THE EXTENT AND IMPACTS OF BALLAST WATER INVASIONS

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Zebra mussels on native clam.
Photo courtesy of GLSGN Exotic Species Library, Wisconsin Sea Grant

In recent decades, it has become increasingly apparent that invasions by non-native organisms threaten aquatic flora and fauna in many of the world's coastal regions, as well as those human activities and economies that depend on healthy aquatic ecosystems. Invasions by non-native organism are often extensive, and data from various systems indicate that the rate of invasion has been increasing – Fig. 1. This increase is thought by many to be linked to the expansion and globalization of commerce, and the wider and faster movement of goods and people around the world. Several human activities contribute to the long-distance transport of aquatic organisms, including aquaculture, the trade in aquarium organisms, live seafood and live bait, and the accidental transport of organisms attached to the hulls of boats and ships. However, it appears that the most important mechanism currently operating, in terms of the number and diversity of organisms transported and the number of resulting invasions, is the transport of organisms in ships' ballast water – Fig. 2.

In the process of loading ballast water, vessels inevitably take aboard large numbers of small or microscopic drifting organisms known as plankton. In addition they sometimes take in significant numbers of small, bottom-dwelling organisms along with sediment stirred up from the bottom. Over the past 15-20 years, several research teams have studied water and sediments collected from the ballast tanks of commercial vessels to see what remains alive after the completion of transoceanic voyages. These studies have identified virtually all types of marine and freshwater organisms in these samples, sometimes in substantial abundance, including at least several hundred different species of marine invertebrates and over a hundred different species of phytoplankton (Table 1). However, given the difficulty of distinguishing many of these organisms at the species level, the true number of species in these samples is surely much higher. Many types of protists, bacteria and viruses are apparently also present in these samples, although there has been relatively less work done on identifying them.

Ballast water has been responsible for a number of recent invasions that have been harmful to ecosystems or human activities:

- In the early 1980s, the western Atlantic comb jelly *Mnemiopsis leidyi*, a small, floating organism similar to a jellyfish, was introduced into the Black and Azov Seas where it became phenomenally abundant. It devoured the zooplankton that had been the main food for anchovies and sprat, devastating the regional fisheries for these species.

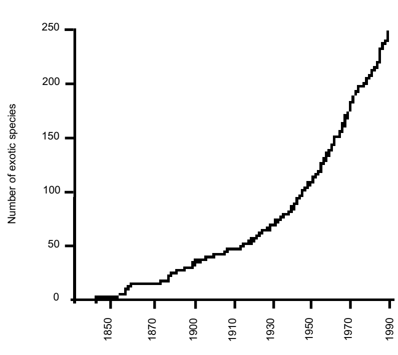

Fig. 1. Increasing Rate of Invasions. Cumulative number of exotic species established in San Francisco Bay/Delta Estuary.
Adapted from Cohen and Carlton, 1998, Science 279:555-58.

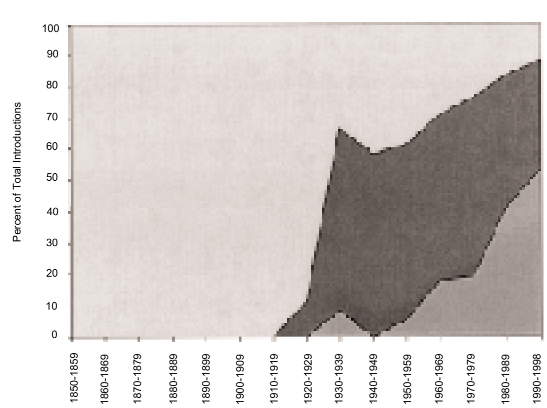

Fig. 2. Ballast Water Introductions
Lower and upper bound estimates of the number of ballast water introductions per decade. Based on the date of the first Pacific Coast record for exotic organisms established in the S.F. Bay/Delta Estuary.
From Cohen, in press, in Proc. 1st Nat'l Conf. Marine Bioinvasions.

In the late 1980s, the zebra mussel, Dreissena polymorpha, was discovered in the Great Lakes, apparently introduced in ballast water from northern European ports. This mussel has been an expensive nuisance, clogging the pipes that deliver water to cities, factories and power plants; attaching in enormous numbers to ship and boat hulls, marine structures and navigational buoys; covering recreational beaches with accumulations of rotting mussels and sharp-edged shells; and disrupting food webs, promoting blooms of nuisance algae and threatening native shellfish. Individual factories, water treatment plants and power plants have suffered millions of dollars of damage, and the overall costs for the region have been estimated at over hundreds of millions of dollars per year. The mussel has now spread across much of North America, from Canada to New Orleans and from the Hudson River to Oklahoma.

In October 1986, three clams, belonging to the Asian species Potamocorbula amurensis, were collected in San Francisco Bay. By the summer of 1987, Potamocorbula was the most abundant clam in the northern part of the Bay and soon spread throughout the rest of the Bay, attaining average concentrations of over 2,000 clams per square meter. It is a highly efficient filter-feeder and severely depleted phytoplankton populations, reducing or altering the food available to organisms higher in the food chain. It may also have reduced native zooplankton populations and made the ecosystem more vulnerable to invasion by Asian species of zooplankton. In addition, the clam accumulates selenium—a contaminant of concern in the ecosystem—in its tissues at concentrations that are apparently high enough to impair the reproductive activities of the fish and birds that feed on it.

Dinoflagellates are microscopic drifting organisms that can become phenomenally abundant, producing discolorations of the sea known as red tides. These red tides can kill fish and shellfish, and some of the dinoflagellates produce human neurotoxins that accumulate in toxic levels in mussels and clams. In recent decades, red tides have been reported in many parts of the world where they were previously unknown, closing shellfisheries and in some cases sickening or killing people. At least some of these red tide outbreaks resulted from dinoflagellates introduced in ballast water or in ballast tank sediments.

Ballast water discharges may pose an even more serious public health threat. During the 1991 South American cholera epidemic, the bacterium that causes cholera was discovered in oysters and fish in Mobile Bay, Alabama. The U.S. Food and Drug Administration then sampled the ballast water of 19 ships arriving in Gulf of Mexico ports from Latin America and found the South American epidemic strain of cholera in five of them. Some medical researchers believe that the epidemic strain was originally transported from Asia to South America in ballast water. The South American epidemic resulted in over a million reported cases of cholera and over 10,000 deaths.

Number of Species Collected	Maximum Concentrations of Organisms per Gallon	No. Ships Sampled	Ballast Water Port of Origin	Ballast Water Port of Release	Sample Type
174 phytoplankton, protist and invertebrate species	Up to 3,000 organisms	46	Outside NW Atlantic	St. Lawrence River, Montreal	Water
210 species collected	Up to 1,500 copepods, 12 million diatoms, 60 million microflagellates, or 10 billion picoplankton (bacteria and/or autotrophic picoplankton	86	Japan	Great Lakes/Upper St. Lawrence River	Water
56 phytoplankton species	Up to 57 million toxic dinoflagellate cysts	12	Japan	Tasmania	Sediment
402 species in 24 animal, plant and protist phyla		159	Foreign Ports	Oregon	Water
275 plant, protist and animal species		70		Chesapeake Bay	Water
At least 198 protist plus several diatom and invertebrate species		17		Israel	Water and Sediment
Over 350 species		189		Germany	

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