The Use of Geographic Information Systems to Assess the Compliance of Ballast Water Management for Commercial Ships Operating in California

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Abstract— **The California State Lands Commission's Marine Invasive Species Program (MISP) administers the state's program to prevent nonindigenous species (NIS) introductions to California waters through the discharge of ballast water from commercial vessels. Ballast water discharge from commercial shipping is a primary source of the introduction of NIS into California waters. Vessels arriving to California are required to submit ballast water reporting forms upon departure from each port or place of call. These forms detail ballast water management activities for more than 10,000 vessel arrivals each year, forming a robust dataset through which compliance and management patterns can be examined, including geographic and temporal analysis of source and exchange patterns of ballast water that is discharged within the state. Compliance with the requirement to submit the ballast water reporting forms have consistently exceeded 95% (from 2004-2013), due in part to an active inspection and outreach program. The use of Geographic Information Systems (GIS) allows the MISP to assess compliance on several levels, including the source and management (ballast water exchange) locations of all reported ballast water discharges into California waters. GIS analyses can also illustrate broad patterns and processes, such as densities of noncompliant ballast water discharges by location, which offer greater insight into potential NIS hotspots and areas of increased risk. These data shed light on the quantities and geographies of managed ballast water, where such water has been exchanged, and where it has been discharged. Such analyses provide valuable information that can inform the development and revision of effective ballast water management regulations, as well as inform both retrospective and predictive studies of NIS invasion patterns.**

Keywords—nonindigenous species; commercial shipping; ballast water; GIS; vector; vessel; invasive species

I. INTRODUCTION

Nonidigenous species (NIS) are transported to new environments mainly through human-mediated modes of transport (vectors). In coastal environments, commercial shipping is the most important vector of NIS, accounting for or contributing to 79.5% of introductions to North America [1] and 74.1% globally [2]. It is estimated that up to 81% of California's 257 established aquatic NIS were introduced via commercial shipping, either through ballast water discharge or by the release or spawning of associated vessel biofouling [3]. Once established, NIS can have detrimental and long lasting ecological, economic and social impacts. The California State Lands Commission's (Commission) Marine Invasive Species Program (MISP) has administered the state's program to prevent commercial shipping NIS introductions to California waters since its inception in 2000.

Ballast water is vital for many vessel functions related to the trim, stability, maneuverability and propulsion. Vessels may take on, discharge, or redistribute ballast during cargo loading and unloading, as they transit through shallow coastal waterways, or as they encounter rough seas. Because of this, ballast water is of crucial necessity to the functioning of the vessel. Typically, a vessel takes up ballast water from a "source" port as cargo is unloaded to compensate for the shift in weight and later discharges that ballast water at a "recipient" port as cargo is loaded. This transfer of water from a source to a recipient port results in the movement of numerous organisms from one region to the next [4]. It has been estimated that more than 7,000 species are moved around the world on a daily basis [5], and that each ballast water discharge potentially releases over 21.2 million individual organisms [6].

In order to mitigate some of the risk involved with the discharge of ballast water, vessels utilize various forms of ballast water management prior to discharge. Mid-ocean ballast water exchange (BWE) is the most accepted and protective form of ballast water management currently in use around the world for vessels requiring discharge. Vessels primarily conduct two types of BWE: flow-through (FT) and empty-refill (ER). In FT exchange, ocean water is pumped through a ballast tank to flush out the coastally sourced water (at 3 times the tank volume). Empty-refill exchange is conducted by draining a ballast tank of coastal source water and then refilling it with open-ocean water. During either type of exchange, the biologically rich water that is loaded while a vessel is in port, or near the coast, is exchanged with the comparatively species-poor waters of the open ocean. Coastal organisms are ill-adapted to survive in the open ocean due to differences in biological and physical characteristics.

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Likewise, open ocean organisms are not expected to survive in coastal waters [7].

The Marine Invasive Species Program's enabling legislation, California Assembly Bill (AB) 703 (Chapter 849, Statutes of 1999), addressed the ballast water threat at a time when there were no mandatory national requirements. This legislation, the Ballast Water Management for Control of Nonindigenous Species Act, established a statewide multiagency program to prevent and reduce aquatic NIS introductions from commercial vessels. AB 703 required that vessels entering California from outside the U.S. Exclusive Economic Zone (EEZ, which extends to 200 nautical miles (nm) off-shore) manage ballast water before discharging into state waters and submit a ballast water reporting form detailing the vessels ballast water management practices to the Commission upon departure from each port of call in California. There was, however, no management requirement for vessels transiting between ports wholly within the U.S. EEZ, despite evidence that "intra-coastal" transfer may facilitate the spread of NIS from one port to the next [8].

In 2003, the California Legislature adopted the Marine Invasive Species Act (Act) (Chapter 491, Statutes of 2003), requiring all vessels to have a ballast water management plan and ballast tank logbook specific to the vessel onboard. The Act also directed the Commission to adopt regulations for vessels transiting within the Pacific Coast Region (PCR), which extends 200 nm from land along the Pacific Coast of North America east of 154 degrees West longitude and north of 25 degrees North latitude, exclusive of the Gulf of California (Fig. 1). The coastal regulations formally establishing the PCR were finalized in March 2006 and require vessels arriving to California ports after operating within the PCR to conduct BWE at least 50 nm from land in waters at least 200 m deep prior to discharging into California waters.

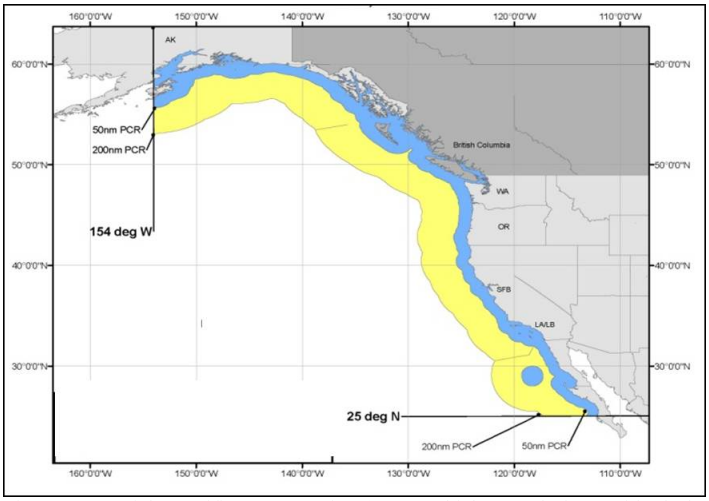

Fig. 1. Map of the Pacific Coast Region (PCR), which extends from mid-Alaska (154°W) south to halfway down the Baja California peninsula (25°N). The outer line signifies the 200 nm zone. The inner line signifies the 50 nm zone.

In addition to mid-ocean or coastal ballast water exchange, vessels have several different options for complying with California's current ballast water management regulations, including retaining all ballast on board the vessel, discharging ballast to an approved shoreside or barge-based reception facility (although no such facilities currently exist in North America), or use an alternative environmentally sound, Commission or United States Coast Guard (USCG) approved method of management. For those vessels requiring discharge, ballast water exchange remains the only viable option currently available.

Measuring compliance with California's ballast water management rules and regulations consists of a two-pronged approach. The first level of compliance assessment is accomplished through the use of MISP field inspectors, who board vessels and check ballast water management plans, review reporting logs, and take samples to assess compliance. One of the more crucial roles of the field inspector is to perform outreach to the vessel's crew. Because of this, inspectors try to target those vessels for boarding that are new to California, have received previous violations, or have not been boarded in the past year. MISP staff is mandated to board and inspect at least 25% of vessels arriving to California ports per year. Given that California ports receive an average of 10,490 commercial vessel arrivals per year (2004-2011) [9], assessing compliance through field inspections alone is impossible and impractical. Because of this, the second level of compliance assessment relies on the use of Geographic Information Systems (GIS) as a means of analyzing the large amount of data submitted by vessels.

II. METHODS

In order to collect the pertinent information on ballast water management practices, California law requires all vessels 300 gross registered tons or larger and capable of carrying ballast water to submit the Ballast Water Reporting Form (BWRF) upon departure from each California port or place. In an attempt to ease the reporting burden vessels encounter, MISP adopted for use the same BWRF used by the USCG. Forms have been submitted to the MISP beginning in 2000 for vessels arriving from outside of the U.S. EEZ and for all vessels (including those travelling coastally or solely within the PCR) beginning in 2004.

The BWRF requests information relating to the vessel's particulars, such as IMO number, vessel type, call sign, flagged country, vessel owner, and the vessel's total ballast water capacity. It also contains information specific to each voyage, such as arrival port, last port, next port, arrival date, and agent. Finally, the BWRF reports information on the ballast water history of a given voyage, including the amount of ballast currently on board, number of tanks to be discharged, and how many of those tanks were exchanged. For each tank to be discharged, the following information is collected: the date, volume, and location (port name or

coordinates) of the ballast water source; the date, volume, location, and type (flow-through, empty-refill, alternative) of any ballast water management; and the date, volume, and location (specific port or coordinates) of the ballast water discharged. The data from each form received are hand-entered by MISP staff into a purpose-built database, where they are quality controlled to ensure accuracy.

Because these data are necessary to assess compliance with ballast water management regulations and to analyze management trends and practices, knowing the form submission rates is important. MISP staff sends monthly reports to shipping agents and/or vessel owners to ensure forms are submitted and to minimize non-compliance. These efforts, coupled with field inspections and associated outreach activities, have resulted in a high form submission compliance rate, averaging 97% per year from 2004-2012 [9].

The high BWRF submission compliance rate is central to the MISP's ability to accurately assess ballast water management compliance. Because vessels have multiple tanks dedicated to ballasting operations, and each tank may be managed individually at separate times, data are analyzed on a per-tank, rather than a per-vessel basis. Because of this, copious amount of data need to be analyzed. For example, for the last half of 2012 (July 1 – December 31), there were 4,607 separate tank discharges at California ports. Whether a discharge is considered compliant is dependent on several factors, including the vessel's last port of call (LPOC), the source of the ballast water, and where the ballast water exchange occurred (Figs. 2 and 3). Since BWE occurs while the vessel is underway, locations are reported using coordinates. Geographic Information Systems (GIS) allows MISP staff to determine if the reported coordinates fall within the geographic range of compliance.

As Figs. 2 and 3 illustrate, there is an intricate process involved with compliance assessment. Because of this, MISP staff use GIS to help automate the process. GIS allows the user to plot large amounts of geographic data, visualize it, and parse it into corresponding layers of information (e.g. within the EEZ, within the PCR). Because of this, MISP staff can process large amounts of data and place each individual tank record into either complaint or non-compliant categories.

In addition to providing a visual means of determining ballast water management compliance, GIS has many powerful tools that allow for further analysis and visualization of the data. For example, using Density Kernel Analysis, MISP staff have been able to determine "hotspots" of non-compliant ballast water exchange that occur along the California coast and to track changes that have occurred as a result of changing management requirements after the adoption of the PCR in 2006.

III. Discussion

The risk for NIS introductions through ballast water discharge is dependent on numerous and varying factors, including, but not limited to, the source, age, and volume of ballast water discharged, environmental similarities between the source and recipient port waters, and time of year [10]. Therefore, an examination of geographic and volumetric patterns of ballast water retention and discharge provides valuable information that may be used to frame relative trends

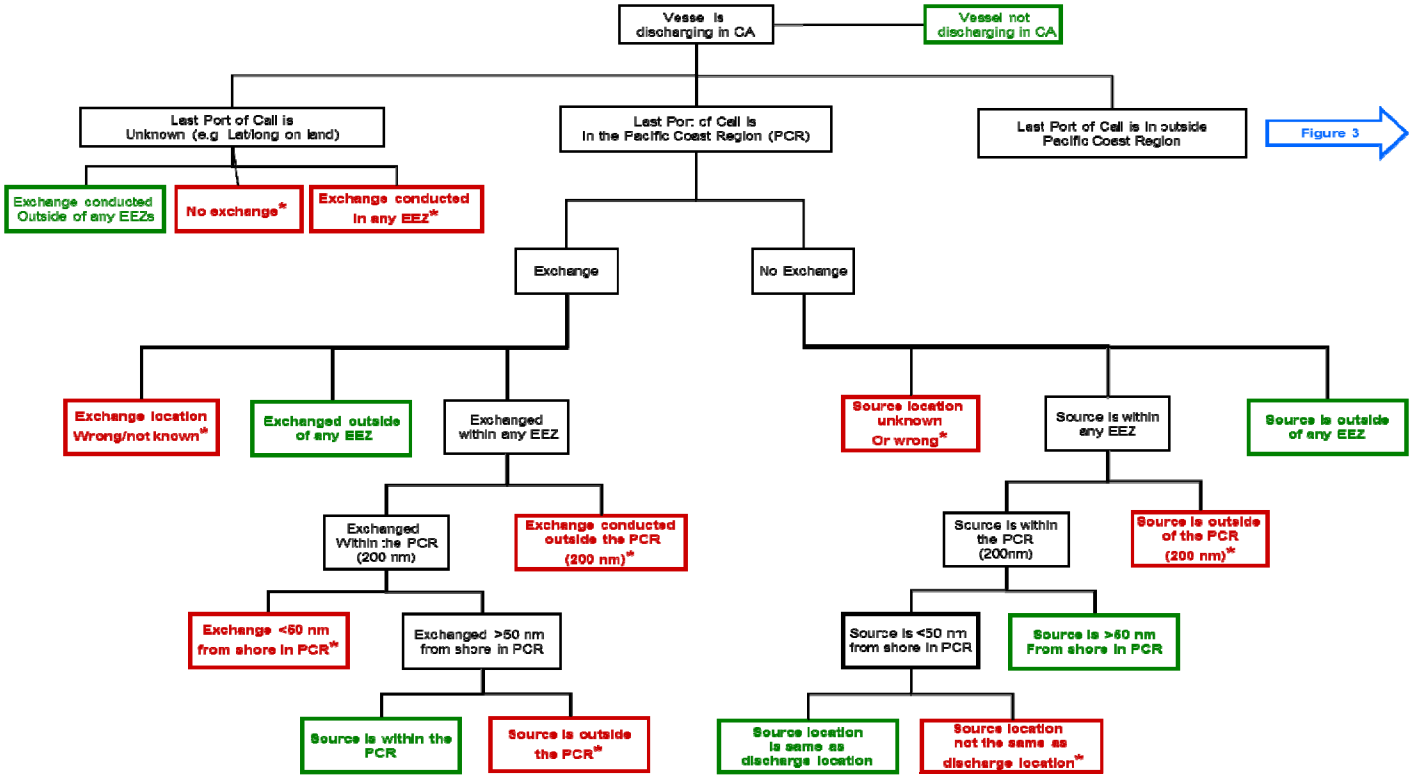

Fig. 2. Flow chart illustrating the ballast water management compliance process for vessels whose last port of call was within the PCR. Boxes with an asterisk signify those discharges that are noncompliant.

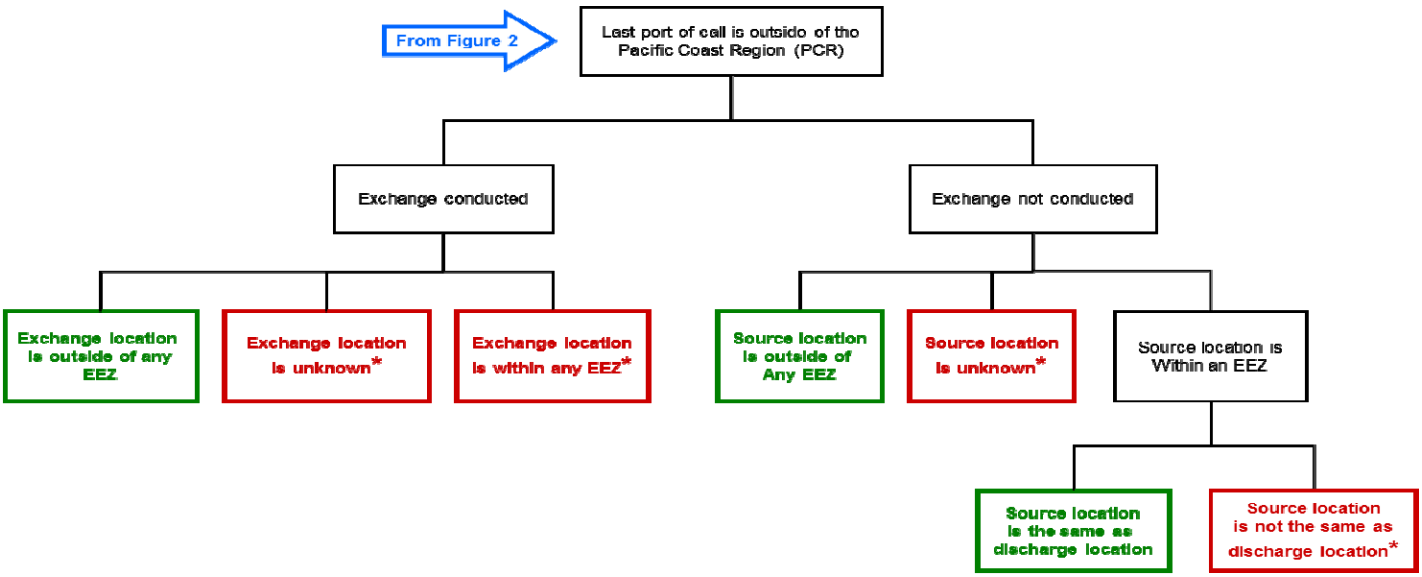

Fig. 3. Flow chart illustrating the ballast water management compliance process for vessels whose last port of call was outside of the PCR. Boxes with an asterisk signify those discharges that are noncompliant.

and risk of species introductions in California.

Vessels that do not discharge any ballast water within California waters pose zero risk of NIS introductions through the ballast water vector; therefore retention is currently the most protective management strategy available. Since ballast water management reporting requirements were implemented in 2000, the percent of qualifying voyages to California retaining all ballast water on board while in state waters (i.e. not discharging) increased from a low of 71% to an average of 84% in the years since 2004 [9].

Since 2005, there has been a decreasing trend in the number of vessels discharging water in California, as well as a decrease in the number of non-compliant ballast water discharges. Despite this, the total volume of ballast water discharge reached an all-time high in early 2012. Given the overall decrease in the number of ships discharging ballast water, and the fact that the majority of water discharged is managed in compliance with California law, the potential per-discharging-ship risk of NIS introduction into California waters is higher today than at any time since reporting began. Current ballast water management practices of BWE have gone a long way to reduce the risk associated with discharges, but coastal organisms may still be present in exchanged ballast [11, 12], so any increase in the volume of discharge has an associated increase in potential risk of NIS introduction.

Eventually, the implementation of ballast water discharge performance standards that limit the concentration of living organisms allowed during discharge will be the norm, and BWE will give way to ballast water treatment technologies in order to comply with these stricter standards. In the interim, BWE will remain the most protective form of ballast water management available. Because of this, the ability of the MISP and other resource management agencies to utilize tools such as GIS for the assessment of compliance with regulations, as well as to inform proper management responses based on data, remains an instrumental tool.

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