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Revisiting the basis for US ballast water regulations

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ABSTRACT

The transport and release of invasive organisms in ballast water has harmed ecosystems, economic activities and human health. Current US ballast water regulations intended to minimize the discharge of such organisms are based on results reported by a scientific advisory committee in 2011. Using the same methods, we re-analyzed the data evaluated by the committee as well as new data. We find that the committee's analysis was flawed, and that some treatment systems can meet limits that are 10 times (for zooplankton) or 1000 times (for phytoplankton) more stringent than the committee reported. These findings suggest that US ballast water standards, and similar standards in a recently ratified international agreement, should be re-evaluated.

1. Introduction

The spread of aquatic organisms around the world in ships' ballast water has harmed ecosystems, disrupted economic activities, and sickened and sometimes killed people (Carlton, 1985; Epstein et al., 1993; McCarthy and Khambaty, 1994; Hallegraeff, 1998). In 2004 the International Maritime Organization (IMO) drafted an international treaty (the Ballast Water Convention) that requires signatory nations to implement limits on the discharge of two groups of organisms and three indicator microbes, known as the IMO D-2 discharge standard. The Convention will enter into force in September 2017.

The United States has not signed the Convention, but instead regulates ballast discharges under laws implemented by the U.S. Coast Guard (USCG) and U.S. Environmental Protection Agency (USEPA). In 2010 these agencies jointly convened a Ballast Water Advisory Panel under the auspices of the USEPA's Science Advisory Board (SAB), to determine what level of ballast water treatment is possible.[1] The Panel and SAB reported that the available test data showed there were several types of treatment systems that could meet the IMO D-2 standard but failed to show that any treatment system could meet a standard ten times as stringent (referred to as 10x IMO D-2) (SAB, 2011). Based on those results, in 2012 and 2013 USCG and USEPA adopted discharge limits incorporating the IMO D-2 standard.

While reviewing data for a related study (Cohen and Dobbs, 2015), we realized that the test data examined by SAB appeared to contradict SAB's conclusion that no treatment system had demonstrated the ability to meet the 10x IMO D-2 standard. We here analyze the same test data examined by SAB, using the same methods, to determine whether the results match those reported by SAB. In addition we analyze test data that have become available since SAB conducted its analysis, to determine whether more recent data alter the results.

2. Methods

2.1. Test data

The Ballast Water Convention requires shipboard ballast water treatment systems to be tested and certified as capable of meeting the IMO's discharge limits, a process known as type approval. SAB (2011) reviewed the type approval test results available through December 1, 2010, which we refer to as the "SAB Data." SAB determined that the data for 9 treatment systems were reliable and analyzed the data for 8 of them, excluding one treatment system that had been withdrawn from the market. Data rated reliable included results from land-based or shipboard testing that used reasonable and appropriate methods and QA/QC procedures and produced credible results.

To determine whether SAB's conclusions were correct, we analyzed the same data for the same 9 treatment systems considered by SAB, using the same analytical method (described below). Because SAB reported results in terms of operational types rather than treatment systems (see below), and the ability of an operational type to meet a standard is not affected by whether a treatment system of that type is currently available on the market, we retained in our data sets the treatment system that SAB excluded from analysis because it had been withdrawn from the market.

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To determine whether analysis of more recent data would produce a different result, we obtained additional test reports for shipboard treatment systems through: internet searches; inquiries of equipment manufacturers, test laboratories, and the government agencies or agents that grant type approvals; Freedom of Information Act requests submitted to USCG; and a Public Records Act request submitted to the California State Lands Commission. We obtained information on detection limits from the test laboratories, or determined detection limits from the test reports and associated documents (see Detection Limits in Supplementary material). To the test data that SAB determined to be reliable (the SAB Data), we added the new data available through September 25, 2016 to produce a database we refer to as "All Data". We excluded treatment systems for which only shipboard test data were available, and systems whose data did not meet SAB's reliability criteria, including consideration of appropriate methods and QA/QC procedures. Treatment systems included in the database are listed in Table S2 in Supplementary material, with citations for the test reports, QA/QC documentation, and other relevant documents.

2.2. Analysis

SAB (2011) assessed the performance of shipboard ballast water treatment systems in terms of four discharge standards (Table 1). The first, the IMO D-2 standard, limits the concentrations of two organism groups and three indicator microbes in treated discharges. The two organism groups are based on size: the larger group comprises organisms whose minimum dimension is greater than or equal to 50 μm (hereafter the "≥50 μm group") and mainly consists of zooplankton, while the smaller group comprises organisms whose minimum dimension is greater than or equal to 10 μm and less than 50 μm (hereafter the "10–50 μm group") and mainly consists of phytoplankton. The other three standards—designated 10x IMO D-2, 100x IMO D-2 and 1000x IMO D-2—refer to concentration limits that are 10 times, 100 times, or 1000 times lower (*i.e.*, more stringent) than the limits in IMO D-2 for one or both of these organism groups (Table 1). The indicator microbe limits are the same in all four standards (see Definitions of Standards in Supplementary material).

SAB (2011) assessed whether treatment systems had demonstrated the ability to meet a given standard using two separate protocols: the G8 Guidelines (IMO, 2008), which are used to assess treatment systems for type approval under IMO's Ballast Water Convention; and the ETV Protocol (USEPA, 2010), used to assess treatment systems for US type approval. The G8 Guidelines base assessment on 10 land-based trials in 2 salinity ranges plus 3 consecutive shipboard trials. The ETV Protocol bases assessment on 6 land-based trials in 2 salinity ranges, and doesn't address shipboard trials. Where data for fewer trials were available, SAB based its assessment on the available data. SAB categorized treatment systems by operational type, and for each operational type reported the results for the treatment system with the best performance, representing the highest level of treatment that the operational type had achieved. Although a chapter in SAB's report discusses approaches for assessing the statistical certainty of results in monitoring or testing based on organism counts and volumes analyzed, no such analysis is mentioned in the methods section. SAB's methods instead base assessment on the G8 Guidelines—which state that a treatment system is deemed to meet the standard for an organism group if the average concentration in the treated discharge samples in each required trial is below the concentration limit (IMO, 2008, Annex §2.3.5)—or the ETV Protocol.

Table 1
Treated discharge concentration limits for the organism groups in the analysis.

Organism group	IMO D-2	10x IMO D-2	100x IMO D-2	1000x IMO D-2
≥50 μm	10/m^3	1/m^3	0.1/m^3	0.01/m^3
10–50 μm	10/mL	1/mL	0.1/mL	0.01/mL

We used these same methods and standards to assess both the SAB Data and All Data, with two adjustments. First, the IMO D-2 standard limits the concentrations of "viable" organisms in discharges while US regulations limit the concentrations of "living" organisms. In tests of ballast water treatment systems, viable photoautotrophs in the 10–50 μm group are counted by observing growth in an appropriate medium after serial dilutions, often referred to as the Most Probable Number or MPN method; living organisms are counted using stains to distinguish live from dead cells. The viable organism (MPN) method generally yields a lower count than the living organism (staining) method (Casas-Monroy et al., 2016). SAB (2011) does not state how these different analytical results were used in its assessment. To assess compliance with the standards in accordance with IMO's G8 Guidelines, for both SAB Data and All Data, we used viable organism counts if available; if not, we used living organism counts; and if these were not available, we used counts of chlorophyll-containing cells (based on chlorophyll autofluorescence) or counts of intact cells, which include both live and dead cells. To assess compliance in accordance with the ETV protocol, we used living organism counts if available; if not, we used chlorophyll-containing or intact cell counts. If microzooplankton in the 10–50 μm size range were counted separately, we added those to the above counts.

Second, after the SAB report was published, USCG (2012) adopted type approval regulations requiring treatment systems to meet discharge standards in 5 consecutive shipboard trials as well as the 6 land-based trials required by the ETV Protocol. We used these requirements as the basis for assessing All Data, but used the ETV Protocol requirements alone (as did SAB) to assess the SAB Data. For both data sets, we refer to the basis for these assessments as the "US Protocol," and the basis for assessments in accordance with IMO's G8 Guidelines as the "IMO Protocol."

We report results both for individual treatment systems and operational types, and compare our results to the results in SAB (2011).

3. Results

3.1. SAB Data

SAB (2011) rated the data for 9 ballast water treatment systems as reliable. Excluding one system that had been withdrawn from the market, SAB found that 7 of the 8 remaining treatment systems, representing 5 operational types, had met the IMO D-2 standards consistent with both the IMO and US Protocols. SAB further reported that the test data showed that none of the treatment systems or operational types had demonstrated the ability to meet the 10x IMO D-2 standard, although with reasonable improvements they might have potential to meet that standard; and that all treatment systems had failed to meet the 100x IMO D-2 standard by such large margins that even with reasonable improvements they still would not meet the 100x IMO D-2 standard, and wholly new types of treatment systems would be needed instead.

However, our analysis of the same data using the same methods found that 2 of the 9 treatment systems, representing 2 operational types, met the 10x IMO D-2 standard for the ≥50 μm organism group when assessed using the IMO protocol; and 4 systems, representing 4 operational types, met that standard when assessed with the US Protocol (Figs. 1, 2). Five (IMO Protocol) and 4 (US Protocol) treatment systems and operational types met the 10x IMO D-2 standard for the 10–50 μm organism group. Several treatment systems approached compliance with the 100x IMO D-2 standard, especially for the 10–50 μm organism group. Two (IMO Protocol) or 3 (US Protocol) treatment systems and operational types met the 10x IMO D-2 standard for both organism groups.

Table 2 provides the test results for one of these treatment systems. Concentrations of ≥50 μm organisms were 0.33/m^3 in 2 of 10 trials (1 organism detected in 3 m^3 of water in each trial) and less than the