Journal of Great Lakes Research xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Journal of Great Lakes Research

journal homepage: www.elsevier.com/locate/jglr

The practicability of ships arriving to the Great Lakes to conduct ballast water exchange *plus* treatment—Analysis of shipping patterns

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ARTICLE INFO

Article history:
Received 5 January 2017
Accepted 24 May 2017
Available online xxxx

Keywords:
Aquatic nuisance species
Bioinvasions
Invasive species
Policy
Shipping

ABSTRACT

Ballast water exchange (BWE) has historically been the most oft-used approach to manage ballast water with the goal of reducing biological invasions. Henceforth, most ships will exclusively perform ballast water treatment (BWT) to comply with limits on concentrations of living organisms in discharge water, although the combination of BWE *and* BWT may reduce the risk of invasion more than BWT alone, particularly for ships arriving to freshwater ports, such as those in the North American Great Lakes. Whether the BWE and BWT is practicable rests upon several factors, particularly the time available to perform both operations in the appropriate area and safely during a voyage. We investigated records of ships arriving to U.S. ports from 2004 through 2014 to characterize the frequency and location of BWE. The National Ballast Information Clearinghouse dataset contained information on 872×10^3 arrivals in the 11-year span, which is summarized herein. In U.S. ports within the Great Lakes, about 1% of vessels arriving—or 921 arrivals over 11 years—conducted BWE. Most vessels arriving to Great Lakes ports did not discharge ballast water, but of those that did, >98% of the volume discharged was from coastwise voyages. In ships arriving from overseas, ballast water was held for at least 4 days after BWE. Ships performing BWE while offshore would still need to meet the limits for living organisms in discharged water, which would require BWT while underway doubling the use rate of the shipboard treatment system, but also making some BWE procedures (e.g., flow-through exchange) impracticable.

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Introduction

In addition to cargo, passengers, and crewmembers, ships can transport large volumes of ballast water between ports. Ships use ballast water—typically drawn from the environment and containing aquatic organisms—to stabilize the vessels and reduce structural stresses. Organisms resident in the ballast water are ferried between locations and may be discharged into favorable environments, where populations can expand to displace endemic species. In an effort to reduce the risk of invasions, according to the Environmental Protection Agency (EPA) Vessel General Permit (VGP; U.S. Environmental Protection Agency, 2015), ships entering the North American Great Lakes are required to conduct ballast water exchange (BWE) if they meet operational criteria (they have operated outside the U.S. Exclusive Economic Zone [EEZ] and >200 nautical miles (nm) from any shore and enter the Great Lakes through the Saint Lawrence Seaway) and salinity requirements (they have taken up coastal, estuarine or freshwater [salinity <18 ppt] in the last 30 days) (U.S. Environmental Protection Agency, 2015). The process of BWE consists of replacing the volume of water in ballast tanks, originating from inland and coastal waters, with marine water (U.S. Coast Guard, 1998). The process of BWE is effective for two reasons: First, inland and coastal waters are often mesotrophic or eutrophic, and the exchange with offshore, oligotrophic water reduces the total concentrations of organisms. Second, residual organisms from the source water are exposed to salinities higher than they typically experience, impairing individuals not capable of osmoregulation and reducing their survivability, thereby minimizing the risk of propagation once residual organisms are released into low-salinity or freshwaters (Ellis and MacIsaac, 2009). For the Great Lakes, BWE appears to have been effective, judged by the decline in the discovery rate of invasive species over the last decade (although see Ruiz and Reid, 2007).

While effective in reducing organism concentrations (e.g., Briski et al., 2010), BWE was not intended as a permanent solution for reducing risks of ballast-mediated invasions. Open-ocean exchange is most effective for voyages starting and ending at different freshwater (or low salinity) ports. Between ports, ships must conduct exchange >200 nm from any coastline (nominally corresponding to countries' EEZs), or, for some vessels, in deep water (>200 m) at least 50 nm from any coastline (U.S. Environmental Protection Agency, 2015). Superseding these constraints, BWE must only be conducted under safe conditions (e.g.,

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http://dx.doi.org/10.1016/j.jglr.2017.05.004
0380-1330/Published by Elsevier B.V. on behalf of International Association for Great Lakes Research.

low winds and wave heights), as emptying and refilling ballast tanks reduces stability and strains the ship's structure. National limits on the concentrations of living organisms in discharged water are in place (USCG, 2012), and international limits—described in Regulation D-2 of the Ballast Water Management Convention (IMO, 2004)—will enter into force in 2017. Most ships will use ballast water treatment (BWT) performed by a ballast water management system (BWMS), which treats the water—usually by a combination of filtration and disinfection—to meet the limits on the concentrations of living organisms. A BWMS may treat water during uptake, in-transit hold, discharge, or in a combination of these events.

It has been proposed that the ideal management of ballast water for ships entering the Great Lakes is a combination of BWE *and* BWT (Canada, 2010). For ballast with high concentrations of organisms from brackish or freshwater sources, this dual process reduces the total abundance of organisms in the source water, and (assuming BWT is effective) assures the organisms remaining following BWE—mostly those from open-ocean waters—are reduced to concentrations below the discharge standard (Briski et al., 2015). Additionally, if problems with BWT result in the under-treatment of discharged water, BWE may mitigate the risk of introducing new species. Notably, however, exchange can have the unintended consequence of increasing the abundance, diversity, or both of some groups of organisms (e.g., Dickman and Zhang, 1999; Gollasch et al., 2000).

In light of the pending reissue of the VGP in 2018, it is relevant to assess the efficacy and practicability of BWE + BWT for vessels arriving to U.S. ports. In preliminary studies, the combination of BWE and BWT was effective in reducing organism concentrations, but it is unclear if the combined approaches are *practicable* for ships entering the Great Lakes. Several considerations follow: What is the frequency of vessel arrivals that would require BWE + BWT? What are typical methods for BWE and where does BWE occur? How much voyage time is available to conduct both processes? To address these questions, we examined records of BWE compiled by the National Ballast Information Clearinghouse (NBIC, 2016). Ships entering U.S. ports and discharging ballast water are required to report this activity (USCG, 1998), and these reports include details on the ship type, source of the ballast water, and the location and method of BWE. We used this dataset to calculate the "age" or hold time of ballast water on ships discharging into U.S. ports in the Great Lakes, to plot the locations of BWE, and to estimate the length of time available for ships to perform both BWE and BWT.

Methods

Data source

All data were obtained from the NBIC online database (NBIC, 2016; http://invasions.si.edu/nbic, last accessed on 5/6/2016). After ship operators submit the reports to NBIC, the data are audited for quality and consistency prior to uploading them into the main database, which is accessible to the public and can be queried based on the arrival state, a range of arrival dates, or the vessel type. While the database includes reports from as early as 1999 and as recent as 2016, for this study, only records from years 2004 through 2014 were used. Prior to 2004, the percentage of vessels meeting their reporting requirements were low: ~38% of arriving vessels submitted records (Miller et al., 2004). After 2004, >70% of vessels reported (Miller et al., 2007). In addition, 2004 was the first year in which arrivals at inland ports and waterways were recorded. As part of the program's quality control protocols, vessel operators can submit a corrected form that would replace the original record (NBIC, 2016). We excluded records after 2014 to minimize the chance that records would be revised.

Data description

The NBIC database partitions information into two tables: arrival records and ballast tank records. Both tables include the arrival port, the date of arrival, and the ship name, so these three fields were used to join the two tables, linking the information from the arrival records and the ballast tank records. Arrival records included *all* arrivals, even for vessels that did not discharge ballast water. The arrival records also included the ship type (e.g., bulk carrier [bulker], tanker, etc.), name and country of the last port, and a summary of information from the ballast tank records, such as the total volume of water exchanged and discharged. Ballast tank records included details on operations performed on specific tanks within a ship: dates and locations of ballast water uptake, management (i.e., BWE), and discharge. A single arrival record might link to multiple ballast tank records, and each of the individual tanks could have been managed on a separate date and at a unique location, using a different method of exchange.

The management method describes the process for exchanging ballast water (for this report, the term "management" is equivalent to "exchange" or "BWE"). Water in individual ballast tanks could be managed via a flow-through or via empty-refill exchange. A flow-through exchange was conducted by "over-filling" the ballast tanks with three times each tank's capacity. For flow-through exchanges, ballast water was discharged out of the tank, for example, though an overflow vent, rather than the drain or discharge line (ABS, 2010). An empty-refill exchange was performed by discharging the entire tank volume and then refilling it with offshore water. The NBIC dataset included a third designation: "alternative management"; but when remarks within these records were examined, they seemingly described the alternative management as BWE, albeit using a different expression (e.g., "saltwater flushing"). For clarity, the ballast tank records labeled as alternative management—as well as records not specifying the exchange type—were categorized in this study as "unknown" exchange.

Ballast tank records also classified ballast water from each individual tank as coastwise (CW) or overseas (OS) when a ship's origin was a U.S. or Great Lakes port or a foreign port, respectively. When information regarding the source port was not specified in the records, the voyage was classified as "unknown". Of course, a single ship may contain ballast water from multiple origins—CW, OS, or unknown locations—so the volume discharged was subtotaled by its origin, and the total discharge for a single ship was the sum of these subtotals. In this manner, such an arrival would not be classified as OS, CW, or UNK (even if the majority of water were from one of these locations).

Analysis

While the focus of this study was vessels entering Great Lakes, to gauge the relative frequency of Great Lakes arrivals to all U.S. arrivals, we compiled arrivals data from all U.S. coastal states. In this investigation, the arrival states were grouped into four regions: the Atlantic Coast, the Great Lakes, the Gulf of Mexico, and the Pacific Coast. In several cases (Florida, New York, and Pennsylvania), states spanned two regions, so the ports in the state were segmented to the corresponding region. For example, ports on the west coast of Florida were grouped into the Gulf of Mexico region, whereas ports on the east coast were grouped with the Atlantic Coast states. For New York and Pennsylvania, inland ports were grouped with the Great Lakes. Arrivals to Hawaii and territories located outside the continental U.S. were not included in the tallies. Minimum tank hold time was calculated as the difference (in days) between the final exchange event and the date of arrival. This metric was relevant as some BWT may require a minimum hold time for treatment to be effective or to dissipate disinfection by-products prior to neutralization.

Data were stored in an electronic database with standard database tools and an interface for generating SQL-based queries (Microsoft Access, 2013, Redmond, WA). In some cases, custom data processing

Please cite this article as: First, M.R., Drake, L.A., The practicability of ships arriving to the Great Lakes to conduct ballast water exchange *plus* treatment—Analysis of shipping patterns..., J. Great Lakes Res. (2017), http://dx.doi.org/10.1016/j.jglr.2017.05.004