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Review

Analyzing trends in ballasting behavior of vessels arriving to the United States from 2004 to 2017

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ABSTRACT

Maritime shipping transports over 90% of global goods. Ballast water, used to provide vessel stability, has been associated with the introduction of marine invasive species. Thus, understanding ballasting trends is imperative to protecting human and environmental health. This paper examines data from the National Ballast Information Clearinghouse to assess ballasting behavior and shipping trends in the United States. From 2005 to 2017, vessel arrivals have remained relatively constant (annual growth rate of 1.2% per year) while total ballast discharge per vessel has grown at an annual rate of 7.6%. Furthermore, from 2014 to 2016, alternative ballast water management methods have been on the rise, and these treatment options are likely to continue increasing in response to the International Maritime Organization Ballast Water Management Convention that entered into force in September 2017. It is critical that the shipping industry monitors potential cascading impacts on other ballasting behaviors stemming from this shift.

1. Introduction

According to the International Maritime Organization (IMO), over 90% of goods are transported by sea. This highlights the large role of maritime shipping in the global economy. Over the last several decades, changes to maritime shipping technology and policy regulations have altered the global shipping landscape. The many mergers and acquisitions which took place over the last 20 years have led to increasingly large shipping firms and vessels (Alexandrou et al., 2014; Wastler, 1997). The maritime shipping industry will undergo further dramatic changes in the coming decades, as sea ice recession is expected to open sea routes through the Arctic by 2050 (Smith and Stephenson, 2013; Stephenson et al., 2013). Given the size and scope of the maritime shipping industry, it is important to understand the role of vessels as sources of inputs to their surrounding environments.

Maritime shipping has many well-documented negative impacts on human and environmental health. Air pollution emissions along shipping routes and coastal cities have garnered attention for their negative association with human health in nearby areas (Beirle et al., 2004; Eyring et al., 2005). In addition to air pollution, ballast water, which is used to provide vessel stability, is a known vector for aquatic invasive species and pathogens worldwide (Bax et al., 2003; Carlton, 2001; McCarthy and Khambaty, 1994). Finally, ballast water may also serve as a vector for the global translocation of antibiotic resistance (Ng et al., 2018). All of these factors suggest that monitoring ballast water should be a top priority to researchers and policy-makers who strive to mitigate human and environmental health risks associated with maritime shipping.

Ballast water management (BWM) became a global focus in the 1980s following several accidental introductions of marine invasive species and a landmark study describing the biology of ballast (Carlton, 1985). Conventional BWM is essentially re-ballasting at sea and is part of the current IMO guidelines. The IMO recommends that conventional BWM be performed 200 nautical miles from shore in water more than 200 m deep, although there are several exceptions that allow vessels to exchange ballast in waters 50 nautical miles from shore and 200 m of depth (IMO, 2005). The primary conventional BWM methods are empty-refill, also called sequential, and flow-through, also known as continuous flushing. A less common option for conventional BWM is to discharge ballast water within designated areas. Empty-refill requires the tanks to be emptied to the lowest level possible with pumping before refilling. This method is estimated to have exchange efficiencies ranging from 70 to 90% according to estimates in previously published literature (Dames Moore, 1999; Tsolaki and Diamadopoulos, 2010). Further research has found that open-ocean exchange replaced 93–100% of coastal water and removed 80–100% of coastal plankton (Wonham et al., 2001). Empty-refill is associated with a 1.6-fold decrease in bacterial concentration; however, this decrease was not shown

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to be significantly different than control tanks (Drake et al., 2002). Flow-through requires vessels to pump open-ocean water into ballast holds during voyage, thereby overflowing tanks with three times the volume of the tank. This method theoretically removes 95% of the original ballast water, but the true removal rate may actually be lower (Dickman and Zhang, 1999). The same researchers concluded that newer vessels are more effective than older vessels at removing organisms using conventional BWM, which may be explained by newer piping systems in the ballast holds (Zhang and Dickman, 1999).

Alternative BWM includes treatment systems using several technologies such as electro-chlorination, ozonation, UV irradiation, sonication, filtration, or heat, among others (Tsolaki and Diamadopoulos, 2010). Alternative BWM that make use of active substances such as ozone, chlorine, or free radicals must be type approved by the IMO member states according to IMO guidelines before they can be used; whereas, systems that do not use active substances require clearance from their respective government agencies. The IMO website lists 42 active substance systems with final type approval and 73 non-active substance systems with type approval from their respective government agencies as of July 2017. In addition to the IMO approval process, the United States Coast Guard (USCG) has a separate approval process that may be more stringent (Cohen et al., 2017). Despite these hurdles, more than 200 vessels arriving to United States ports reported using 58 different systems to treat $4.42 \times 10^6\,m^3$ of ballast water over a 28-month period from September 2013 to December 2015 (Davidson et al., 2017). The proportion of ballast water treated using alternative BWM during this 28-month period only comprised approximately 2% of the total ballast discharge in United States waters. There are several concerns surrounding the use of alternative BWM systems, including: 1) Variable efficacy in real-world settings; 2) Regrowth of microorganisms after treatment; and 3) Co-discharge of disinfection by-products (Delacroix et al., 2013; Gollasch et al., 2007; Werschkun et al., 2012, 2014). Molecular analyses should be used in studies to address these concerns, because previous studies of water quality in tropical regions have reported atypical findings in culture-based tests (Gerhard et al., 2017; Toranzos, 1991).

Ballasting behavior differences across vessel types and regions of the United States are important to understand, as they can be used to predict possible impacts of different types of shipping activity in United States ports. Vessels that are used to export goods from a port are more likely to discharge ballast in that port. As a result, certain vessel types are likely to be associated with a high volume of ballast discharge in ports that export large amounts of cargo relevant to that vessel type. For example, ballast water discharge in Alaska and Hawaii was dominated by tankers – a finding that makes sense in light of the volume of crude oil exported from Alaska to the rest of the United States (McGee et al., 2006). Additional information about ballasting behavior to other regions of the United States provided herein should be insightful to researchers and decision-makers as they prioritize certain vessel types or regions in future research or legislation.

Data-driven perspectives are necessary to create informed policy to protect human and environmental health. Ballasting data is gathered by some governments such as Australia, China, and the United States among many others; however, the characteristics of data gathered and its availability to the public ranges depending on the agency or country collecting the data. The United States ballast water data is publicly available online through the National Ballast Information Clearinghouse (NBIC), which is a partnership of the USCG and the Smithsonian Environmental Research Center (SERC). The NBIC started gathering ballast data in 2004 with the first full year of data collection occurring in 2005. Although the database is meant to include all arrivals, the percentage of overseas arrivals reporting in the early years was around 82–84% (Miller et al., 2011a, 2011b). The percentage of vessels reporting was expected to slightly increase as capacity for oversight increased following the implementation of the program. Several studies have previously examined different characteristics of the ballasting behavior of vessels arriving to the United States via the NBIC data (Davidson et al., 2017; Miller et al., 2011a, 2011b; Miller et al., 2007). Despite the common use of NBIC data in ballast research, a peer-reviewed overview of the NBIC data has not been published in the last five years.

The IMO Ballast Water Management Convention of 2004 received enough support to achieve ratification and entered into force in September 2017. Changes to BWM are likely to occur on several levels, such as volume of ballast, treatment of ballast, and location of BWM. A before-and-after comparison of ballasting behavior and BWM would provide insight to the real-world impacts of the implementation of the IMO Ballast Water Management Convention. As a result, now is a critical time to characterize ballasting behaviors of vessels in United States ports. It is imperative that researchers and decision makers have the necessary understanding of recent ballasting behavior to identify likely areas of importance, both for additional research and for effective policy measures to protect human and environmental health in this changing time. This paper examines ballasting behavior of vessels arriving in regions of the United States from 2004 to 2017, including BWM location, number of vessel arrivals, total ballast discharge, ballast discharge per vessel, and BWM method.

2. Methods

2.1. Data acquisition

All data used in this study were acquired from the NBIC. The NBIC database compiles information from commercial vessels arriving to the United States after an international journey. All vessels, with some exceptions for those operating exclusively in the United States Exclusive Economic Zone (USEEZ), must submit a report upon arrival in a United States port [dataset] (National Ballast Information Clearinghouse, 2017).

A function was written in R using the readr and httr packages to access the ballast records, both arrivals and tanks, for each state or territory (R Core Team, 2017; Wickham, 2017; Wickham et al., 2017). All files were saved locally to avoid repetitive requests to the NBIC database servers. Although permission to use the data was not required by the data use agreement found on the NBIC website, the authors contacted and received permission from the USCG to ensure compliance.

2.2. Defining regions

All analyses were performed using different regions of the United States (Eastern, Western, Gulf States, and Alaska & Hawaii) similar to those defined in previous publications by researchers from the SERC (Minton et al., 2015). The regions as defined in the present study are: 1) Western – California, Oregon, Washington; 2) Eastern – Maine, New Hampshire, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Pennsylvania, Delaware, Maryland, Virginia, West Virginia, Ohio, Michigan, Indiana, Wisconsin, Minnesota, Illinois, Nevada, South Carolina, Georgia; 3) Gulf States – Texas, Louisiana, Arkansas, Missouri, Iowa, Mississippi, Alabama, Tennessee, Kentucky, Oklahoma, Florida; and 4) Alaska & Hawaii – Alaska, Hawaii. There are additional locations in the NBIC database, including Guam, the US Virgin Islands, Puerto Rico, and American Samoa. These locations are included in this paper when describing "all regions", but they are not grouped for the regional analyses in this report.

Some of the states with ballast records in the NBIC database are not located on a coast and were not clearly included in specific regions in the literature. These states were added to the region from which the majority of the arriving vessels were likely to originate. For example, Iowa was added to the Gulf States based on the belief that most arrivals to the state were transiting along the Mississippi River, which has its mouth on the Gulf of Mexico. On the other hand, Michigan was added

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