Ballast Water and Aquatic Invasive Species: A Preliminary Estimate of Propagule Pressure for Canadian Ports

Veronica Lo[1], Colin D. Levings[1,2], Nathalie Simard[3], and Kai M.A. Chan[1]

[1]Institute for Resources, Environment and Sustainability at the University of British Columbia
[2]Fisheries and Oceans Canada, Pacific Region
[3]Fisheries and Oceans Canada, Maurice Lamontagne Institute

Abstract

The introduction of aquatic invasive species (AIS) to ecosystems can cause widespread and irreversible damage to ecosystems. One of the principle mechanisms for the transport of AIS is through the uptake and release of ballast waters, which also carries suspended sediments harbouring AIS. Unfortunately, there are few studies that determine the extent to which propagule pressure—the frequency of introduction events and the abundance of AIS within each event—affects the successful establishment of invasive species. We addressed this knowledge gap by estimating the potential propagule pressure exerted on Canadian ports, using ship arrival and ballast water data as a surrogate for potential propagule pressure. Shipping data were extracted from the Canadian Ballast Water Database Application for the year 2005. These data were collected from ballast water reporting forms submitted voluntarily to port authorities and the Canadian Coast Guard. Our preliminary analysis identified the ports that have the highest number of arrivals and ballast volume discharges within three major shipping regions in Canada. The Atlantic coast had the highest number of reported arrivals in 2005, although more ballast water is discharged in the Pacific coast. Although the data do not represent all ship arrivals and ballast discharges, this study will provide guidelines for future ballast water sampling efforts, as well as baseline shipping data for further investigation of the relationship between propagule pressure and invasion success.

Introduction

The introduction of aquatic invasive species (AIS) to ecosystems is the second greatest threat to biodiversity (IUCN 2004). AIS can cause widespread and irreversible damage to their introduced ecosystems, predating on or competing with native species for food and habitat and spreading diseases. Over 330 AIS have been identified and recorded in the Canadian Wildlife Federation Invasive Species Database (CWF 2006). The invasive sea lamprey, zebra and quagga mussels are now permanent residents of the Great Lakes ecosystem (Mills et al. 1994), while Eurasion water milfoil, European green crab, and various tunicate species pose serious threats to Canada’s west coast (Lim 2004, Ray 2005).

There are numerous vectors for AIS, including deliberate introduction via aquaculture, horticulture, or the animal trade. AIS can also be introduced unintentionally by commercial shipping activities, through hull fouling or the uptake and discharge of ballast waters. This latter pathway is considered one of the principle mechanisms for the transport of AIS (Lavoie 1999).

Approximately 3 to 5 billion tons of ballast water are transferred among international waters annually (Raaymakers 2002). Ballast waters also carry large amounts of suspended sediments harbouring invasive species (Gramling 2000). Mid-ocean exchange (MOE), in which ballast water taken up in coastal/estuarine waters is exchanged with mid-ocean waters, is often conducted to minimize invasion threats. This process operates on the premise that survival of organisms upon release in more saline conditions is unlikely. However, coastal organisms can still persist in the ballast tank after MOE (Levings et al. 2004). To date, there is no comprehensive nation-wide data set on the quantities and locations of ballasting and de-ballasting activities. The information available is regionally localized – in comparison to the Great Lakes, fewer studies on AIS have been published for the Atlantic and Pacific coasts, which represented 20% and 36.4% of national trade in international cargo handling in 1996, respectively (Herbert 2004).

The objective of our study is to estimate potential propagule pressure exerted on Canadian ports by using ship arrivals and volumes of ballast discharged as a proxy for the direct sampling of propagules. There are few studies that determine the extent to which propagule pressure – the frequency of introduction events and the abundance of AIS within each event – affects the successful establishment of invasive species (Colautti et al. 2006). This shipping pattern analysis is an initial step in a nation-wide research project, the Canadian Aquatic Invasive Species Network (CAISN) (http://www.uwindsor.ca/CAISN), a collaboration between government and university scientists and the shipping and aquaculture industry. The results will contribute towards testing hypotheses about propagule pressure, such as the relative importance of frequency of events and abundance of AIS to establishment success, and the importance of ballast water *vs.* other shipping-related methods of introductions such as hull fouling.

Method

The primary shipping data were extracted from the Canadian Ballast Water Database Application (CBWDA), developed in 2006 by Fisheries and Oceans Canada (DFO) and by Transport Canada (TC). This data is taken from ballast water reporting forms that were voluntarily submitted to the Canadian Coast Guard and to individual ports. The forms include information on the country of origin, the source port of ballast water, discharge coordinates, temperature, specific gravity, volume of ballast discharged, and many other parameters. The year 2005 was chosen for analysis because it had the most complete data. The Vancouver Port Authority provided additional ballast water data, which had been independently collected until the introduction of the ballast water management regulations in June 2006 by Transport Canada. The number of arrivals and ballast water discharges were categorized into three major regions (the Pacific coast, Great Lakes-St. Lawrence, and Atlantic coast), tabulated and mapped.

As submission of ballast water reporting forms was voluntary during 2005, there were many entries that were incomplete or incorrectly filled out. For example, there were 264 forms indicating that ballast tanks had been emptied, but the volumes were not provided. There were a total of 25,841 records in the database, but only 13,587 forms provided information about ballast water discharges. The data was verified by a team at Fisheries and Oceans Canada, then imported into Microsoft Access and Excel and subsequently filtered to remove duplicates and investigate reasons for outliers. Obvious human errors were corrected; for example, many of the records indicating very long voyage durations had the wrong year inputted.

Results

Figures 1 – 3 show total discharge volumes for ports in the Atlantic coast, Great Lakes-St. Lawrence, and Pacific coast. Figure 4 is a comparison between regions, ranking ports by the number of arrivals and volume of ballast discharged. While there were more arrivals (2,867) on the Atlantic coast in 2005, the ballast discharged (21,654,052 MT) was approximately half of the volume that was discharged on the Pacific coast (39,925,544 MT). The Great Lakes-St. Lawrence region had the fewest reported arrivals (935) and the lowest volume (865,064 MT) of ballast discharge.

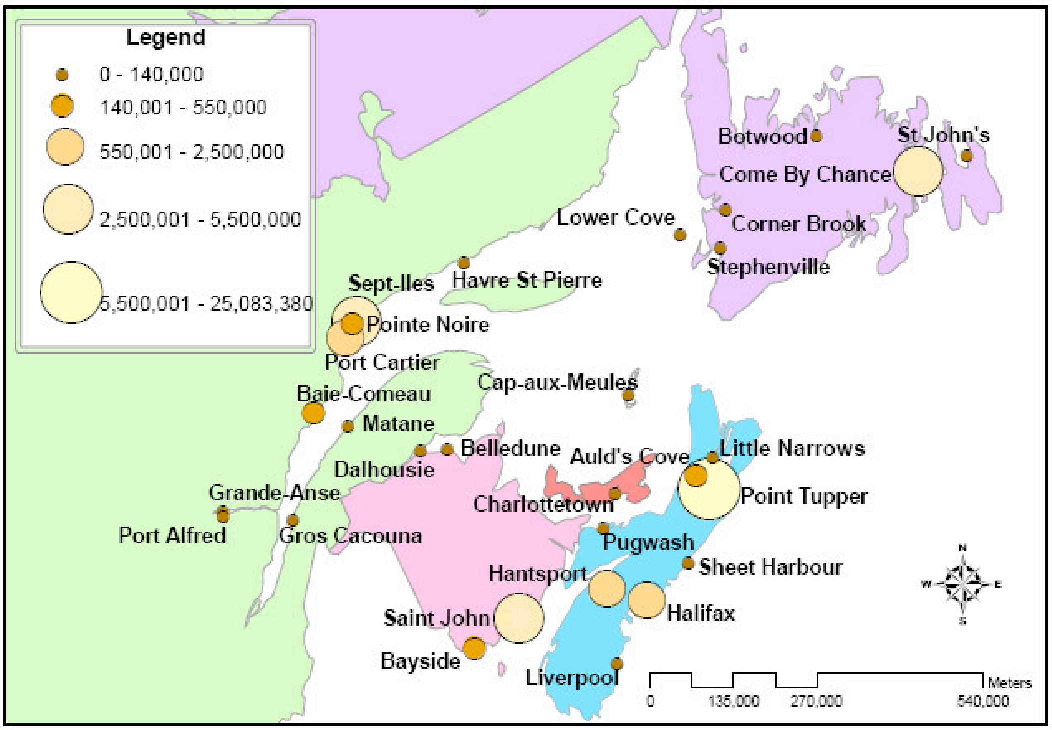

Figure 1: Total ballast water discharge volumes (in megatons, MT) on the Atlantic Coast, based on 2005 CBWDA data

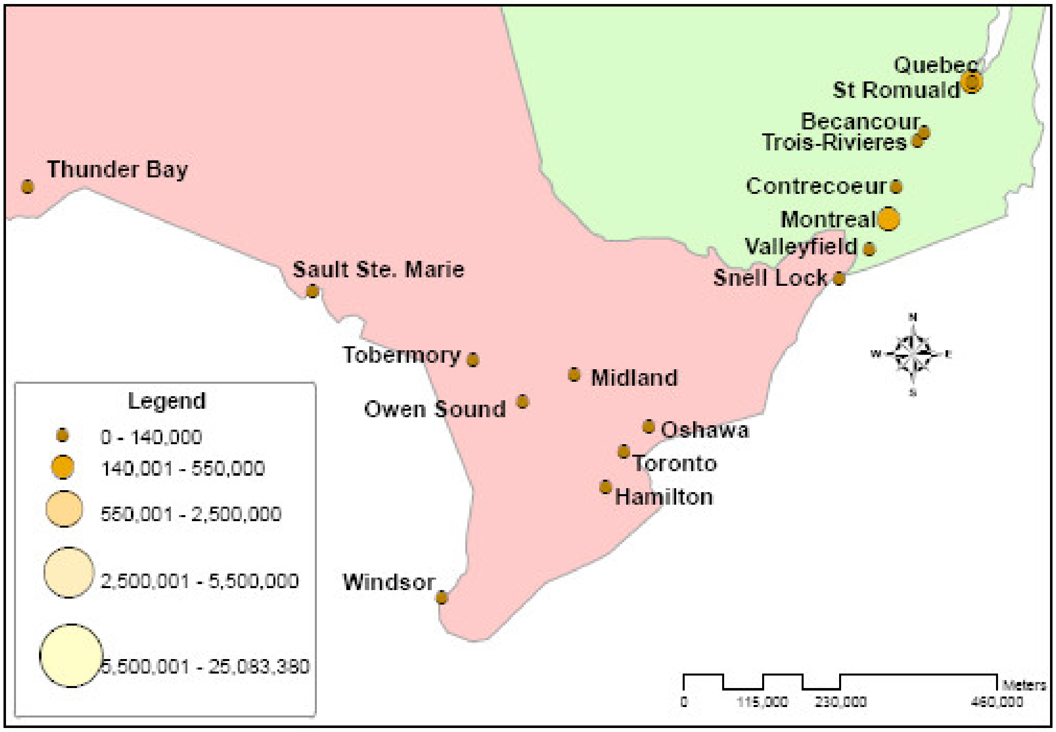

Figure 2: Total ballast water discharge volumes (in megatons, MT) in the Great Lakes-St. Lawrence, based on 2005 CBWDA data

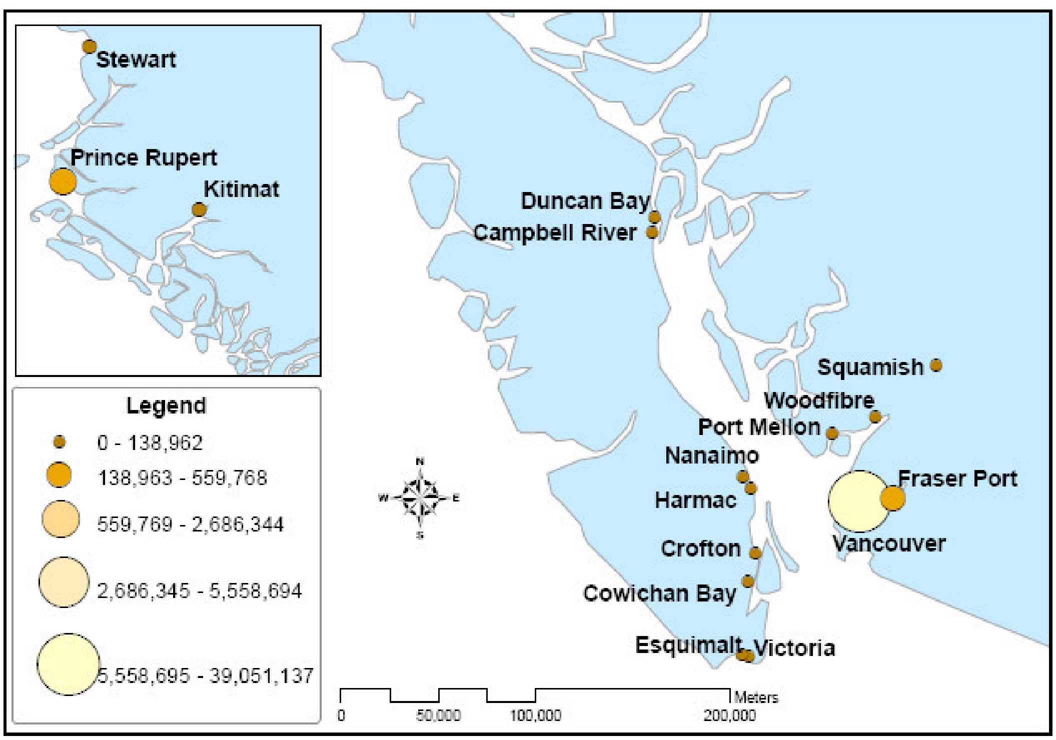

Figure 3: Total ballast water discharge volumes (in megatons, MT) on the Pacific Coast, based on 2005 CBWDA data

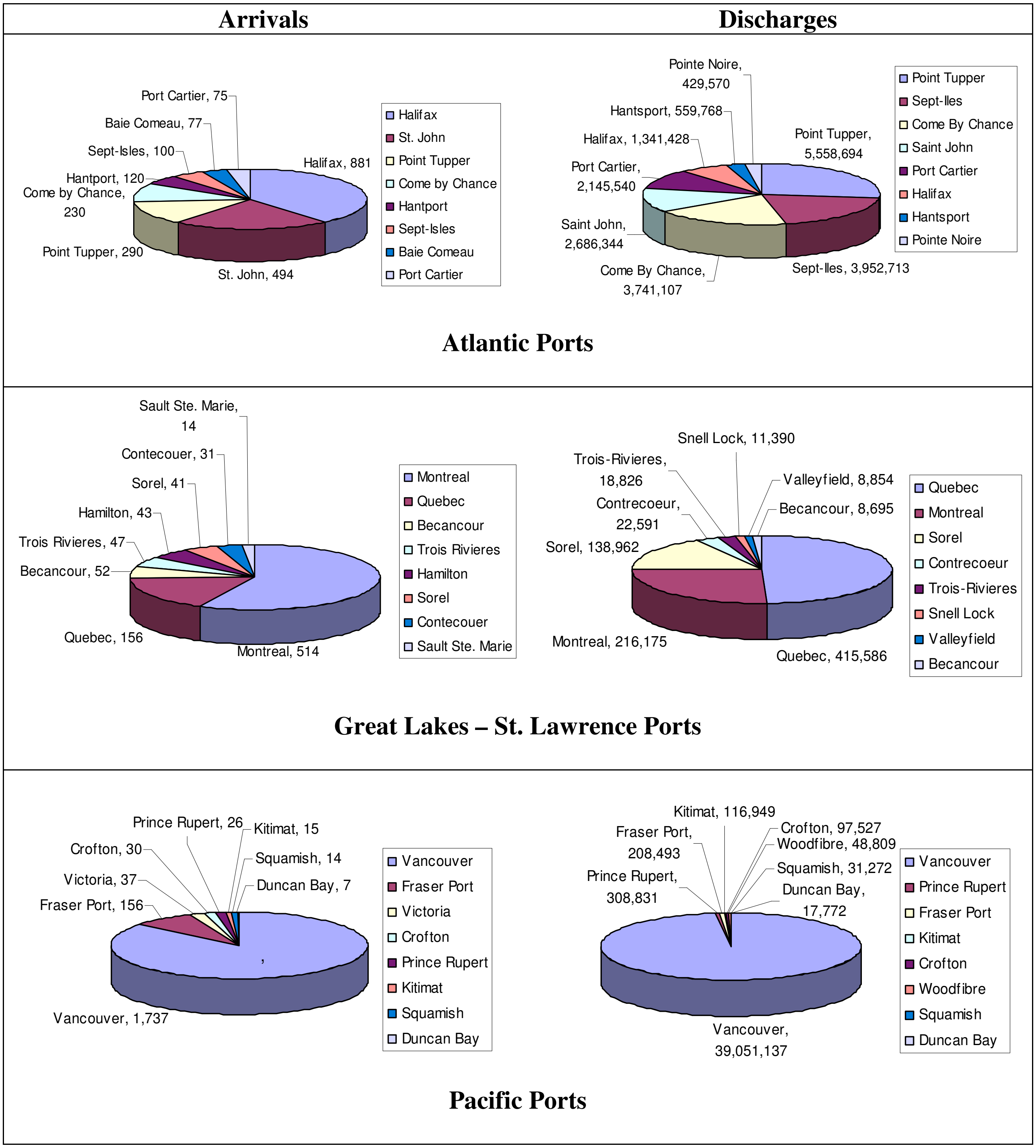

Figure 4: Ports Ranked by Number of Arrivals and Ballast Water Discharges (MT)

Discussion

As noted above, the data in the ballast water reporting forms were submitted voluntarily during 2005, and are an underestimate of the total number of arrivals. New ballast management regulations were introduced by Transport Canada in June 2006 (see http://www.tc.gc.ca/MarineSafety/TP/Tp13617/menu.htm), so there is the potential to compare the 2005 data with 2007 data. In addition, the majority of the forms represent ships that declared “ballast on board” (BOB), where MOE was conducted prior to arrival. “No ballast on board” (NOBOB) ships are exempted from the regulations and are allowed to follow alternative procedures. However, NOBOB ships can be a significant source of propagules, particularly in the Great Lakes-St. Lawrence shipping region. When ballast is taken up during unloading of cargo at a particular part, it mixes with residual, non-exchanged ballast water and sediments, and is subsequently discharged at another Great Lakes port (Colautti et al. 2003). Because no water is exchanged, it is not mandatory to submit ballast water reporting forms.

As evident in Figure 4, the number of arrivals does not necessarily correspond to larger volumes of ballast released. For example, Victoria ranks third in arrivals on the Pacific Coast in 2005, the majority of which are passenger vessels that normally do not discharge much ballast. Propagule pressure resulting from hull fouling for a port such as Victoria may thus be more important than ballast water discharges. This assumption, however, must be balanced with the consideration that hull fouling is less likely to occur on cruise ships traveling at faster speeds. The shipping data gathered for this study is thus important to determine general traffic patterns and vessel categories, which can vary greatly between ports. Furthermore, the data will allow us to compare the different risks of AIS introductions posed by ballast discharges and hull fouling.

The results from this study will aid in determining where future ballast water sampling efforts should occur. In addition, identifying the highest-traffic ports and the areas that receive the most ballast discharges will aid in focusing management efforts specific to those areas. Our study provides an initial assessment of propagule pressure, given the assumption that the number and diversity of propagules released in a given area is proportional to the number of ship arrivals or the amount of ballast water discharged. Propagule pressure can also vary by a number of different factors, however, such as voyage duration, source region, and efficacy of ballast water exchange (Colautti et al. 2003). By further analyzing the data, factoring in the above variables, this study will contribute to a more integrated understanding of propagule pressure and its role in invasion success.

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