Biological Oceanography

Estimating Domestic and Foreign Ballast Water as a Vector for Invasive Species: Regional Analysis for New England, Northeast North America

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ABSTRACT

Biological invasions of coastal ecosystems are increasing at an alarming rate, with the increases attributed primarily to shipping, especially plankton in ballast water discharge. Although regulations of ballast water discharge have focused primarily on arrivals from foreign last ports of call, domestic arrivals also transfer ballast water and associated organisms within and among regions on coastwise voyages. However, to date there has been little effort to measure patterns of domestic ballast water discharge for any region of the U.S. We examined shipping patterns and estimated volumes of ballast water discharged by domestic compared to foreign arrivals for ports of the New England region using nationwide data on U.S. shipping arrivals and ballast water discharge by ship type for a three-year period (July 1999-June 2002). Overall, New England ports combined receive similar numbers of domestic and foreign arrivals, although the number and composition of domestic versus foreign arrivals differ greatly among ports. Domestic arrivals differed from foreign arrivals by composition of Ship Type (Bulk Carrier, Container, General Cargo, Passenger, Tanker and Other), and the composition of Ship Type differed among ports within the region. Estimates of ballast water discharge also differed greatly by Ship Type, with Bulk Carriers and Tankers discharging 4-6 times the volume of other types. In combination, domestic arrivals contributed about 35% of the estimated 24.8 million metric tons of the total ballast water discharged into ports of the New England region. In general, domestic ballast water often has high densities of plankton, because domestic voyages are of short duration and survival of entrained organisms in ballast tanks is high. Based on the patterns of ship arrivals, many New England ports are receiving discharges of domestic ballast water at high frequencies on a repeated basis from the same source ports along the East Coast of North America. This combination of large volume, high density of entrained organisms, and repeated discharge from the same ports, creates a high risk of introduction and invasion by nonindigenous species. Although our comparison of domestic and foreign ballast water discharge for New England is extrapolated from limited data, our estimates indicate that domestic ballast water is an important component of invasion risk that requires more accurate measurement.

INTRODUCTION

Biological invasions of coastal ecosystems result globally in serious ecological and economic consequences (Carlton 1989; Carlton and Geller 1993; Ruiz et al. 1997, 1999). Marine invasions have received relatively little attention compared to terrestrial and freshwater communities, but the consequences of invasions are no less evident in marine systems than in freshwater and terrestrial systems (Carlton 1989, 2001; Pew Ocean Commission 2002). Approximately 500 marine and estuarine NIS are known for the coastal U.S., and over 200 of these can occur in a single estuary (Cohen and Carlton 1995; Ruiz et al. 1997, 2000). The number of nonindigenous species and their documented rates of invasions are increasing at an alarming pace in many U.S. ports as well as along all three coasts of North America (Cohen and Carlton 1998; Ruiz et al. 2000). Although many vectors cumulatively are responsible for the transport and introduction of non-native species into coastal waters, commercial shipping—particularly release of plankton in ballast water—is a primary cause of the rapidly increasing rate of invasion (Ruiz et al. 2000). The United States and Australia each receive >79 million metric tons of ballast water annually on ships arriving from foreign ports (Kerr 1994; Carlton et al. 1995). A taxonomically diverse community of organisms is entrained and transported within ballast tanks, resulting in many successful invasions of nonindigenous species at ports throughout the world (e.g., Carlton and Geller 1993; Cohen and Carlton 1995; Smith et al. 1999; Hines and Ruiz 2000).

A number of legislative and regulatory actions have attempted to reduce the risk of invasion associated with ballast water transport. In 1991, the International Maritime Organization (IMO) established voluntary guidelines for ships to perform mid-ocean ballast water exchange (BWE). BWE reduces risk of invasion by discharging a large percentage of the entrained coastal plankton into inhospitable mid-ocean ecosystems, and by increasing salinity within ballast tanks to a level that many freshwater and brackish water species cannot survive (Taylor et al. 2002; Murphy et al. 2004; Ruiz et al. 2004). BWE is now the primary method for reducing the risk of species transfer and introduction by ships. To prevent further invasion of the freshwater ecosystems of the Great Lakes, the U.S. and Canada mandated mid-ocean ballast water exchange for all ships entering the St. Lawrence seaway. The National Invasive Species Act of 1996 established the National Ballast Information Clearinghouse (NBIC) and required that vessels arriving to all U.S. ports from foreign ports outside the exclusive economic zone (EEZ) report their ballast water management practices to the NBIC. However, voluntary compliance to conduct mid-ocean exchange is low (NBIC 2001). In addition, several U.S. states (California, Oregon, Washington) now require BWE for all vessels intending to discharge ballast water from foreign voyages. Moreover, the U.S. Coast Guard intends to extend mandatory BWE regulations to all discharge of ballast water from foreign arrivals.

Ballast water is also carried by ships on domestic voyages, which may be a significant source of coastwise transport and spread of nonindigenous species (Hines and Ruiz 2000; Lavoie et al. 1999). Domestic, coastwise voyages are often of shorter duration (12-72 hr) than foreign, transoceanic voyages (6-30 days), and survival of entrained plankton within ballast tanks is much higher on short voyages (Hines and Ruiz 2000, Ruiz et al., unpublished data). However, the quantity and discharge pattern of domestic ballast water is poorly understood.

In this paper we provide a first quantitative estimate of ballast water delivered by domestic (including voyages originating in Canada, as defined by NISA 1996) and by foreign arrivals of shipping on a regional basis, using New England as a test region. Because ballast water management practices differ greatly among types of vessels, we present summaries of foreign and domestic arrivals, quantities of ballast water and their sources (ports of last call) for New England ports by ship type.

Methods

Ship Arrivals

Ship arrivals information was provided by the U.S. Department of Transportation's Maritime Administration (MARAD). MARAD compiles U.S. Customs and U.S. Army Corps of Engineers data on ships arriving to the coastal United States. These data are used to characterize both foreign (overseas) arrivals as well as domestic (coastwise) traffic. The National Invasive Species Act of 1996 (NISA) and associated federal regulations characterize foreign arrivals as ships that visit U.S. ports immediately following time spent outside the Exclusive Economic Zone (see NBIC 2001). Because all ships arriving to the Atlantic coast of the United States from the Atlantic Canadian Maritime and Atlantic provinces are considered domestic coastwise arrivals under NISA, they are included here as such. Arrivals from other North American countries (Mexico and Central America) are considered by NISA and here as foreign. All ship arrivals data refer to the 3-year time period from July 1, 1999 to June 30, 2002.

Ballast Water Volumes

Foreign Traffic

Ballast water discharge volumes are estimated by querying the National Ballast Information Clearinghouse database. The National Invasive Species Act requires that all foreign ship arrivals report ballast practices with NBIC. However, it has been shown at the national level that only about 30% of qualifying vessels in fact reported (N = 12,015) (NBIC 2001). For this reason, we chose to estimate a projected foreign arrival discharge volume to selected New England ports by calculating average discharge volume per ship based upon foreign arrivals across the United States for each of six ship types: Bulk Carrier, Container, General Cargo, Tanker, Passenger, and Other. The category "Other" includes many unidentified ships that were likely Bulk Carriers and Tankers.Clearly, not all ship arrivals discharge ballast (e.g., many arrive full of cargo and little ballast water), so only the subset of ballast water reports that indicated ballast discharge was included in the mean volume discharge for ship types. To avoid inflating discharge volumes by including all arrivals (some of which do not discharge), the number of dischargers was estimated to be 26.4% of overall arrivals as calculated by NBIC (2001).

Domestic Traffic

Domestic coastwise traffic has not been required under federal law to report ballasting activities, so such data are not systematically compiled. However, significant numbers of domestic arrivals did report to the NBIC during the July 1999 to June 2002 time period (N = 1,219). Using these data, average discharge volumes per ship were calculated for the nation as a whole for each ship type and multiplied by the number of overall arrivals to New England ports. In the absence of more comprehensive domestic data, we also applied the proportion of discharging foreign arrivals (26.4%) to estimate the fraction of total domestic arrivals that discharged ballast water.

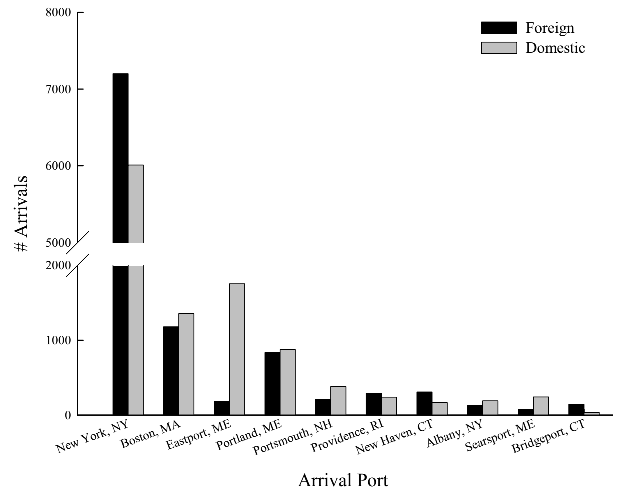

Figure 1. Number of foreign and domestic (coastwise) ship arrivals to selected New England ports. Data were provided by the Maritime Administration (MARAD) and cover the time period from July 1999 to June 2002.

Results

The number of domestic arrivals (11,248) was similar to the number of foreign arrivals (10,544) for all ships coming to New England over the three-year period (1999-2002) of analysis (Fig. 1). Based on the national average of 26.4% of foreign arrivals reporting ballast water discharge in U.S. ports, we estimated that 2,784 foreign arrivals and 2,969 domestic arrivals discharged ballast water into New England ports during this period. However, individual ports differed substantially in the number and pattern of foreign and domestic arrivals, with New York receiving six to seven times the number of ship arrivals than ports such as Boston or Portland. New York had about 17% more foreign than domestic arrivals; whereas Eastport had about 600% more domestic than foreign arrivals; most other ports had similar numbers of domestic and foreign arrivals.

The composition of ship types differed between foreign and domestic arrivals to New England as a region (Fig. 2). Overall, arrivals of Container Ships and Tankers were most abundant, followed by General Cargo, Bulk Carriers, Passenger Ships and Others. Numbers of foreign and domestic arrivals were similar for Bulk Carriers, Container Ships, Passenger Ships and

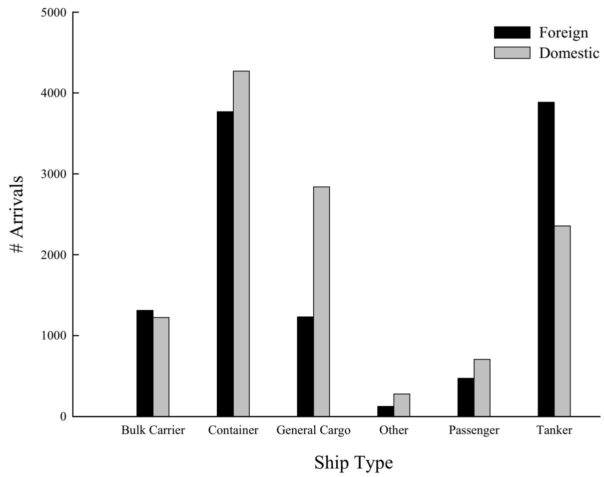

Figure 2. Number of foreign and domestic (coastwise) ship arrivals to New England ports (see Fig. 1) by ship type. Data were provided by MARAD and cover the time period from July 1999 to June 2002.

Others; while foreign arrivals were greater for Tankers, but domestic arrivals were greater for General Cargo Ships.

The composition of ship types also differed among New England ports for both foreign arrivals (Fig. 3) and domestic (coastwise) arrivals (Fig. 4). For example, New York received large numbers of Container Ships for both foreign and domestic arrivals, but nearly three times as many foreign as domestic arrivals for Tankers. Eastport received General Cargo ships almost exclusively as foreign arrivals, but both General Cargo and Bulk Carriers as domestic arrivals.

The reported volumes of ballast water discharged differed substantially by Ship Type for both foreign and domestic arrivals reporting nationally (Table 1). Generally, Bulk Carriers and Tankers have the greatest capacity of ballast water and discharge four to six times the volume of ballast water of Container, General Cargo and Passenger Ships. Ballasting practices for domestic arrivals differed from foreign arrivals. For most types of ships (except the "Other" category), domestic arrivals discharged only 50-70% of the volume of foreign arrivals. Thus, in addition to the number of arrivals, the type of ships and whether they were foreign versus domestic arrivals had great influence on the volume of ballast water discharged.

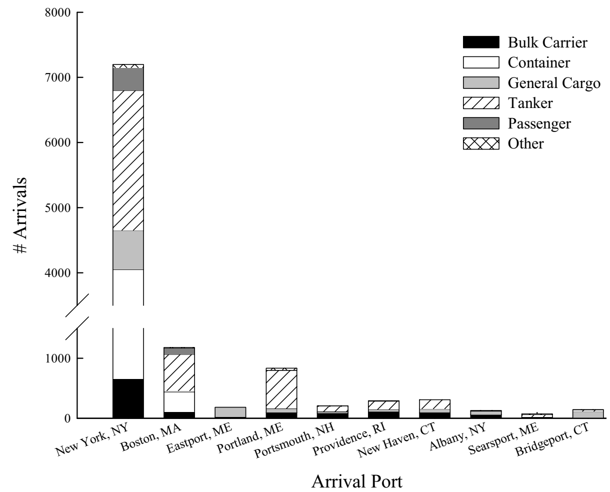

Figure 3. Foreign ship arrivals to New England ports by ship type. Data were provided by MARAD and cover the time period from July 1999 to June 2002.

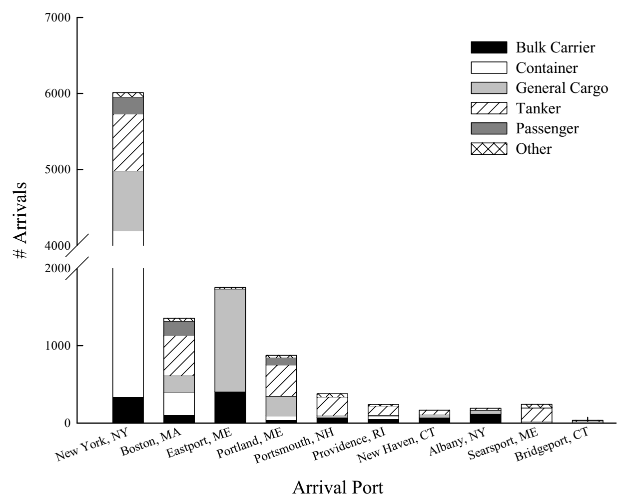

Figure 4. Domestic (coastwise) ship arrivals to New England ports by ship type. Data were provided by MARAD and cover the time period from July 1999 to June 2002.

In combination, foreign and domestic arrivals discharged a total extrapolated ballast water volume of about 24.8 million metric tons of ballast water into the ports of the New England region during the three year period (1999-2002). The estimated volume of ballast waster discharged from foreign arrivals totalled about 16.2 million metric tons (65.3% of total), whereas ballast water discharge from domestic arrivals totalled about 8.6 million metric tons (34.7% of total). However, the composition of

Table 1. Comparison of mean volume of ballast water discharge reported per ship for domestic (coastwise) and foreign arrivals by Ship Type. Volumes are in metric tons (MT), with standard error of the mean (SE) and number of ships (N) indicated. Data were provided by the NBIC and cover the time period from July 1999 to June 2002.

Ship Type	Domestic			Foreign		
	Mean Vol. Discharged [MT]	SE	N	Mean Vol. Discharged [MT]	SE	N
Bulker	6,660	582	197	12,328	228	2,706
Container	969	268	586	1,942	63	3,236
General Cargo	1,113	207	101	1,992	144	1,151
Other	8,268	1,050	48	5,677	687	168
Passenger	495	241	73	753	12	3,379
Tanker	6,566	545	214	9,251	486	1,375
Total			1,219			12,015

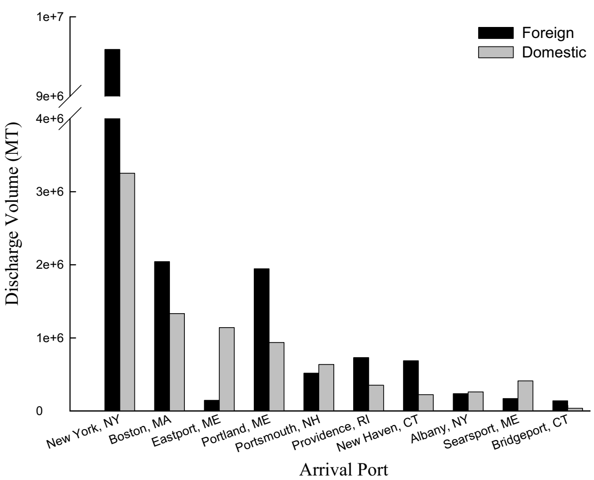

Figure 5. Total projected discharge volumes (in millions of metric tons) to New England ports by foreign and domestic arrivals. Mean, per ship, discharge volumes were estimated using the National Ballast Information Clearinghouse database for the time period from June 1999 to July 2002. Mean estimates were based on all ballast water reporting forms indicating ballast discharge. Foreign and domestic arrival discharge averages were multiplied by the number of MARAD arrivals and summed for each port to determine volume (see Methods for details).

foreign and domestic ballast water discharge differed substantially among ports (Fig. 5). For example, New York received three times the volume of foreign ballast water as domestic ballast water, while Eastport received six times the volume of domestic ballast water as foreign ballast water, and Albany received similar volumes of both foreign and domestic ballast water.

For foreign arrivals, the Last Ports of Call, which are often—but not always—the main sources of ballast water, were primarily in Europe, but included disparate ports from South America, North America (Mexico), Caribbean, Africa and Asia, as well as many others (Fig. 6). For domestic arrivals, the Last Ports of Call

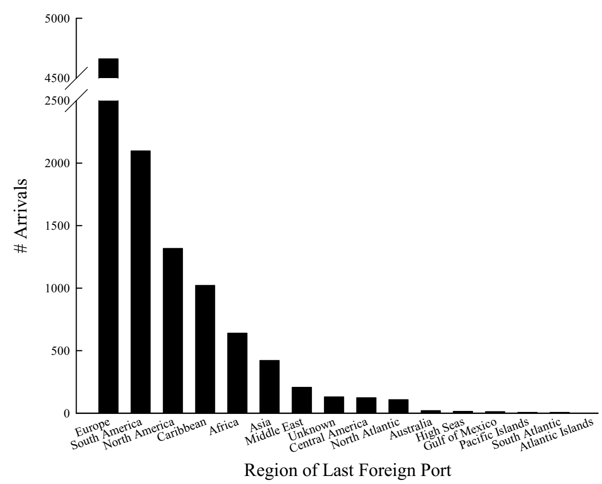

Figure 6. Number of foreign arrivals to New England ports (see Fig. 1) from regions of last port of call. Data were provided by MARAD and cover the time period from July 1999 to June 2002.

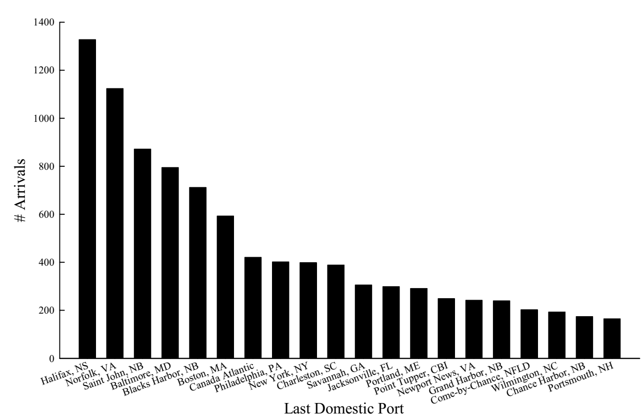

Figure 7. Number of domestic arrivals to New England ports (see Fig. 1) from twenty most common last ports of call. Data were provided by MARAD and cover the time period from July 1999 to June 2002.

were primarily in the Canadian Maritime Provinces,(namely, NB, NS, PEI), the Chesapeake ports of Baltimore and Norfolk, as well as Boston, plus many other ports both within and far outside the New England region along the East Coast (Fig. 7).

Discussion

As a first approximation on a regional scale for New England ports, ballast water from domestic arrivals appears to comprise nearly 35% of the total ballast water discharged by commercial ships. Domestic ballast water discharges often include high densities of plankton, because domestic voyages are of short duration and survival of entrained organisms in ballast tanks is high (Lavoie et al. 1999, Hines and Ruiz 2000). Based on the patterns of ship arrivals, many New England ports are receiving discharges of domestic ballast water at high frequencies on a repeated basis from the same source ports along the East Coast of North America. While we recognize that the origin of ballast water does not always equate to the last port of call, the combination of large volume, high density of viable entrained plankton, and frequent, repeated discharge, creates a high risk of introduction and invasion by nonindigenous species. Moreover, since a significant percentage of foreign arrivals have undergone ballast water exchange, while domestic arrivals have not, the contribution of coastal plankton in domestic ballast water discharge may be significantly greater than foreign ballast water based on calculations of volume alone.

Our estimates of the quantities and patterns of domestic and foreign ballast water discharged in New England ports include a number of uncertainties, because they are based on extrapolations from relatively small fraction of ship arrivals actually reporting (NBIC 2001). This is especially the case for domestic voyages, because there has been no federal requirement that domestic traffic report their ballast activities. Our extrapolations are based on reported discharges by ship type nation-wide, because that appears to provide the most integrative and inclusive use of the limited data available. Our extrapolations incorporated the national average of 26.4% of foreign arrivals that actually discharged ballast water. However, the larger dataset for foreign arrivals indicates first that only about 30% of arrivals report, and that ballast management practices may vary among regions. For the New England region, only about 25% of foreign arrivals reported to NBIC during the three-year period (1999-2002), and of these only about 10% of foreign arrivals claimed to discharge ballast water. Other regions have much more complete data for both foreign and domestic ballast water discharges, because of state requirements (e.g., California, Oregon, Washington) or types of shipping (e.g., oil tanker trade transiting from West Coast ports to Port Valdez, Alaska (Hines and Ruiz 2000, NBIC 2001). Until the data are more comprehensive, we rely on estimates derived from larger sample sizes that integrate across regions. The U.S. Coast Guard has initiated new regulations to increase reporting for both foreign and domestic arrivals that should increase the scope and quality at national, regional, and port levels of shipping activity. At the present time, however, we readily acknowledge both the uncertainties and that ballasting practices certainly differ among regions and ports, as well as between types of voyages (domestic versus foreign).

While we have only limited estimates of the volumes and management practices for ballast water on coastwise voyages, it is clear that the composition of ship types differs markedly among ports within New England. The volume and management practices of ballast water differ greatly among ship types, with Bulk Carriers and Tankers having much greater ballast water capacity than other ship types. Ports that export bulk cargo (e.g., coal, grain, oil) receive the greatest volume of ballast water discharged by ships arriving in ballast to take on loads. However, while Container Ships tend to carry small volumes of ballast water, the frequency of their arrivals may be much greater than Bulk Carriers (e.g., New York). We still have poor understanding of the relative contributions of volume compared to repetition of inoculations in the success of invasions, although both are probably important (Ruiz et al. 2000).

It is evident that the composition of ship types differs markedly among regions. For example, ballast water discharged by ships arriving in Alaska derives mainly from domestic voyages of oil tankers picking up crude oil from the trans-Alaska Pipeline (Hines and Ruiz 2000). The volume of foreign ballast water discharged into Chesapeake Bay is more than ten-fold than of any other U.S. port along the East Coast, primarily as a result of the large number of Bulk Carriers coming in ballast to the ports of Norfolk and Baltimore from European and Mediterranean ports (Carlton et al. 1995, NBIC 2001, Ruiz et al., unpublished data). Although the volume of ballast water discharged into the New England region is considerably smaller than some other regions of North America, the pattern of discharge of nearly 25 million metric tons from both domestic and foreign voyages may create significant risks of invasion, including coastwise transfer from other sites that receive even larger quantities of ballast water.

Many of the source ports for domestic voyages extend past biogeographic barriers, such as Cape Hatteras, Cape Cod, and Nova Scotia, as well as from ports within the region. These coastwise voyages may facilitate rapid dispersal of foreign invaders within a region and from one region to another. Many non-native species in New England and the Canadian Maritimes—including crabs, tunicates, and bryozoans—appear to have spread coastwise, although it is difficult to determine the relative contribution of human-assisted and natural means of transport in the spread (Ruiz et al. 2000).

Given the well-recognized increase in rate of marine invasions and their consequesnces, it is clear that domestic as well as foreign ballast water needs to be incorporated as a risk component of any effective management strategy for reducing coastal invasions. A crucial first step is to include accurate measures of ballast water discharge on domestic arrivals, so that we can better understand spatial and temporal variation in this risk.

Acknowledgements

This work is supported by the National Ballast Information Clearinghouse with funds from the U.S. Coast Guard and by the National Sea Grant Program for Aquatic Nuisance Species. Thanks to MARAD for providing data. Thanks to Judith Pederson and Gayle Sherman for their assistance and patience with the manuscript.

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