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Failure of the public health testing program for ballast water treatment systems

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ABSTRACT

Since 2004, an international testing program has certified 53 shipboard treatment systems as meeting ballast water discharge standards, including limits on certain microbes to prevent the spread of human pathogens. We determined how frequently certification tests failed a minimum requirement for a meaningful evaluation, that the concentration of microbes in the untreated (control) discharge must exceed the regulatory limit for treated discharges. In 95% of cases where the result was accepted as evidence that the treatment system reduced microbes to below the regulatory limit, the discharge met the limit even without treatment. This shows that the certification program for ballast water treatment systems is dysfunctional in protecting human health. In nearly all cases, the treatment systems would have equally well "passed" these tests even if they had never been turned on. Protocols must require minimum concentrations of targeted microbes in test waters, reflecting the upper range of concentrations in waters where ships operate.

1. Introduction

Ships' ballast water discharges can introduce bacterial pathogens and diseases into novel regions of the world (McCarthy and Khambaty, 1994; Dobbs and Rogerson, 2005; Cohen et al., 2012; Rivera et al., 2013). For example, there is strong evidence that ballast water has introduced pandemic strains of both *Vibrio cholerae* and *V. parahaemolyticus* into new coastal regions (McCarthy and Khambaty, 1994; Quilici et al., 2005; Cabanillas-Beltran et al., 2006; Nair et al., 2007; Ansede-Bermejo et al., 2010; Rivera et al., 2013), and scientists at the Centers for Disease Control recently warned of the need to treat ballast water to prevent the spread of cholera from Haiti (Cohen et al., 2012). Several researchers (National Research Council, 1992; Epstein et al., 1993; McCarthy and Khambaty, 1994) and the Pan American Health Organization (Anderson, 1991) concluded that the 1991 cholera epidemic in South America, which resulted in over one million cases of cholera and 10,000 deaths (Tauxe et al., 1995), likely arrived from Asia in ballast water, though others have questioned this pathway (Martinez-Urtaza et al., 2008; Lam et al., 2010). At least 38 species of pathogenic bacteria and a high incidence of antibiotic resistance have been detected in ballast tanks (Dobbs and Rogerson, 2005; Altug et al., 2012; Buzoleva et al., 2012; Dobbs et al., 2013).

The global health risk posed by ballast water discharges was recognized 40 years ago, when the UN's International Conference on Marine Pollution asked the World Health Organization to initiate research on "the role of ballast water as a medium for the spreading of epidemic disease bacteria" (International Conference on Marine Pollution, 1973). The risks were noted again in 1991 when the UN's International Maritime Organization (IMO) adopted ballast water guidelines recognizing that "the discharge of ballast water and sediment has led to unplanned and unwanted introductions of...pathogens that are known to have caused injury to public health" and "the introduction of diseases may...arise as a result of...waters being inoculated with large quantities of ballast water containing viruses or bacteria, thereby posing health threats to indigenous human, animal and plant life" (IMO, 1991).

In 2004 the IMO drafted an international treaty, the International Convention for the Control and Management of Ships' Ballast Water and Sediments (hereafter "IMO Convention"), which would limit the concentrations of five organism groups in ballast water discharges (Table 1), including three bacteria (referred to by IMO as "indicator microbes") whose limits are intended to protect human health. The limits on *Escherichia coli* and intestinal enterococci are based on the use of these microbes as indicators of human fecal contamination resulting from inadequately treated or

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untreated sewage discharges, and are identical to European Union water quality parameters for coastal bathing waters (Council of European Community, 2006). The limit on toxigenic *V. cholerae*, which refers to the toxigenic strains of *V. cholerae* serogroups O1 and O139 responsible for the 7th and 8th cholera pandemics, was included at Brazil's request after the 7th pandemic strain erupted in South America and was found in the ballast tanks of ships arriving in Brazilian ports (IMO, 2003). These same ballast water discharge limits were later included in US Coast Guard regulations adopted under the National Invasive Species Act in 2012 (US Coast Guard, 2012) and in permit requirements issued by the US Environmental Protection Agency under the Clean Water Act in 2013 (US EPA, 2013).

Implementation of the IMO Convention (which may be close to ratification) is effected in part through a program initiated in 2004 that tests and certifies shipboard ballast water treatment systems as being capable of meeting the discharge limits, referred to as type approval. Protocols for conducting type approval tests both in land-based testing facilities and in shipboard installations are described in an annex to the Convention (IMO, 2005). Although it is possible that type approving agencies may sometimes consider other performance data, these test results are the only performance data mentioned or required by the IMO guidelines on granting type approval (IMO, 2005), and the only data cited in the IMO documents reporting type approvals. These tests are thus central to the type approval process. Similar protocols for the tests needed for US type approval were developed by the US Coast Guard and the US Environmental Protection Agency (US Coast Guard, 2012; Lemieux et al., 2010). Under the Alternate Management Systems (AMS) program, the Coast Guard can also allow temporary use (for up to 5 years) of treatment systems that have been type approved by an IMO member country (US Coast Guard, 2012).

Testing based on IMO protocols began 10 years ago, and testing based on the draft or final US protocols began four years ago. Although disclosure of the test results used to assess treatment system performance and grant type approval is not required, some system manufacturers have voluntarily released test reports or summaries of the results; others have chosen not to do so. However, there is now sufficient data available to support a review of the test program. Here we evaluate whether the tests are effective in verifying that approved treatment systems are capable of meeting the international and US ballast water discharge standards for microbes.

2. Methods

In both the IMO and US test protocols, the water used to test the treatment system is split into treatment and control streams. The control stream is passed into either an actual ballast tank (in shipboard tests) or a large tank intended to simulate a ballast tank (in land-based tests), where it is held for a period of time (variable in shipboard tests; at least 5 days (IMO) or 1 day (US) in land-based tests) before being discharged (IMO, 2005; Lemieux et al., 2010). The procedure for the treatment stream is identical except that the water treatment being tested is applied at the appropriate stage or stages, either on intake before entering the tank, while the water is in the tank, or during discharge from the tank. The concentrations of organisms targeted by the regulations are measured at various points, and a treatment system is determined to have passed the test if the concentrations in the treated discharge do not exceed the regulatory limits. To date, 53 shipboard treatment systems have been granted type approval by one or more IMO member countries, and 45 of these have been accepted as AMS by the US Coast Guard.

We assembled and analyzed all available data on the concentrations of the three regulated microbes in intake, treated discharge, and untreated (control) discharge samples in tests of ballast water treatment systems that followed the IMO or US protocols (Table S1 in Supplementary Material). We assembled these data from publicly released reports on land-based or shipboard trials conducted by test facilities and researchers (35 reports), supplemented by summary results included in IMO documents or type approval certificates (20 documents) or released by equipment manufacturers or test facilities (4 reports), that were available through October 1, 2013.

Since a treatment system passes these tests if the organism concentrations in the treated discharges do not exceed the regulatory discharge limits, the concentrations in the untreated (control) discharge water must, at a minimum, exceed the discharge limits if the test results are to provide information about the effectiveness of the treatment systems. We checked the assembled data against the regulatory discharge limits to determine what portion of the tests conducted under the IMO or US protocols satisfied that requirement (see Detailed Methods in Supplementary Material). We calculated these proportions for all treatment systems, for all type-approved treatment systems and for all AMS for which there are publicly released data on untreated discharge concentrations. For trials where untreated discharge concentrations are not available, we checked whether the intake concentrations exceeded the regulatory discharge limits.

Table 1
Concentration limits for living organisms in ballast water discharges set by the IMO Convention, the US Coast Guard, and the US Environmental Protection Agency.[a]

Organism group	Concentration limit
Organisms >50 μm in minimum dimension	10/m^3
Organisms 10–50 μm in minimum dimension	10/mL
Indicator microbes	
Escherichia coli	250 cfu/100 mL
Intestinal enterococci	100 cfu/100 mL
Toxigenic *Vibrio cholerae* (O1 and O139)[b]	1 cfu/100 mL

[a] IMO, International Maritime Organization; cfu, colony-forming units.
[b] The IMO Convention also contains a limit of 1 cfu of toxigenic *V. cholerae* (O1 and O139) per 1 g (wet weight) of zooplankton samples.

3. Results

We obtained data on 390 land-based or shipboard trials conducted between 2004 and 2013 on 38 different treatment systems, including 31 of the 53 treatment systems granted type approval under the IMO Convention and 28 of the 45 treatment systems accepted as AMS by the US Coast Guard. In trials where untreated discharge concentrations were reported, they were less than the regulatory discharge limit for *E. coli* 97% of the time (n = 332 trials, 35 treatment systems), below the limit for intestinal enterococci 91% of the time (n = 315 trials, 35 treatment systems), and below the limit for toxigenic *V. cholerae* 100% of the time (n = 176 trials, 26 treatment systems) (Table 2: All treatment systems; Fig. 1). Untreated discharge concentrations for total *V. cholerae* were below the regulatory discharge limit for toxigenic *V. cholerae* 95% of the time (n = 152 trials) (Table S1 in Supplementary Material). About half of the *E. coli* and intestinal enterococci untreated discharge concentrations, and all of the toxigenic *V. cholerae* untreated discharge concentrations, were below detection limits (Table 2: All treatment systems; Fig. 1). In all, out of 823 measurements of regulated microbes in untreated discharges, the concentrations were below the discharge limits 95% of the time, and below detection limits 62% of the time (Table 2: All treatment systems).

The results are similar when the analysis is restricted to treatment systems granted type approval under the IMO Convention,