced by treatment technologies can be neutralized to legal levels for the state of California.

Systems that do not require active substance approvals include those which use UV light to kill organisms entrained in ballast water. Mortality is often delayed for organisms in UV-light systems. In other words, UV systems that treat on uptake may be most beneficial to ships that retain ballast water for several days.

In summary, there is sufficient evidence to conclude that multiple ballast water treatment systems are available for purchase that will meet California's standards in shipboard compliance assessments carried out for research and enforcement purposes as mandated by California law, with the exception of the standard for organisms in the 10 – 50 micron size range. The ballast water treatment technologies available today are more numerous and more effective than when the previous legislatively mandated report was presented to the Legislature by the Commission in 2010. The systems that are available have mechanisms in place that can treat effluents to remove chemical residuals. Large data gaps still exist regarding the efficacy of systems for all vessel types and under all operational conditions, but without widespread and assertive efforts to install and correctly use treatment systems onboard vessels, it is unlikely that these gaps will be filled.

VIII. RECOMMENDATIONS

Recommendations

California remains the leader in the nation for ballast water management, because of the Legislative mandate for comprehensive ballast water performance standards regulations. California has standards set in statute, conducts regular reviews of the efficacy and availability of treatment technologies to meet those standards, and is developing protocols to assess vessel compliance with California's standards (see Notice of Proposed Rulemaking for 2 California Code of Regulations, Section 2291 *et seq*.). The compliance protocols in development will clearly delineate the methods that will be used to assess vessel compliance with California's performance standards for the discharge of ballast water and will provide transparency to the regulated industry. No other state or federal agency has such a comprehensive program in place at this time.

Given the conclusion that multiple systems exist that have demonstrated potential to meet California standards, the Commission recommends that the Legislature:

1) Support the development of compliance assessment protocols pursuant to Commission direction, including a provision to delay enforcement of standards beyond the IMO standards for all but the *Escherichia coli* and intestinal enterococci standards so that important data on treatment system ability to satisfy a protective standard may be collected.

2) Support the Commission to move forward with the implementation of performance standards for vessels in the 1500 – 5000 metric ton ballast water capacity size class, in coordination with the compliance protocols described above that would delay enforcement beyond the IMO standards for all but the *Escherichia coli* and intestinal enterococci standards for two years while Commission staff collects data on treatment system ability to meet a protective standard.

3) Support the Commission's collection of important data using the compliance assessment protocols currently in development. In two years, performance standard evaluation practices can then be revisited by Commission scientists in light of the data gathered. This will enable Commission staff to provide recommendations in subsequent reports to the

Commission and Legislature in advance of the January 1, 2016 implementation date.

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XII. APPENDICES

APPENDIX A

Ballast Water Treatment System

Efficacy Matrix

Staff included data from shipboard, dockside and laboratory studies of system performance. In an effort to standardize results, staff evaluated any data on zooplankton abundance as representative of the largest size class of organisms (greater than 50 µm in size), and phytoplankton abundance was evaluated on par with organisms in the 10 – 50 µm size class. Results presented as percent reduction in organism abundance or as concentration of pigments or biological compounds associated with organism presence were noted, but these metrics were not comparable to the performance standards.

In the following tables, systems with at least one test (averaged across replicates) in compliance with the performance standard are scored as having the potential to meet California standards. Efficacy data with no tests demonstrating potential compliance with the standards are scored as not meeting California standards. Systems that presented data for a given organism size class but presented the results in metrics not comparable to the standards are classified as "Unknown." For example, a system that presented results of system efficacy as percent reduction of zooplankton abundance could not be compared against the California standards, and thus ability of the system to comply with the standards is unknown. Open cells indicate lack of data for a given organism size class. Compliance with the bacteria standard was assessed using the concentration of culturable heterotrophic bacteria in discharged ballast water. Due to the lack of available methods to both quantify and assess the viability of all viruses, systems cannot be assessed for compliance with the viral standard at this time. The source(s) of the data for each system can be found in the Literature Cited section of the main report.

Appendix A1 Organisms > 50 μm

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls	# Organisms/cubic meter	Methods	Reference
21 Century Shipbuilding	Laboratory	2	1	Unk	Unk	0 - 10	Unk	148
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Alfa Laval	Laboratory	1	0	-	-	Unk (% Reduction)	Visual Assesment	61, 170, 173, 176
	Land-Based	10	4	3	Y	0 - 63.7±33.2	Visual Assessment	61, 170, 173, 176
	Shipboard	4	1	9	Y	0 - 3	Microscope/mobility	61, 170, 173, 176
atg UV Technology	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Aqua Eng. Co. Ltd	Laboratory	10	0	Unk	Y	2 - 5	-	149, 153
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Auramarine Ltd.	Laboratory	-	-	-	-	-	-	3, 177
	Land-Based	11	0	3	Y	0 - 448 ± 295	Visual Assessment	3, 177
	Shipboard	-	-	-		-	-	3, 177
Brillyant Marine LLC	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Coldharbour Marine	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
COSCO/Tsinghua Univ.	Laboratory	-	-	-	-	-	-	124, 153
	Land-Based	-	-	-	-	-	-	124, 153
	Shipboard	-	-	-		-	-	124, 153
DESMI Ocean Guard A/S	Laboratory	-	-	-	-	-	-	29, 133
	Land-Based (fresh)	6	1	3	Y	0-30	Microscope/mobility	29, 133
	Land-Based (brackish)	5	4	3	Y	0-5	Microscope/mobility	29, 133
	Shipboard	-	-	-	-	-	-	29, 133
Ecochlor	Laboratory[1]	2	2	2	Y	0 - $3.5x10^5$	Visual, Neutral Red Stain	54, 116, 162
	Land-Based	15	8	-	Y	0 - 81	Visual Assess, Neutral Red	54, 116, 162
	Shipboard[1]	3	3	3	Y	0-5	Visual Assessment	54, 116, 162
Electrichlor	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
ETI	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-

Unk = Unknown, [1] = Filter added to system since testing conducted

Appendix A1 Organisms > 50 μm

Manufacturer	Location	#	# Tests Met Std	Replicates	Controls	# Organisms/cubic meter	Methods	Reference

		Tests						
Hamworthy Aquarius EC	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Hamworthy Aquarius UV	Laboratory	-	-	-	-	-	-	57, 58
	Land-Based	-	-	-	-	-	-	57, 58
	Shipboard	2	0	3	Y	BD - 3.6	Microscope/Mobility	57, 58
Hi Tech Marine	Laboratory	-	-	-	-	-	-	66
	Land-Based	-	-	-	-	-	-	66
	Shipboard	2	0	-	-	Unk (% mortality)	-	66
Hitachi	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Hyde Marine	Laboratory	1	0	Y	Y	-	Visual Assessment	89, 163, 231
	Land-Based	10	1	Y	Y	0 - 7.3	Visual, Neutral Red Stain	89, 163, 231
	Shipboard	3	3	9	Y	0	Visual, Neutral Red Stain	89, 163, 231
Hyundai Heavy Industries (1)	Laboratory	2	2	9	Y	0	Unk	134, 139
	Land-Based	-	-	-	-	-	-	134, 139
	Shipboard	-	-	-	-	-	-	134, 139
Hyundai Heavy Industries (2)	Laboratory	2	2	9	Y	0	Unk	134, 139
	Land-Based	-	-	-	-	-	-	134, 139
	Shipboard	-	-	-	-	-	-	134, 139
JFE Engineering Corp	Laboratory	-	-	-	-	-	-	49
	Land-Based	11	6	Y	Y	0 - 5.8	Microscope Count	49
	Shipboard	6	3	N	Y	0 - 2.3	Microscope Count	49
Kwang San Co. Ltd.	Laboratory	2	0	Unk	Y	160-180	Unk	136, 140
	Land-Based	-	-	-	-	-	-	136, 140
	Shipboard	-	-	-	-	-	-	136, 140
MAHLE	Laboratory	-	-	-	-	-	-	52, 165
	Land-Based	11	1	N	Y	0.3-26.3	Neutral Red	52, 165
	Shipboard	4	4	3	Y	0	Microscope Count	52, 165
MARENCO	Laboratory	-	-	-	-	-	-	83, 84, 229
	Land-Based	4	3	3	Y	0 - 1.57	Visual Assessment	83, 84, 229
	Shipboard	-	-	-	-	-	-	83, 84, 229
Maritime Solutions Inc.	Laboratory	-	-	-	-	-	-	98, 146
	Land-Based	5	0	5	Y	6 - 2170	Microscope/Mobility	98, 146
	Shipboard	-	-	-	-	-	-	98, 146

Unk = Unknown, BD = Below Detection Limits

Appendix A1 Organisms > 50 μm

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls	# Organisms/cubic meter	Methods	Reference
MH Systems	Laboratory	11	10	Y	Y	Unk (No Units)	Visual Assessment	45

	Land-Based	-	-	-	-	-	-	45
	Shipboard	-	-	-	-	-	-	45
Mitsui Engineering	Laboratory	-	-	-	-	-	-	72, 74, 75
	Land-Based	4	0	3-5	Y	BD, 2 $x10^5$ - $1.4x10^6$	Visual Assessment	72, 74, 75
	Shipboard	1	0	-	Y	8	Visual Assessment	72, 74, 75
NEI	Laboratory	-	-	-	-	-	-	208, 210
	Land-Based	5	1	Y	Y	0, Unk (% Survival)	Visual Assessment	208, 210
	Shipboard	2	1	Y	Y	0 - 7	Visual Assessment	208, 210
NK-O3	Laboratory	-	-	-	-	-	-	81, 117
	Land-Based	12	1	N	N	0 - 99	Microscope/Mobility	81, 117
	Shipboard	4	0	N	N	0 - 2	Microscope/Mobility	81, 117
Nutech O3 Inc.	Laboratory	3	0	4	Y	$1.2x10^2$ - $1.2x10^4$	Visual Assessment	65, 192, 234
	Land-Based	3	0	Y	Y	Unk (% Live)	Visual Assessment	65, 192, 234
	Shipboard	3	2	12	Y	0 - 150	Visual Assessment	65, 192, 234
OceanSaver	Laboratory	-	-	-	-	-	-	114, 171
	Land-Based	25	2	0-3	Y	0-189	Visual Assessment	114, 171
	Shipboard	3	1	3	Y	0 - 9720	Visual Assessment	114, 171
OptiMarin	Laboratory	1	0	-	Y	> 0	Visual Assessment	168, 172
	Land-Based	14	8	3	Y	0 - 2.3 ± 1.2	Microscope/Mobility	168, 172
	Shipboard	8	0	9	Y	1.4 - ~5500	Microscope/Mobility	168, 172
Panasia Co.	Laboratory	-	-	-	-	-	-	80, 82
	Land-Based (Brackish)	5	1	3	Y	ND - 18	Microscope/Mobility	80, 82
	Land-Based (Seawater)	5	3	3	Y	ND - 9	Microscope/Mobility	80, 82
	Shipboard	3	0	3	Y	ND - 4	-	80, 82
Qingdao Headway Tech	Laboratory	-	-	-	-	-	-	141, 175
	Land-Based	13	4	3	Y	0 - 15.3	Microscope/Mobility	141, 175
	Shipboard	3	3	Y	Y	0	Microscope/Mobility	141, 175
Resource Ballast Tech	Laboratory	-	-	-	-	-	-	106, 130
	Land-Based	3	3	Unk	Y	0	Microscope/Mobility	106, 130
	Shipboard	2	0	3	Y	0.6 - 1.1	Microscope/Mobility	106, 130
RWO Marine Water Tech	Laboratory	1	1	-	-	0	Visual Assessment	53, 178
	Land-Based	13	6	N	Y	0 - 63.7 ± 33.2	Visual Assessment	53, 178
	Shipboard	5*	4	3	Y	0	Microscope/Motility	53, 178

Unk = Unknown, BD = Below Detection Limits

Appendix A1 Organisms > 50 µm

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls	# Organisms/cubic meter	Methods	Reference
Severn Trent[1]	Laboratory	-	-	-	-	-	-	64, 142, 164

	Land-Based	11	7	3	Y	0 - 4.3	Visual Assessment	64, 142, 164
	Shipboard	4	2	3	Y	0 - 6.41	-	64, 142, 164
Siemens	Laboratory	-	-	-	-	-	-	60, 97, 155
	Land-Based	2	0	5	Y	4.5 - 57 ± 37	Microscope/Mobility	60, 97, 155
	Shipboard	-	-	-	-	-	-	60, 97, 155
Sunrui CFCC	Laboratory	-	-	-	-	-	-	138
	Land-Based	-	-	-	-	-	-	138
	Shipboard	-	-	-	-	-	-	138
Techcross Inc.	Laboratory	-	-	-	-	-	-	78, 79
	Land-Based	12	9	3	Y	0-6	Visual Assessment	78, 79
	Shipboard	3	3	3	Y	0	Visual Assessment	78, 79

[1] System has added a filter since testing was conducted, nd = not detected

Appendix A2 Organisms 10 - 50 µm

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls	# Organisms/ml	Methods	Reference
21 Century Shipbuilding	Laboratory	2	0	Unk	Unk	1	Unk	148
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Alfa Laval	Laboratory	1	0	-	-	Unk (% Reduction)	Visual Assesment	82
	Land-Based	10	3	3	Y	0-169±47	Microscope/stain (CDFA_AM), MPN	137
	Shipboard	4	1	9	Y	0-1.7	Microscope/stain (CDFA_AM), MPN	138
AQUA Eng. Co. Ltd.	Laboratory	10	8	Unk	Y	0-1	-	149, 153
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Auramarine Ltd.	Laboratory	-	-	-	-	-	-	3, 177
	Land-Based	11	5	3	Y	0 - 348 ± 22	CDFA-AM	3, 177
	Shipboard	-	-	-		-	-	3, 177
COSCO/Tsinghua Univ.	Laboratory	-	-	-	-	-	-	124, 153
	Land-Based	-	-	-	-	-	-	124, 153
	Shipboard	-	-	-		-	-	124, 153
DESMI Ocean Guard A/S	Laboratory							29, 133
	Land- Based (Fresh)	6	0	3	Y	0.2-5.3	Flourescence Microscopy	29, 133
	Land-Based (Brackish)	5	0	3	Y	29.2-52.7	Flourescence Microscopy	29, 133
	Shipboard	-	-	-		-	-	29, 133
DESMI Ocean Guard A/S Ecochlor	Laboratory[1]	2	0	2	Y	<0.1 - >60, Unk ([Chl a])	Visual Assessment, MPN, [Chl a]	54, 116, 162
	Land-Based	11	9	N	Y	0.0 - 3.7	Visual, Sytox, flow cytometer, PAM fluorometer	54, 116, 162
	Shipboard[1]	3	3	3	Y	0-81	Visual Assessment, [Chl a], flourometry, flow cytometry	54, 116, 162
EcologiQ	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Electrichlor	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
ETI	Laboratory	-	-	-	-	-	-	-
	Land-Based	3	0	2-3	Y	1 - 1.5	Growout (+, -), Flowcam	73,74,75
	Shipboard	-	-	-	-	-	-	-

Unk = Unkown, MPN = Most Probable Number, [1] = Filter added to system since testing conducted

Appendix A2 Organisms 10 - 50 µm

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls	# Organisms/ml	Methods	Reference
Hamworthy EC	Laboratory							
	Land-Based							
	Shipboard							
Hamworthy UV	Laboratory							57, 58
	Land-Based							57, 58
	Shipboard	2	2	3	Y	BD	-	57, 58
Hi Tech Marine	Laboratory	-	-	-	-	-	-	66
	Land-Based	-	-	-	-	-	-	66
	Shipboard	2	Unk	Unk	Unk	Unk (% Mortality)	Unk	66
Hitachi	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Hyde Marine	Laboratory	1	0	Y	Y	26 - 210	Visual Assessment, Coulter, MPN	89, 163, 231
	Land-Based	10	0	Y	Y	0.0 - 10.9	SYTOX Green, FCM, [Chl a]	89, 163, 231
	Shipboard	3	1	9	Y	0.002 - 0.10	Visual, [Chl a], Growout, neutral red	89, 163, 231
Hyundai Heavy Industries (1)	Laboratory	2	2	9	Y	0	Unk	134, 139
	Land-Based	-	-	-	-	-	-	134, 139
	Shipboard	-	-	-	-	-	-	134, 139
Hyundai Heavy Industries (2)	Laboratory	2	2	9	Y	0	Unk	134, 139
	Land-Based	-	-	-	-	-	-	134, 139
	Shipboard	-	-	-	-	-	-	134, 139
JFE Engineering Corp	Laboratory	-	-	-	-	-	-	49
	Land-Based	11	0	Y	Y	<0.1 - 1.5	CDFA flourescence, most probable number	49
	Shipboard	6	5	N	Y	0 - 0.3	microscope counts	49
Kwang San Co. Ltd.	Laboratory	2	0	Unk	Y	1	Unk	136, 140
	Land-Based	-	-	-	-	-	-	136, 140
	Shipboard	-	-	-	-	-	-	136, 140
MAHLE	Laboratory	-	-	-	-	-	-	52, 165
	Land-Based	11	4	Y	Y	0 - 5.92	flow cytometry, SYTOX Green	52, 165
	Shipboard	4	4	Y	Y	0	Flourescence Microscopy	52, 165
MARENCO	Laboratory	-	-	-	-	-	-	83, 84, 229
	Land-Based	1	0	3	Y	0.05 - 0.186	MPN, [Chl a], ^{14}C, PAM	83, 84, 229
	Shipboard	-	-	-	-	-	-	83, 84, 229
Maritime Solutions Inc.	Laboratory	-	-	-	-	-	-	98, 146
	Land-Based	5	0	5	Y	0.6-12	CDFA-AM, Chl a	98, 146
	Shipboard	-	-	-	-	-	-	98, 146

Unk = Unkown, MPN = Most Probable Number, Below Detection Limits

Appendix A2 Organisms 10 - 50 µm

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls	# Organisms/ml	Methods	Reference

MH Systems	Laboratory	-	-	-	-	-	-	45
	Land-Based	-	-	-	-	-	-	45
	Shipboard	-	-	-	-	-	-	45
Mitsui Engineering	Laboratory	-	-	-	-	-	-	72, 74, 75
	Land-Based	4	Unk	3-5	Y	BD, 206.6 - 387.4, Unk	Visual Assessment (20 - 50um)	72, 74, 75
	Shipboard	1	Unk	Unk	Y	BD	Visual Assessment	72, 74, 75
NEI	Laboratory	-	-	-	-	-	-	208, 210
	Land-Based	1	0	Y	Y	Unk	[Chl a]	208, 210
	Shipboard	4	Unk	Y	Y	443 - 593	Total Counts (Preserved), [Chl a], Regrowth	208, 210
NK-O3	Laboratory	-	-	-	-	-	-	81, 117
	Land-Based	12	7	N	N	0 - 9	-	81, 117
	Shipboard	4	3	N	N	0 - 3	CDFA, microscopy	81, 117
Nutech O3 Inc.	Laboratory	3	0	4	Y	Unk	[Chl a]	65, 192, 234
	Land-Based	2	0	Y	Y	22 - 190	Total Counts (Preserved)	65, 192, 234
	Shipboard	3	0	5	Y	0.016 - 4	[Chl a], Grow Out, Counts	65, 192, 234
OceanSaver	Laboratory	-	-	-	-	-	-	114, 171
	Land-Based	25	5	0-3	Y	0-8.7	dilution, microscopy (CFDA stain), plate counts	114, 171
	Shipboard	2	0,Unk	3	Y	0-2.8	Microscope (CFDA stain), Photosynethic rates	114, 171
OptiMarin	Laboratory	1	0	-	Y	26 - 210	MPN, Coulter	168, 172
	Land-Based	14	6	3	Y	0 - 274 ± 133	CDFA, Microscope/stain, MPN, agar plates	168, 172
	Shipboard	8	2	9	Y	0 - 3.9	CDFA, microscopy, MPN	168, 172
Panasia Co.	Laboratory	-	-	-	-	-	-	80, 82
	Land-Based (Brackish)	5	3	3	Y	ND - 8	CDFA, microscopy	80, 82
	Land-Based (Seawater)	5	3	3	Y	ND - 5	CDFA, microscopy	80, 82
	Shipboard	3	2	3	Y	ND - <1	CDFA, microscopy	80, 82
Qingdao Headway Tech	Laboratory	-	-	-	-	-	-	141, 175
	Land-Based	13	8	3	Y	0-35	Serial dilution, CFDA-AM	141, 175
	Shipboard	3	3	Y	Y	0.0007 - 0.003	Microscope/stain (CDFA), MPN	141, 175
Resource Ballast Tech	Laboratory	-	-	-	-	-	-	106, 130
	Land-Based	3	0	Unk	Y	0.32 - 2.7	FDA stain, FlowCAM	106, 130
	Shipboard	2	0	3	Y	0.5 - 1.4	FDA stain, FlowCAM	106, 130
RWO Marine Water Tech	Laboratory	1	1	Unk	Unk	0	Visual Assessment	53, 178
	Land-Based	13	8	N	Y	0 - 169 ± 47	Microscope Counts	53, 178
	Shipboard	5*	5	3	Y	0	-	53, 178

Unk = Unknown, BD = Below Detection Limits, MPN = Most Probably Number

Appendix A2 Organisms 10 - 50 µm

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls	# Organisms/ml	Methods	Reference
Severn Trent[1]	Laboratory	-	-	-	-	-	-	64, 142, 164

	Land-Based	11	7	3	Y	0 - 3.7	flow cytometry	64, 142, 164
	Shipboard	4	0	3	Y	0.11 - 6.13	FDA flow cytometry, MPN	64, 142, 164
Siemens	Laboratory	-	-	-	-	-	-	60, 97, 155
	Land-Based	2	1	5	Y	0 - 0.5 ± 0.3	CFDA PAM, Chl a	60, 97, 155
	Shipboard	-	-	-	-	-	-	60, 97, 155
Sunrui CFCC	Laboratory	-	-	-	-	-	-	138
	Land-Based	-	-	-	-	-	-	138
	Shipboard	-	-	-	-	-	-	138
Techcross Inc.	Laboratory	-	-	-	-	-	-	78, 79
	Land-Based	12	10	3	Y	0-4	Light micro., epifluor. and fluorometer (FDA stain)	78, 79
	Shipboard	3	3	3	Y	0	Light micro., epifluor. and fluorometer (FDA stain)	78, 79
Wartsila	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-

Unk = Unknown, BD = Below Detection Limits, MPN = Most Probably Number, [1] = Filter added to system since testing conducted

Appendix A6 Organims < 10 µm (Bacteria)

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls	# Organisms/100 ml	Methods	Reference
21 Century Shipbuilding	Laboratory	-	-	-	-	-	-	148
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Alfa Laval	Laboratory	1	0	-	-	Unk (% Reduction)	Visual Assesment	82
	Land-Based	8	0	3	Y	$1.3 \pm 0.1 \times 10^4$ - $4.0 \pm 0.7 \times 10^5$	Plate counts, NS-EN 6222:1999	137
	Shipboard	2	2	9	Y	480 - 800	Plate Counts, Difco marine agar	141
AQUA Eng. Co. Ltd.	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Auramarine Ltd.	Laboratory	-	-	-	-	-	-	3, 177
	Land-Based	11	10*	3	Y	$15 \pm 3 \times 10^1$ - $7.3 \pm 1.7 \times 10^4$	Plate counts, NS-EN 6222:1999	3, 177
	Shipboard	-	-	-		-	-	3, 177
COSCO/Tsinghua Univ.	Laboratory	-	-	-	-	-	-	124, 153
	Land-Based	10	-	-	-	0 – 7.62×10^2**	-	124, 153
	Shipboard	3	-	-	-	-	-	124, 153
DESMI Ocean Guard A/S	Laboratory						-	29, 133
	Land-Based (Fresh)	6	6	3	Y	22-69	Unk	29, 133
	Land-Based (Brackish)	5	5	3	Y	75-2149	Unk	29, 133
	Shipboard	-	-	-		-	-	29, 133
Ecochlor	Laboratory[1]	2	2	2	Y	0,Unk (% of control, % Plate cover)	Plate Counts, ^{3}H-leucine	54, 116, 162
	Land-Based	11	8	N	Y	<10 - 1700	plate, NEN-EN-ISO 6222:1999	54, 116, 162
	Shipboard[1]	-	-	-	-	-	-	54, 116, 162
EcologiQ	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Electrichlor	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
ETI	Laboratory	1	0	3	Y	-	Plate Counts, BacLight	72
	Land-Based	3	0	2-3	Y	5×10^7 - 1×10^9	Growout (+, -), FCM/PicoGreen	73,74,75
	Shipboard	-	-	-	-	-	-	-

Unk = Unknown, BD = Below Detection Limits, FCM = Flow Cytometer, [1] = Filter added to system since testing conducted, ** = minimum and maximum known, but not number of replicates.

Appendix A6 Organims < 10 µm (Bacteria)

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls	# Organisms/100 ml	Methods	Reference

Hamworthy Aquarius EC	Laboratory							
	Land-Based							
	Shipboard	1	1	3	Y	BD	-	
Hamworthy Aquarius UV	Laboratory	-	-	-	-	-	-	57, 58
	Land-Based	-						57, 58
	Shipboard	2	2	3	Y	BD	Unk	57, 58
Hi Tech Marine	Laboratory	-	-	-	-	-	-	66
	Land-Based	6	5	Y	Y	1 - $1.9x10^{6}$	APHA 9215B, pour plate method	66
	Shipboard	-	-	-	-	-	-	66
Hyde Marine	Laboratory	1	0	Y	Y	~5000 - 7000	Plate Counts	89, 163, 231
	Land-Based	10	5	Y	Y	<1000 - >100000	Plate Counts, AODC	89, 163, 231
	Shipboard	3	3	9	Y	1 - 148	Plate Counts	89, 163, 231
Hyundai Heavy Industries (1)	Laboratory	-	-	-	-	-	-	134, 139
	Land-Based	-	-	-	-	-	-	134, 139
	Shipboard	-	-	-	-	-	-	134, 139
Hyundai Heavy Industries (2)	Laboratory	-	-	-	-	-	-	134, 139
	Land-Based	-	-	-	-	-	-	134, 139
	Shipboard	-	-	-	-	-	-	134, 139
JFE Engineering Corp	Laboratory	-	-	-	-	-	-	49
	Land-Based	11	11	Y	Y	3 - 2.1 $\pm$ 0.7 X 10^{2}	NS-EN 6222:1999	49
	Shipboard			-	-	-	-	49
Kwang San Co. Ltd.	Laboratory	2	2	Unk	Y	0	Unk	136, 140
	Land-Based	-	-	-	-	-	-	136, 140
	Shipboard	-	-	-	-	-	-	136, 140
MAHLE	Laboratory	-	-	-	-	-	-	52, 165
	Land-Based	11	11	Y	Y	nd - 1000	NEN-EN-ISO 6222:1999	52, 165
	Shipboard	4	4	Y	Y	0		52, 165
MARENCO	Laboratory		-	-	-	-	-	83, 84, 229
	Land-Based	3	2	3	Y	0 - ~$5x10^{8}$	Plate Counts, Membrane Filtration	83, 84, 229
	Shipboard	-	-	-	-	-	-	83, 84, 229
Maritime Solutions Inc.	Laboratory	-	-	-	-	-	-	98, 146
	Land-Based	5	3	5	Y	116.88-7860	Plate Counts	98, 146
	Shipboard	-	-	-	-	-	-	98, 146

Unk = Unknown, AODC = Acridine Orange Direct Counts, FCM = Flow Cytometer, BD = Below Detection Limits

Appendix A6 Organims < 10 µm (Bacteria)

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls	# Organisms/100 ml	Methods	Reference
MH Systems	Laboratory	-	-	-	-	-	-	45

	Land-Based	-	-	-	-	-	-	45
	Shipboard	-	-	-	-	-	-	45
Mitsui Engineering	Laboratory	-	-	-	-	-	-	72, 74, 75
	Land-Based	2	0	3	Y	BD, Unk	Plate Counts	72, 74, 75
	Shipboard	1	0	-	Y	BD	Plate Counts	72, 74, 75
NEI	Laboratory	-	-	-	-	-	-	208, 210
	Land-Based	2	0	Y	Y	> 1x10^{8}	FCM	208, 210
	Shipboard	2	0	Y	Y	7.3x10^{7} - 7.9x10^{7}	FCM	208, 210
NK-O3	Laboratory	-	-	-	-	-	-	81, 117
	Land-Based	-	-	-	-	-	-	81, 117
	Shipboard	-	-	-	-	-	-	81, 117
Nutech O3 Inc.	Laboratory	3	3	4	Y	≤ 10^{1} - 10^{8}	Plate Counts, Membrane Filtration	65, 234
	Land-Based	3	3	Y	Y	3x10^{-1} - 3x10^{2}	Plate Counts, Membrane Filtration	65, 234
	Shipboard	2	2	9-12	Y	0	Plate Counts, Filtration	65, 234
OceanSaver	Laboratory	-	-	-	-	-	-	114, 171
	Land-Based	16	16	0-3	Y	0 - 8.2x10^{5}/ml	Plate Counts	114, 171
	Shipboard	-	-	-	-	-	-	114, 171
OptiMarin	Laboratory	2	0	Unk	Y	~ 5x10^{3} - ~7x10^{3}	Plate Counts	168, 172
	Land-Based	14	2	3	Y	3.9 ± 1.9 - 1.2 ± 0.5x 104	NS-EN6222/NS 4791	168, 172
	Shipboard	-	-	-	-	-		168, 172
Panasia Co.	Laboratory	-	-	-	-	-	-	80, 82
	Land-Based (Brackish)							80, 82
	Land-Based (Saltwater)					-	-	80, 82
	Shipboard					-	-	80, 82
Qingdao Headway Tech	Laboratory	-	-	-	-	-	-	141, 175
	Land-Based	13	9	3	Y	30 - 19000	Plate Counts	141, 175
	Shipboard	3	3	Y	Y	243 - 590	Plate Counts	141, 175
Resource Ballast Tech	Laboratory	-	-	-	-	-	-	106, 130
	Land-Based	-	-	-	-	-	-	106, 130
	Shipboard	-	-	-	-	-	-	106, 130
RWO Marine Water Tech	Laboratory	-	-	-	-	-	-	53, 178
	Land-Based	13	13	N	Y	2.2 ± 1.5 x 10^{3} - 0.9 ± 0.9	Plate counts	53, 178
	Shipboard	5	5	3	Y	0	-	53, 178

Unk = Unknown, FCM = Flow Cytometer, BD = Below Detection Limits

Appendix A6 Organims < 10 µm (Bacteria)

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls	# Organisms/100 ml	Methods	Reference
Severn Trent[1]	Laboratory	-	-	-	-	-	-	64, 142, 164
	Land-Based	11	10	3	Y	ND - 300,000	plate counts	64, 142, 164

	Shipboard	4	4	3	Y	0 - 54,000	MPN	64, 142, 164
Siemens	Laboratory	-	-	-	-	-	-	60, 97, 155
	Land-Based	2	2	5	Y	2.2 - 169,100	Plate Counts	60, 97, 155
	Shipboard	-	-	-	-	-	-	60, 97, 155
Sunrui CFCC	Laboratory	-	-	-	-	-	-	138
	Land-Based	-	-	-	-	-	-	138
	Shipboard	-	-	-	-	-	-	138
Techcross Inc.	Laboratory	-	-	-	-	-	-	78, 79
	Land-Based	4	4	3	Y	0 - 500	plate counts, DAFI stain	78, 79
	Shipboard	3	3	3	Y	ND	Fluorescent microscopy (DAFI)	78, 79
Wartsila	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-

Unk = Unknown, [1] = Filter added to system since testing conducted.

Appendix A3 ***E. coli***

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls used	# CFU/100 ml	Methods	Reference
21 Century Shipbuilding	Laboratory	2	2	Unk	Unk	0	Unk	148
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Alfa Laval	Laboratory	1	0	-	-	Unk (% Reduction)	-	82
	Land-Based	10	10*	3	Y	0 - 800	NS 4792, NS-EN ISO 9308-3	137
	Shipboard	4	4*	9	Y	0*		138
AQUA Eng. Co. Ltd.	Laboratory	10	9	Unk	Y	0-1	-	149, 153
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Auramarine Ltd.	Laboratory	-	-	-	-	-	-	3, 177
	Land-Based	11	11*	3	Y	<1	NS 4792, NS-EN ISO 9308-3	3, 177
	Shipboard	-	-	-		-	-	3, 177
COSCO/Tsinghua Univ.	Laboratory	-	-	-	-	-	-	124, 153
	Land-Based	10	-	-	-	<0.3**	-	124, 153
	Shipboard	3	-	-		<1**	-	124, 153
DESMI Ocean Guard A/S	Laboratory	-	-	-	-	-	-	29, 133
	Land-Based (Fresh)	6	6	3	Y	1	Unk	29, 133
	Land-Based (Brackish)	5	5	3	Y	1	Unk	29, 133
	Shipboard			-		-	-	29, 133
Ecochlor	Laboratory	-	-	-	-	-	-	54, 116, 162
	Land-Based	10	10	N	Y	<0.1	NEN-EN-ISO 9308-1	54, 116, 162
	Shipboard[1]	3	3	3	Y	0 - ~21	Idexx Labs Colilert, plate counts	54, 116, 162
EcologiQ	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Electrichlor	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
ETI	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Ferrate Treatment Tech.	Laboratory	1	0	-	-	300	Idexx Labs QuantiTray MPN	22
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-

Unk = Unkown, MPN = Most Probable Number, [1] = Filter added to treatment system since testing conducted, * = Initial concentration at intake was 0, unk or non-detectable, ** = minimum and maximum known, but not number of replicates.

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls used	# CFU/100 ml	Methods	Reference
Hamworthy Aquarius EC	Laboratory							
	Land-Based							
	Shipboard							
Hamworthy Aquarius UV	Laboratory							57, 58
	Land-Based							57, 58
	Shipboard	2	2	3	Y	BD		57, 58
Hi Tech Marine	Laboratory	-	-	-	-	-	-	66
	Land-Based	6	6	Y	Y	0	APHA 9222	66
	Shipboard	-	-	-	-	-	-	66
Hitachi	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Hyde Marine	Laboratory	-	-	-	-	-	-	89, 163, 231
	Land-Based	10	10*	N	Y	<10	NEN EN ISO 9308-1	89, 163, 231
	Shipboard	3	3*	9	Y	0	Idexx Labs Colisure	89, 163, 231
Hyundai Heavy Industries (1)	Laboratory	2	2	9	Y	0	Unk	134, 139
	Land-Based	-	-	-	-	-	-	134, 139
	Shipboard	-	-	-	-	-	-	134, 139
Hyundai Heavy Industries (2)	Laboratory	2	2	9	Y	0	Unk	134, 139
	Land-Based	-	-	-	-	-	-	134, 139
	Shipboard	-	-	-	-	-	-	134, 139
JFE Engineering Corp	Laboratory	-	-	-	-	-	-	49
	Land-Based	11*	11*	Y	Y	0	NS-EN-ISO 9308-3	49
	Shipboard	6	6	N	Y	0	Unk	49
Kwang San Co. Ltd.	Laboratory	2	2	Unk	Y	0	Unk	136, 140
	Land-Based	-	-	-	-	-	-	136, 140
	Shipboard	-	-	-	-	-	-	136, 140
MAHLE	Laboratory	-	-	-	-	-	-	52, 165
	Land-Based	11	11	Y	Y	-	NEN EN ISO 9308-1	52, 165
	Shipboard	4	4	Y	Y	0	ISO Standards	52, 165
MARENCO	Laboratory	-	-	-	-	-	-	83, 84, 229
	Land-Based	-	-	-	-	-	-	83, 84, 229
	Shipboard	-	-	-	-	-	-	83, 84, 229
Maritime Solutions Inc.	Laboratory	-	-	-	-	-	-	98, 146
	Land-Based	5	5	5	Y	0	IDEXX kit, Membrane Filtration	98, 146
	Shipboard	-	-	-	-	-	-	98, 146

Unk = Unknown, * = Initial concentration at intake was 0, unk or non-detectable, BD = Below Detection Limits

Appendix A3 *E. coli*

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls used	# CFU/100 ml	Methods	Reference
MH Systems	Laboratory	7	0, Unk	Unk	Y	BD-420	IDEXX Colilert 18	45
	Land-Based	-	-	-	-	-	-	45
	Shipboard	-	-	-	-	-	-	45
Mitsui Engineering	Laboratory	-	-	-	-	-	-	72, 74, 75
	Land-Based	2	0	3	Y	BD, Unk	Plate Counts	72, 74, 75
	Shipboard	-	-	-	-	-	-	72, 74, 75
NEI	Laboratory	-	-	-	-	-	-	208, 210
	Land-Based	1	0	Y	Y	10 - 160	Idexx Labs MPN Kit	208, 210
	Shipboard	2	2*	Y	Y	<100	Idexx Labs MPN Kit	208, 210
NK-O3	Laboratory	-	-	-	-	-	-	81, 117
	Land-Based	12	12	N	N	1 - 9	-	81, 117
	Shipboard	4	4	N	N	1	US EPA 1603	81, 117
Nutech O3 Inc.	Laboratory	-	-	-	-	-	-	65, 192, 234
	Land-Based	-	-	-	-	-	-	65, 192, 234
	Shipboard	3	3*	11-12	Y	0*	IDEXX Labs MPN Kit	65, 192, 234
OceanSaver	Laboratory	-	-	-	-	-	-	114, 171
	Land-Based	14	14*	3	Y	0-0.6X10^5	Membrane Filtration	114, 171
	Shipboard	3	3*	3	Y	0*	Membrane Filtration	114, 171
OptiMarin	Laboratory	-	-	-	-	-	-	168, 172
	Land-Based	14	14*	3	Y	0 - <1	ND 4792, NS-EN ISO 9308-1	168, 172
	Shipboard	8	8*	9	Y	0	NS 4788	168, 172
Panasia Co.	Laboratory	-	-	-	-	-	-	80, 82
	Land-Based (Brackish)	5	5	3	Y		Filtration and plate counts	80, 82
	Land-Based (Saltwater)	5	4	3	Y	-	Filtration and plate counts	80, 82
	Shipboard	3	3	3	Y	-	Filtration and plate counts	80, 82
Pinnacle Ozone Solutions	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Qingdao Headway Tech	Laboratory	-	-	-	-	-	-	141, 175
	Land-Based	13	13*	3	Y	<1	Plate Counts	141, 175
	Shipboard	3	3*	Y	Y	0	Membrane Filtration	141, 175
Resource Ballast Tech	Laboratory	-	-	-	-	-	-	106, 130
	Land-Based	3	3	Unk	Y	0	Unk	106, 130
	Shipboard	2	2*	3	Y	0	"Standard methods"	106, 130
RWO Marine Water Tech	Laboratory	-	-	-	-	-	-	53, 178
	Land-Based	13	13*	N	Y	0	EN ISO 9303-3	53, 178
	Shipboard	5	5	3	Y	0	-	53, 178

Unk = Unknown, MPN = Most Probable Number, BD = Below Detection Limits, * = Initial concentration at intake was 0, unk or non-detectable for some test cycles

Appendix A3 ***E. coli***

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls used	# CFU/100 ml	Methods	Reference

Severn Trent	Laboratory	-	-	-	-	-	-	64, 142, 164
	Land-Based	11	11	3	Y	ND - <10	plate counts	64, 142, 164
	Shipboard	4	0	3	Y	0	MPN	64, 142, 164
Siemens	Laboratory	-	-	-	-	-	-	60, 97, 155
	Land-Based	2	2	5	Y	0 - 1.2	Membrane Filtration	60, 97, 155
	Shipboard	-	-	-	-	-	-	60, 97, 155
Sunrui CFCC	Laboratory	-	-	-	-	-	-	138
	Land-Based	-	-	-	-	-	-	138
	Shipboard	-	-	-	-	-	-	138
Techcross Inc.	Laboratory	-	-	-	-	-	-	78, 79
	Land-Based	10	10*	3	Y	0	Plate counts	78, 79
	Shipboard	3	3*	3	Y	0	Plate Counts	78, 79
Wartsila	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-

Unk = Unknown, * = Initial concentration at intake was 0, unk or non-detectable

Appendix A4 Intestinal Enterococci

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls	# CFU/100 ml	Methods	Reference
21 Century Shipbuilding	Laboratory	2	2	Unk	Unk	0	Unk	148
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Alfa Laval	Laboratory	-	-	-	-	-	-	-
	Land-Based	10	10	6	Y	<1	NS-EN ISO 7899-2	137
	Shipboard	4	4*	9	Y	0	Membrane filtration	138
AQUA Eng. Co. Ltd.	Laboratory	10	6	Unk	Y	0-12	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Auramarine Ltd.	Laboratory	-	-	-	-	-	-	3, 177
	Land-Based	11	11*	3	Y	<1	NS-EN ISO 7899-2	3, 177
	Shipboard	-	-	-		-	-	3, 177
COSCO/Tsinghua Univ.	Laboratory	-	-	-	-	-	-	124, 153
	Land-Based	10	-	-	-	<0.3**	-	124, 153
	Shipboard	3	-	-		<0.3**	-	124, 153
DESMI Ocean Guard A/S	Laboratory	-	-	-	-	-	-	29, 133
	Land-Based (Fresh)	6	6	3	Y	1	Unk	29, 133
	Land-Based (Brackish)	5	5	3	Y	1	Unk	29, 133
	Shipboard			-		-	-	29, 133
Ecochlor	Laboratory	-	-	-	-	-	-	54, 116, 162
	Land-Based	11	11	N	Y	<1	NEN-EN ISO 7899-2	54, 116, 162
	Shipboard	3	3	Y	Y	0	plate counts	54, 116, 162
EcologiQ	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Electrichlor	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
ETI	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Ferrate Treatment Tech.	Laboratory	1	0	Unk	Unk	80	Idexx Labs QuantiTray MPN	22
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-

Unk = Unknown, * = Initial concentration at intake was 0, unk or non-detectable. **Minimum and maximum known, but not number of replicates.

Appendix A4 Intestinal Enterococci

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls	# CFU/100 ml	Methods	Reference
Hamworthy Aquarius EC	Laboratory							
	Land-Based							
	Shipboard							
Hamworthy Aquarius UV	Laboratory	-	-	-	-	-	-	57, 58
	Land-Based							57, 58
	Shipboard	2	2	3	Y	BD - 20		57, 58
Hi Tech Marine	Laboratory	-	-	-	-	-	-	66
	Land-Based	-	-	-	-	-	-	66
	Shipboard	-	-	-	-	-	-	66
Hitachi	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Hyde Marine	Laboratory	-	-	-	-	-	-	89, 163, 231
	Land-Based	10	10*	N	Y	<100	NEN EN ISO 7899-2	89, 163, 231
	Shipboard	3	3*	9	Y	0-3.4	Idexx Labs Enterolert	89, 163, 231
Hyundai Heavy Industries (1)	Laboratory	2	2*	9	Y	0	Unk	134, 139
	Land-Based	-	-	-	-	-	-	134, 139
	Shipboard	-	-	-	-	-	-	134, 139
Hyundai Heavy Industries (2)	Laboratory	2	2	9	Y	0	Unk	134, 139
	Land-Based	-	-	-	-	-	-	134, 139
	Shipboard	-	-	-	-	-	-	134, 139
JFE Engineering Corp	Laboratory	-	-	-	-	-	-	49
	Land-Based	11	11	Y	Y	0 - 2 ± 2	NS-EN-ISO 7899-2	49
	Shipboard	6	6	N	Y	0	Unk	49
Kwang San Co. Ltd.	Laboratory	2	2	Unk	Y	0	Unk	136, 140
	Land-Based	-	-	-	-	-	-	136, 140
	Shipboard	-	-	-	-	-	-	136, 140
MAHLE	Laboratory	-	-	-	-	-	-	52, 165
	Land-Based	11	9	Y	Y	0 - 80	NEN EN ISO 7899-2	52, 165
	Shipboard	4	4	Y	Y	3.0 - 9.0	ISO standards	52, 165
MARENCO	Laboratory	-	-	-	-	-	-	83, 84, 229
	Land-Based	-	-	-	-	-	-	83, 84, 229
	Shipboard	-	-	-	-	-	-	83, 84, 229
Maritime Solutions Inc.	Laboratory	-	-	-	-	-	-	98, 146
	Land-Based	5	5	5	Y	0	IDEXX kit, Membrane Filtration	98, 146
	Shipboard	-	-	-	-	-	-	98, 146

Unk = Unknown, * = Initial concentration at intake was 0, unk or non-detectable, BD = Below Detection Limits

Appendix A4 Intestinal Enterococci

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls	# CFU/100 ml	Methods	Reference

MH Systems	Laboratory	3	0	Unk	Y	90-350	IDEXX Enterolert	45
	Land-Based	-	-	-	-	-	-	45
	Shipboard	-	-	-	-	-	-	45
Mitsui Engineering	Laboratory	-	-	-	-	-	-	72, 74, 75
	Land-Based	2	0	3	Y	BD, Unk	Plate counts	72, 74, 75
	Shipboard	-	-	-	-	-	-	72, 74, 75
NEI	Laboratory	-	-	-	-	-	-	208, 210
	Land-Based	1	0	Y	Y	36	Idexx Labs MPN Kit	208, 210
	Shipboard	2	Unk	Y	Y	Unk	Idexx Labs MPN Kit	208, 210
NK-O3	Laboratory	-	-	-	-	-	-	81, 117
	Land-Based	12*	12	N	Y	1 - 8	-	81, 117
	Shipboard	4	4	N	N	1	US EPA 1600	81, 117
Nutech O3 Inc.	Laboratory	-	-	-	-	-	-	65, 192, 234
	Land-Based	-	-	-	-	-	-	65, 192, 234
	Shipboard	3	3*	11-12	Y	0*	Idexx Labs Enterolert	65, 192, 234
OceanSaver	Laboratory	-	-	-	-	-	-	114, 171
	Land-Based	25	20*	0-3	Y	0-133	Membrane Filtration	114, 171
	Shipboard	3	3*	3	Y	0*-9	Membrane Filtration	114, 171
OptiMarin	Laboratory	-	-	-	-	-	-	168, 172
	Land-Based	14	14*	3	Y	0 - <1	NS-EN ISO 7899-2, 7899	168, 172
	Shipboard	8	8*	9	Y	0	NEN-EN ISO 7899-2, 7899-1	168, 172
Panasia Co.	Laboratory	-	-	-	-	-	-	80, 82
	Land-Based (Brackish)	5	5	3	Y	ND - 2	Filtration and plate counts	80, 82
	Land-Based (Saltwater)	5	5	3	Y	ND - 1	Filtration and plate counts	80, 82
	Shipboard	3	3	3	Y	ND	Filtration and plate counts	80, 82
Pinnacle Ozone Solutions	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Qingdao Headway Tech	Laboratory	-	-	-	-	-	-	141, 175
	Land-Based	13	13*	3	Y	0.3 - <1	Membrane Filtration	141, 175
	Shipboard	3	3*	Y	Y	0.3 - 1	Membrane Filtration	141, 175
Resource Ballast Tech	Laboratory	-	-	-	-	-	-	106, 130
	Land-Based	-	-	-	-	-	-	106, 130
	Shipboard	2	2	3	Y	5.0 - 9.3	"Standad methods"	106, 130
RWO Marine Water Tech	Laboratory	-	-	-	-	-	-	53, 178
	Land-Based	13	13	N	Y	0	plate counts	53, 178
	Shipboard	5	5	3	Y	0	-	53, 178

Unk = Unknown, BD = Below Detection Limits, * = Initial concentration at intake was 0, unk or non-detectable, for some tests

Appendix A4 Intestinal Enterococci

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls	# CFU/100 ml	Methods	Reference
Severn Trent	Laboratory	-	-	-	-	-	-	64, 142, 164

	Land-Based	11	11	3	Y	<100	plate counts	64, 142, 164
	Shipboard	4	4	3	Y	0 - 1.67	MPN	64, 142, 164
Siemens	Laboratory	-	-	-	-	-	-	60, 97, 155
	Land-Based	2	2	5	Y	1.00 - 2.22	IDEXX kit	60, 97, 155
	Shipboard	-	-	-	-	-	-	60, 97, 155
Sunrui CFCC	Laboratory	-	-	-	-	-	-	138
	Land-Based	-	-	-	-	-	-	138
	Shipboard	-	-	-	-	-	-	138
Techcross Inc.	Laboratory	-	-	-	-	-	-	78, 79
	Land-Based	11	11*	3	Y	0-5	Plate counts	78, 79
	Shipboard	2	2*	3	Y	0	Plate counts	78, 79
Wartsila	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-

Unk = Unknown, BD = Below Detection Limits, * = Initial concentration at intake was 0, unk or non-detectable

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls	# Organisms/100 ml	Methods	Reference
21 Century Shipbuilding	Laboratory	2	2	Unk	Unk	0	Unk	148
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Alfa Laval	Laboratory	-	-	-	-	-	-	-
	Land-Based	10	10*	3	Y	<1*	filtration, plate counts	137
	Shipboard	4	4*	9	Y	<1*	Supplemented Agar Plates	138
AQUA Eng. Co. Ltd.	Laboratory	10	10	Unk	Y	0	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Auramarine Ltd.	Laboratory	-	-	-	-	-	-	3, 177
	Land-Based	11	11*	3	Y	<1	filtration, plate counts	3, 177
	Shipboard	-	-	-		-	-	3, 177
COSCO/Tsinghua Univ.	Laboratory	-	-	-	-	-	-	124, 153
	Land-Based	10	-	-	-	<1**	-	124, 153
	Shipboard	3	-	-		<1**	-	124, 153
DESMI Ocean Guard A/S	Laboratory	-	-	-	-	-	-	29, 133
	Land-Based (Fresh)	6	6	3	Y	0	Unk	29, 133
	Land-Based (Brackish)	5	5	3	Y	0	Unk	29, 133
	Shipboard			-		-	-	29, 133
Ecochlor	Laboratory[1]	1	1	2	Y	0 (% cover)	Plate Counts	54, 116, 162
	Land-Based	-	-	-	-	-	-	54, 116, 162
	Shipboard[1]	3	3	3	Y	0	Plate Counts	54, 116, 162
EcologiQ	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Electrichlor	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
ETI	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Ferrate Treatment Tech.	Laboratory	1	0	Unk	Unk	108	Indexx Labs QuantiTray MPN	22
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-

Unk = Unknown, * = Initial concentration at intake was 0, unk or non-detectable, ** = minimum and maximum known, but not number of replicates, [1] = Filter added to system since testing conducted, BD = Below Detection Limits

Appendix A5 ***Vibrio cholerae***

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls	# Organisms/100 ml	Methods	Reference
Hamworthy Aquarius EC	Laboratory							
	Land-Based							
	Shipboard							
Hamworthy Aquarius UV	Laboratory							57, 58
	Land-Based	-	-	-	-	-	-	57, 58
	Shipboard	2	2	3	Y	BD	Unk	57, 58
Hi Tech Marine	Laboratory	-	-	-	-	-	-	66
	Land-Based	-	-	-	-	-	-	66
	Shipboard	-	-	-	-	-	-	66
Hitachi	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Hyde Marine	Laboratory	-	-	-	-	-	-	89, 163, 231
	Land-Based	-	-	-	-	-	-	89, 163, 231
	Shipboard	3	3*	9	Y	0*	PCR	89, 163, 231
Hyundai Heavy Industries (1)	Laboratory	2	Unk	9	Y	BD	Unk	134, 139
	Land-Based	-	-	-	-	-	-	134, 139
	Shipboard	-	-	-	-	-	-	134, 139
Hyundai Heavy Industries (2)	Laboratory	2	2*	9	Y	0	Unk	134, 139
	Land-Based	-	-	-	-	-	-	134, 139
	Shipboard	-	-	-	-	-	-	134, 139
JFE Engineering Corp	Laboratory	-	-	-	-	-	-	49
	Land-Based	11	11*	Y	Y	<1	plate counts	49
	Shipboard	6	6*	N	Y	0*	Unk	49
Kwang San Co. Ltd.	Laboratory	2	2*	Unk	Y	0	Unk	136, 140
	Land-Based	-	-	-	-	-	-	136, 140
	Shipboard	-	-	-	-	-	-	136, 140
MAHLE	Laboratory	-	-	-	-	-	-	52, 165
	Land-Based	-	-	-	-	-	-	52, 165
	Shipboard	4	4	Y	Y	0	ISO Standards	52, 165
MARENCO	Laboratory	-	-	-	-	-	-	83, 84, 229
	Land-Based	-	-	-	-	-	-	83, 84, 229
	Shipboard	-	-	-	-	-	-	83, 84, 229
Maritime Solutions Inc.	Laboratory	-	-	-	-	-	-	98, 146
	Land-Based	5	5*	5	Y	0*	DFA	98, 146
	Shipboard	-	-	-	-	-	-	98, 146

Unk = Unknown, BD = Below Detection Limits, * = Initial concentration at intake was 0, unk or non-detectable

Appendix A5 ***Vibrio cholerae***

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls	# Organisms/100 ml	Methods	Reference

MH Systems	Laboratory	1	Unk	3	N	Unk (% Reduction)	Plate Counts	45
	Land-Based	-	-	-	-	-	-	45
	Shipboard	-	-	-	-	-	-	45
Mitsui Engineering	Laboratory	-	-	-	-	-	-	72, 74, 75
	Land-Based	2	0	3	Y	BD, Unk	Plate Counts	72, 74, 75
	Shipboard	-	-	-	-	-	-	72, 74, 75
NEI	Laboratory	-	-	-	-	-	-	208, 210
	Land-Based	-	-	-	-	-	-	208, 210
	Shipboard	2	2*	Y	Y	0	DFA	208, 210
NK-O3	Laboratory	-	-	-	-	-	-	81, 117
	Land-Based	12*	12	N	N	ND	-	81, 117
	Shipboard	4	4	N	N	ND	Standard Method 9260, API 20E kit	81, 117
Nutech O3 Inc.	Laboratory	-	-	-	-	-	-	65, 192, 234
	Land-Based	-	-	-	-	-	-	65, 192, 234
	Shipboard	3	3*	11-12	Y	0*	Unknown	65, 192, 234
OceanSaver	Laboratory	-	-	-	-	-	-	114, 171
	Land-Based	25	25*	0-3	Y	<1*	Plate counts (TCBS agar)	114, 171
	Shipboard	3	3*	3	Y	0*	Plate counts (TCBS agar)	114, 171
OptiMarin	Laboratory							168, 172
	Land-Based	14	14*	0-3	Y	<1	Flitration and plate count	168, 172
	Shipboard	8	8*	9	Y	<1	Filtration, Plate count	168, 172
Panasia Co.	Laboratory	-	-	-	-	-	-	-
	Land-Based (Brackish)	5	5	3	Y	ND	Filtration, Plate count	KOMERI
	Land-Based (Saltwater)	5	5	3	Y	ND	Filtration, Plate count	KOMERI
	Shipboard	3	3	3	Y	ND	Filtration, Plate count	KOMERI
Qingdao Headway Tech	Laboratory	-	-	-	-	-	-	141, 175
	Land-Based	13	13*	3	Y	<1	Membrane Filtration	141, 175
	Shipboard	3	3*	Y	Y	0	Membrane Filtration	141, 175
Resource Ballast Tech	Laboratory	-	-	-	-	-	-	106, 130
	Land-Based	3	3*	Unk	Y	0	Unk	106, 130
	Shipboard	2	2*	3	Y	0	Unk	106, 130
RWO Marine Water Tech	Laboratory	-	-	-	-	-	-	53, 178
	Land-Based	13	13	N	Y	<1	Plate counts	53, 178
	Shipboard	5	5	3	Y	0 - 2.3	-	53, 178

Unk = Unknown, BD = Below Detection Limits, DFA = Direction Fluorescent Antibody, * = Initial concentration at intake was 0, unk or non-detectable for some test cycles

Appendix A5 *Vibrio cholerae*

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls	# Organisms/100 ml	Methods	Reference
Severn Trent	Laboratory	-	-	-	-	-	-	64, 142, 164
	Land-Based	-	-	-	-	-	-	64, 142, 164

	Shipboard	38	38	Unk.	Y	0	Plate counts	64, 142, 164
Siemens	Laboratory	-	-	-	-	-	-	60, 97, 155
	Land-Based	2	2*	5	Y	ND	DFA	60, 97, 155
	Shipboard	-	-	-	-	-	-	60, 97, 155
Sunrui CFCC	Laboratory	-	-	-	-	-	-	138
	Land-Based	-	-	-	-	-	-	138
	Shipboard	-	-	-	-	-	-	138
Techcross Inc.	Laboratory	-	-	-	-	-	-	78, 79
	Land-Based	11	11*	3	Y	0*	Plate counts (TCBS agar)	78, 79
	Shipboard	3	3*	3	Y	0*	Plate counts (TCBS agar)	78, 79
Wartsila	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-

Unk = Unknown, BD = Below Detection Limits, DFA = Direction Fluorescent Antibody, * = Initial concentration at intake was 0, unk or non-detectable

Appendix B7 < 10 µm (Viruses)

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls	# Organisms/100 ml	Methods	Reference
Alfa Laval	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Ecochlor	Laboratory	2	Unknown	2	Y	0,Unk (% of Control)	Plaque Forming Units	100
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
EcologiQ	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-		-	-	-
Electrichlor	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
ETI	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Hi Tech Marine	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Hyde Marine	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
JFE Engineering Corp	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
MARENCO	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Maritime Solutions Inc.	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-

Unk = Unknown

Appendix B7 < 10 µm (Viruses)

Manufacturer	Location	# Tests	# Tests Met Std	Replicates	Controls	# Organisms/100 ml	Methods	Reference

MH Systems	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Mitsui Engineering	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
NEI	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
NK-O3	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Nutech O3 Inc.	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
OceanSaver	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
OptiMarin	Laboratory	-	-	-	-	-	-	-
	Land-Based	1	Unknown	-	Y	Unk (% Reduction)	Spiked Coliphage MS2 Exp.	11
	Shipboard	5	Unknown	-	Y	Unk (% Reduction)	Spiked Coliphage, SYBR Gold	11,135
Panasia Co.	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
RWO Marine Water Tech	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
SeaKleen (Hyde)	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Severn Trent	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-
Techcross Inc.	Laboratory	-	-	-	-	-	-	-
	Land-Based	-	-	-	-	-	-	-
	Shipboard	-	-	-	-	-	-	-

Unk = Unknown

1

APPENDIX B

Ballast Water Treatment Technology Vendor Retrofit Questionnaire (Delivered Electronically February 13, 2012)

Dear Ballast Water Treatment Technology Vendors:

The California State Lands Commission staff is gathering information on the retrofit capability of any and all treatment systems to be included in the 2012 ballast water treatment technology assessment report. We request that you answer the following 9 questions as completely as possible so that we may gather accurate information about current industry-wide retrofit capabilities. Please use as much typing space as needed to completely answer each question. The information you provide will also let potential clients know specifics about retrofitting existing vessels with your company's ballast water treatment system (BWTS).

This form can be filled out electronically and returned via email to amanda.newsom@slc.ca.gov. Please return this form by **Monday, March 12** to have your BWTS retrofit information included in the Commission's 2012 report.

Thank you for your participation in the Commission's 2012 technology assessment. Please do not hesitate to contact me at the email address provided above with any questions about this survey or how the information may be used.

Regards,

Amanda Newsom, PhD
SeaGrant Fellow
California State Lands Commission
Marine Invasive Species Program

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1) Has your company ever retrofit its BWTS to one or more existing vessels? If so, please indicate the number (i.e. quantity) and types (e.g. tankers, cruise ships) of vessels retrofit and the maximum pump capacity of the systems installed.
8T

2) Do you have any orders for future retrofits? If so, please indicate the quantity and types of vessels to be retrofit and an estimate of when these retrofits will be completed.
8T

3) What are the footprint and vertical clearance requirements of your company's BWTS? If your company manufactures both small and large BWTS, please specify footprint and vertical clearance for each available size.

Type response here

4) Does your company's BWTS break down into components that could be retrofit as space allows? If so, how many components and how much space (footprint and vertical clearance) is required for each component?

8T

5) What are the power requirements for your company's BWTS?

8T

6) Are there any limitations on your company's ability to retrofit an existing vessel with a BWTS (example: explosion hazard for oil tankers)? If so, are these limitations for certain vessel types or for all vessels?

8T

7) Does a vessel have to be in drydock to be retrofit with your company's BWTS?

8T

8) Are any estimates available regarding the cost (US$) of retrofitting your company's BWTS to existing vessels for the categories (a-d) written below? This estimate can be stated as a range, as we are aware these costs will be different for each vessel.

a) installation/labor

b) parts

c) cost of the system (capital equipment costs)

d) energy usage

8T

9) Please use the space below to include additional information regarding retrofitting your company's BWTS.

8T

APPENDIX C

California State Lands Commission
Marine Invasive Species Program
Technical Advisory Group Meeting Notes
2012 Ballast Treatment Technology Assessment Report
April 11, 2012

<u>Participants</u>

Amanda Newsom – CSLC
Chris Scianni – CSLC
Chris Brown – Smithsonian Environmental Research Center
Shuka Rastegarpour – California State Water Resources Board
Sonia Gorgula – Hawaii State Department of Land and Natural Resources*
Karen McDowell – San Francisco Estuary Partnership*
Jackie Mackay – CSLC*
Enrique Galeon – CSLC*
Steve Morin – Chevron Shipping*
Maurya Falkner – CSLC*
Nick Welschmeyer – Moss Landing Marine Laboratories*
Abigail Blodgett – San Francisco Baykeeper*
Sharon Shiba – DFG/OSPR*
Rian Hooff- Oregon Department of Environmental Quality*
Ryan Albert – US Environmental Protection Agency*
Lisa Swanson – Matson Navigation*
Andrea Fox – California Farm Bureau*
John Berge – Pacific Merchant Shipping Association*
John Stewart – International Maritime Technology Consultants, Inc.*
* = participated by phone

<u>Meeting Notes</u>

Amanda Newsom – Purpose of meeting

1. Meet to discuss the Treatment Technology Assessment Report itself. This is not to discuss the standards themselves.
2. Provide regulatory updates from the International, Federal and State levels.
3. Efficacy and availability – SLC is asking members/industry for concrete numbers of systems being used now. It will give an indication of the methodology of systems in the market and how reliable these systems are. Currently, there are three (3) systems that show compliance.

4. Environmental Impacts – MAHLE uses a UV system that does not fall under VGP. Qingdao does not use an active substance.
5. Recommendations – Move forward with 2014 implementation date.
6. Report timeline –Would like final comments by April 20, 2012.
7. Commission needs – Regulatory development and insight. Would like additional information on the impacts of aquatic invasive species to the environment. Needs data on the additional cost of installation and retrofit of systems on vessels.

Pressing questions, concerns about the report – Roundtable discussion to collect initial comments and ideas regarding report for a later discussion

"bullet point" denotes person initiating comment

- Sharon – How serious is the problem? Seems the information is sparse. Do we have to look elsewhere for the information? Could it be augmented more?

- Shuka – No comments at this time.

- Chris B. – No comments at this time.

- Abigail – Did not have time to review thoroughly. Concerned with enforcement. How often will samples be taken and how long will it take?

  Amanda – Need to look at Art 4.7, it is still in the public comment period.

- Andrea – Concerned about the availability of TS that will be able to do what it needs to do to meet the standard. Are there TS out there?

  Amanda – The systems reviewed are compliant and commercially available.

- Karen – No initial comments.

- Nick W. – What are the criteria to be compliant? Are there categories or one category? Is it one test to meet all regulatory standards? Are we endorsing the top vendors?

  Chris S. – No endorsement, just showing they are compliant.

- Ryan Albert – No comment.

- Sonia – No comment.

- Steve – Sent in detailed comments. Baffled that the Feds and other States are backing off on standard back to D2. But, CA is remaining with standards that industry cannot meet.

  Chris S. – Systems can meet the standards.

  Steve – Statement is debatable

  Amanda – Systems can meet the standards

  Maurya – That's why compliance standards are written

  Steve – Is there scientifically proven protocol?

- John B. – There is concern whether systems can meet the standard. Based on IMO D2 testing VGP, pg 82. EPA states CA data "Do not have test efficacy". Echolor, the scientific methods cannot quantify standards. That is a major concern. At the September commission meeting, there was skepticism about the standards to verify by a third party. It is remiss if not mentioned with adoption of CG rule, vessels will not meet CA standard. If it is not certified by CG.

  Amanda – CSL used data to determine efficacy. We will need additional insight on CG approval.

  Maurya – CG has a two pronged approach. Systems installed on existing vessels. Vessels submit an application for management of system that must show at least as good as BWE. CG working on policy to accept which should be out in the next week.

  Amanda – IMO is using a similar methodology.

  John B. – Is CA essentially using IMO standard?

  Amanda – No, more stringent. We looked at data that had actual numbers and used appropriate methodology.

- Steve – The top three companies were compliant 50% of the time. Industry needs to meet compliance 100%, this is not good. These systems did not pass land based tests.

  Amanda – Compliance is based on shipboard operations.

  Sharon – Why are these test results so low?

Amanda – The availability of lab testing.

Maurya – Nick has done a lot of work, any insight why different in testing?

Nick W. – Land based is more stringent, ship side more sloppy.

John S. – A lot of variety in the way testing is conducted. Weather conditions challenge the interpretation as does who is conducting the tests.

Amanda – No way to verify the systems have given us all the information. We reported what we were given.

Nick W. – Systems passed the CA standard? Does the data give the data score? Do we take your evaluations as presented?

Amanda – The body of the report is a summary of the data. The reader can go back to the appendix for further information.

Nick W. – How can we pass compliance? What is the number? We can make the test happen the way you want it to. Can we pass a non-detectable standard?

Amanda – It's left to the reader to go to the appendix to see the methodology used.

Nick W. – The data do not always appear as numbers.

Amanda – Passes under a certain methodology. It's the closest thing we have.

- Andrea – What is the availability of TS that meets CA standard? Are they commercially available? It is a huge process for retrofit. Is there technology available to do the job?

Amanda – Refer to table V1-4, pg. 69.

Chris S. – On vessels of BW capacity of 5000 MT, it is a small group that represents about 10% of the fleet.

Amanda – Refer to pg. 67-68. Vessels discharging once must install TS, but there are caveats to the rule. Not every vessel meets the profile.

John B. – All new builds over 5000 MT will have to comply, so CA is addressing only a small percentage of the fleet that will need retrofitting.

- Maurya – The last report was approved by the Commissioners. We may need to incorporate that language into this report.

John B. – Commissioners did not approve that report, they expressed concerns.

Maurya – Commission approved larger class size in 2010 report. 2011 report is an update, which is not legislatively mandated and so doesn't need approval. Make recommendation to look at report and incorporate the language.

- Lisa S. – I give support to John and Steve. Concerned about measuring the standard and what it means.

  Amanda – Will look at the 2010 report and issues brought up by industry. Top systems language does not appear in the report. The framing of the report is based on the systems that are being used.

- Nick W. – Back to the same question as with the 2010 report, are we overly optimistic with these systems? Can vendors actually achieve these standards? I will go back and look at the numbers. We are in a fuzzy area saying systems can comply with CA standards currently, but not knowing if the tests were sensitive enough to test to standards, without knowing tests. Gives a one foot on ice, one foot on banana peel scenario because numbers are not appearing very well. Certainty in statements comes with backpedalling to explain how the test was actually performed. Need to make sure that the top performing systems arrived at their results based on real numbers and not on assumptions.

  Amanda – Will look again at the data and be more critical in the evaluation.

- Ryan A. – EPA supports Nick's question. One caution when considering this language, we are only looking at the shipboard results and not looking at land based. Even though I fully appreciate that you will have a fully ship based protocol, Worried at not taking advantage of quality control available in land based testing. Have lower detection levels. May steer regulated community towards systems which may not be best for long term.

  John S. – Worked with tech developers, can't defend them. Received from non-regulatory perspective. Take out "top performer" language on systems. The language is being abused in the market place. Be careful of the language that is suggestive, creates a perception of compliance with a standard. It reads as an endorsement and it should not become an endorsement.

- John B. – Is the data based on IMO D2? Is that data appropriate for the standard?

  Ryan A. – Good question. There are definite shortcomings in current testing approaches under the 2004 ballast water convention. Improvements being looked at, such as the ETV protocols. We discuss CA discussion on analysis of data and how to look at it through a BAT approach. Not going to say whether IMO or CA approach is better other than they are fundamentally different. CA has done a very good job noting the potential to apply which doesn't guarantee performance. As detection limits improve the effective CA limit will be better. Currently limited by approaches.

John B. – Appropriate to use data in report to determine compliance?

Ryan A. – Would not use type approval for 10-50 um. Need to look at these differently. Existing G8 protocols using a BAT standard doesn't give us adequate resolution.

John B. – We will have to comply, that is the concern.

- Steve M. – Report suggests compliance, isn't that the purpose of the report, to meet the standard?

  Amanda – The report is on the systems that meet the standard. All we can do is report the data.

- Nick W. – You back pedal each time the question comes up. I agree with John Stewart. Vendors will take advantage of the test. A no detect is a stringent level. Zero is zero no matter how you cut and dice it up.

  Amanda – Invasions in CA provide more details. We need additional information on economic and health impacts on CA.

  Andrea – Check with CA invasive species advisory committee, who are currently funding an impacts study. Pose questions to committee and they will provide more information.

  Chris B. – Report should be available in August. Vector impact analysis report should augment information.

- John S. – Is it conceivable this report could not reflect the names of companies? Just report data of what technologies are available? Could have a misinterpretation of data. Appropriate to name names? Keep it general of technologies?

  Amanda – Staff will discuss

  Maurya – From historical perspective, it was done in the original report. EO/Commissioners would like to go that way, potential misuse of the report.

- John B. – The Invasive Species Fund pays for one person at the Water Board to collaborate with CSLC. Can we get information from Water Board on what implications it will have on the standard?

  Chris S. – State Water Board will work with us to discuss any regulatory updates.

- Amanda – Any additional additives at the Federal, International level? Cost? Numbers? We have used Lloyd's Registry, it may be out of date.

- Maurya – Any contact with vendors?

  Amanda – Yes, they are very helpful. Especially those with retrofit issues.

- Amanda – Any closing comments?

  John B. – Submitting written comments to the group.

  Amanda – Submit comments by email. Expand more on what was said here or additional.

  End of meeting.