EXOTIC ORGANISMS

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In 1852, Commodore John Sloat of the U.S. Navy arrived in San Francisco on a special mission from Washington. His task was to find a site for the first U.S. naval base on the Pacific coast. His orders directed him to select a location that was "safe from attack by wind, by waves, by enemies and by marine worms."

The "worm" that the U.S. Navy was concerned about was the Pacific coast shipworm. It is not actually a worm, but rather a kind of clam with a long, skinny naked body and some small shells at its anterior end that it uses to bore into wood: wood like the hulls of wooden ships, and wood like the pilings that hold up wharves and piers. Shipworms can be very destructive of wooden structures — in San Francisco Bay, for example, dense infestations of the shipworm frequently caused pilings to break off at the mud line.

To avoid problems such as these, Commodore Sloat decided to locate the naval base on Mare Island in the northern part of San Francisco Bay, where the water was too fresh for the Pacific shipworm to survive. The base was established and thrived, without attack from any of its feared enemies for several decades, until the year 1913, when an Atlantic shipworm arrived on the Pacific coast, where it was, ironically, first discovered in a piling at Mare Island.

The Atlantic shipworm is more tolerant of fresh water, and over the next few years it became increasingly abundant in the northern part of San Francisco Bay. It eventually came to the attention of the general public, when beginning in the year 1919, a major wharf, pier or ferry slip collapsed into the waters of San Francisco Bay at an average of one every two weeks over a period of two years. The damage from this one long-forgotten and little-recognized introduction, in this one estuary on the Pacific coast comes out to somewhere between $2 and $20 billion in current dollars. It destroyed the entire maritime infrastructure in the northern part of San Francisco Bay.

If we were to take a tour of the San Francisco Bay system today, what organisms would we find? In the marina at Berkeley, we have pulled a styrofoam float or boat bumper out of the water, and found it completely covered with a variety of marine organisms: sea squirts from Asia and the Atlantic; sponges and bryozoans from the Atlantic; and mussels, which might be native to the Pacific Coast, or might have come from the Mediterranean. Such an assemblage of organisms is typical of what we find in the central part of San Francisco Bay, growing on hard surfaces or on the docks -- virtually every organism comes from some other part of the world and is not native to this ecosystem.

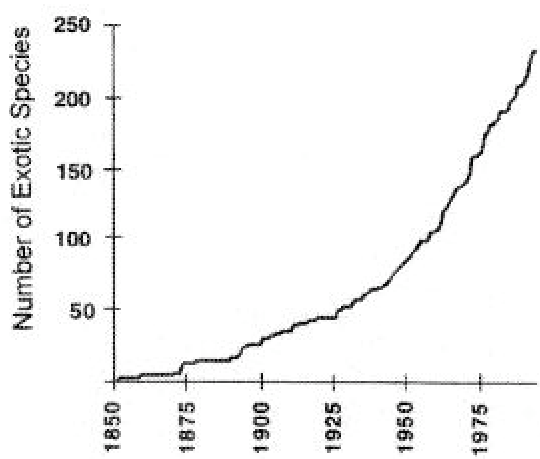
A little farther north in the Bay, in fresher or brackish water areas, we find a different set of organisms growing on the sides of the docks and hanging from the bottoms of boats and buoys: long, dangling, silt-covered strands that consist of an Atlantic hydroid (an early life stage of a jellyfish), covered by an Atlantic bryozoan, and crawling in amongst these, small, crustacean isopods from Asia.

Moving into more protected waters, we find the sides of the docks and the rocks often coated with reef-like agglomerations of white calcareous tubes. The tubes are built by a worm from the Indian Ocean. When we break these masses apart, we often find within them a little brackish water crab from the Atlantic coast of the U.S., and in recent years, alongside this crab can be found the juveniles of the Chinese mitten crab which arrived in San Francisco Bay a few years ago. Here we have a typical California story: the Atlantic crab meeting up with the Chinese crab in a structure built by an Indian Ocean worm on the side of a dock in San Francisco Bay.

Meanwhile, in the marshes, in many places around the Bay we find expanding clumps and patches of a tall, robust Atlantic cord grass that outcompetes the native California cord grass. The Atlantic cordgrass also grows much farther out into the mudflats, covering them with this exotic vegetation, which has raised concerns about the huge populations of migratory shorebirds that come here to feed on the mudflats each winter. These shorebirds — the sorts of birds that you often see probing in the mud at the water's edge — will only feed on open mudflats, not within vegetation, and if they lose the mudflats of San Francisco Bay, there is really no place else for them to go.

The mudflats themselves are often covered with small snails, the Atlantic mud snail, which is the most common snail in San Francisco Bay. The most common clam in the Bay these days is what is often referred to as the Asian clam (a recent arrival from China), the Japanese little-neck clam, and the Atlantic gem clam. In recent years, we have likewise found that the microfauna has been taken over by a Japanese foraminifera, a shelled protozoan which arrived in the 1980s. It is now the most common foraminifer in San Francisco Bay, and has spread up and down the Pacific coast. In 1995, Jim Carlton and I completed the first part of a study (which we have revisited in the last couple of years), in which we identified over 200 exotic species that have become established within the San Francisco Bay and Delta system. Beyond the sheer number of these organisms, we have been impressed by how they dominate many habitats and biological communities -- in terms of the number of organisms, the number of species, or the biomass. These two things together -- the number and the dominance of exotic organisms -- led us to suggest that the San Francisco Bay system may be the most invaded estuary in the world. However, even more striking to us than their number and dominance is the rate at which these organisms are coming in (Figure 1). The data clearly show that the rate is dramatically increasing. During the period prior to 1960, over California's history, we find roughly one new species arriving in the system and becoming established every year; since 1960, there are about four new species every year.

Figure 1. Increasing Rate of Invasions



How are these organisms coming in? There are several mechanisms. Historically, an important mechanism that still operates to some degree is that organisms come attached to the hulls of ships (or, in the case of wooden ships, bored into the hulls like the shipworm), and then release their young, which may become established on the new coast. Sponges, seaweeds, barnacles and some mussels were introduced in this manner. Another important mechanism was the importing of oysters into San Francisco Bay from different parts of the world. Oysters from the Atlantic coast and from Japan were laid out in vast rearing beds in shallow areas around San Francisco Bay, fenced off from the bay to keep out oyster-eating leopard sharks and bat rays. These oysters never became established, but many other organisms that were attached to the shells of oysters, or that were in the mud or the water that the oysters were carried in, did become established within San Francisco Bay and in other bays along the Pacific coast.

These mechanisms do not operate very much anymore, but we have developed new and ever more effective mechanisms for moving organisms around the world. One mechanism that has received a good deal of attention in recent years involves the transport of ballast water in cargo ships travelling about the world. When a ship is empty of cargo or light in cargo, it sits high in the water and can easily be knocked over by wind or by waves. Since this is unsafe for travelling across oceans, ships that are light in cargo will pump aboard vast quantities of water in order to sink the ship down to a more stable level. Upon arriving at its destination, a ship will then dump its ballast water out into the coastal water, before taking on cargo.

Table 1. Types of Organisms Collected in Ballast Water

Vascular plants	Gastrotrichs
Bacteria	Annelid worms
Blue-green algae	Peanut worms
Green algae	Molluscs
Red algae	Crustaceans & mites
Diatoms	Tardigrades
Dinoflagellates	Bryozoans
Flagellates	Starfish, brittle stars, sea urchins & sea cucumbers
Forams	Phoronid worms
Radiolarians	Arrow worms
Ciliates	Lancelets
Jellyfish	Acorn worms
Comb jellies	Sea squirts
Flatworms	Fish
Ribbon worms	
Round worms	
Rotifers	

In the last 15 years or so, biologists have begun to examine ballast water, and have found that it contains virtually all types of marine organisms (see Table 1). Within these groups, probably thousands of different individual species have now been identified as live organisms in ballast water. For example, organisms that live on the bottom of the ocean -- the clams, the mussels, the barnacles and so forth -- release larval forms that are microscopic and float in the water, and we tend to find these, sometimes in great numbers, in ballast water. In addition to small organisms, we sometimes find larger organisms, such as fish or crabs.

There have been some spectacular invasions over the last 15 years via ballast water, which have focused attention on this issue. Probably the most publicized is the arrival of the European zebra mussel in the Great Lakes. The zebra mussel has become so abundant that it has covered beaches with sharp-edged shells and rotting masses of mussel flesh, closing them. The mussels attach to hard surfaces such as the hulls and surfaces of boats, ships and buoys, weighing them down, increasing the fuel consumption of boats and ships, and increasing their maintenance costs. The mussels imperil many types of native clams and other organisms. The most damaging economic impacts result from their tendency to grow inside water pipes, in enormous densities -- one mussel growing on top of another -- to the point where they clog the flow and sometimes entirely block pipes, causing water systems to shut down. They have hampered municipal and industrial water operations and reduced the flow of cooling water in nuclear and coal-fired power plants. The estimated damages within the Great Lakes region alone are in the billions. The zebra mussel has now spread throughout much of eastern North America.

Another impressive invasion involves a comb jelly -- a small, jellyfish-like organism. This one is about two inches long, semi-transparent and iridescent. It was introduced from the western Atlantic into the Black Sea in ballast water. It eats zooplankton **--** the fish food in the water -- and is insatiable. It became abundant enough in the Black Sea to eliminate virtually all the zooplankton. The fisheries have been closed, probably in substantial part because of the arrival of this organism.

Yet another recent invasion is that of a Japanese sea star that has arrived in estuaries in Australia. It has become very abundant, though not yet widespread. Where abundant, it has been helping itself to the clams that once supported a clam fishery. Efforts are under way to do something about it, but no one knows what.

In recent decades, biologists have recognized what has been described as an epidemic of noxious algal blooms and red tides around the oceans. These blooms of microscopic algae are harmful to marine life, and some of the red tide organisms produce human neurotoxins. These neurotoxins become concentrated in the tissues of clams and mussels, and can cause illness and death when these shellfish are eaten by humans. There are probably a number of factors contributing to this epidemic of algal blooms and red tides around the world, but accumulating evidence suggests that at least some of them are due to the introduction of these organisms into new parts of the world in discharges of ballast water.

In addition to red tide organisms, we also now know that cholera can be moved about the world in ballast water. It appears that in the 1990s the epidemic strain of South American cholera was transported in ballast water into the Gulf of Mexico, where it was found in oysters and fish along the U.S. coast.

San Francisco Bay has also been host to a recent spectacular invasion. In the fall of 1986, three Asian clams, a species never before collected on the west coast of North America, were found in San Francisco Bay by a community college biology class. By the summer of 1987, nine months later, it had become the most abundant clam in the northern part of the bay, with average densities of over 2,000 clams per square meter. Clams were packed practically side by side, over tens of thousands of acres of muddy bay bottom. This clam is so abundant that it is capable of filtering out of the water virtually all of the phytoplankton **--** the microcopic floating plants that are one of the basic foods in the estuarine food chain. Phytoplankton blooms, which had characterized this system up until the arrival of the clam, no longer occur in this part of the ecosystem.

There are things that we can do about the problem of exotic organisms. The San Francisco Bay Regional Water Quality Control Board recently listed exotic species released by ballast water as a priority pollutant impairing the health of the ecosystem. We can require ships to exchange their ballast water at sea, as is done in some parts of the country. Another technically feasible option is to move ballast water on-shore and treat it to kill or remove the organisms in it, much as we treat water or wastewater. I am currently working on assembling a team of water and wastewater engineers, shipping experts and regulators to investigate this approach.

I should emphasize that invasions have occurred on the land as well as in the sea. Table 2 provides a rough compilation of the numbers of exotic species reported in California. Several of these groups are underestimated, and other important groups are missing entirely, but even from this rough tally it is clear that there must be well over 300 species of macroscopic animals (we know virtually nothing about the microscopic ones), and something on the order of 1,000 plants that have been introduced into the State of California from other parts of the world.

Table 2. Exotic Species in California*

Mammals	22
Birds	24
Reptiles and Amphibians	10
Fish	55
Marine and Freshwater Worms	25
Snails and Slugs	43
Clams and Mussels	14
Crustaceans	66
Insects	??
Other Marine/Freshwater Invertebrates	38
Other Terrestrial Invertebrates	??
Animals	>> 297
Plants	1029

*Sources: Hanna 1966, Moyle 1976, Carlton 1979, Taylor 1981, Laudenslayer *et al.* 1991 (updated by Ron Jurek), Hickman 1993, Cohen & Carlton 1995, Cohen 1996

The story that I have told here of a rapidly accelerating rate of invasions into the bays and estuaries of the world **--** in the areas that are the first to feel the effects of expanding international commerce and shipping **--** may simply be a preview of what to expect on the land. Virtually all of the mechanisms that transport exotic species around the world are likely to increase in scale as we further liberalize international trade, open new global markets and accelerate the movement of goods and people. The accompanying movement of exotic organisms will not only involve those that affect natural environments, it will also introduce new crop pests, livestock pests, and human parasites and diseases. Yet when policymakers discuss mitigating the impacts of trade liberalization, they never address these obvious, direct and predictable consequences. As a state and a country, we are failing to make the investments needed to enhance our capacity to prevent, to monitor, to quarantine, to investigate and to respond to the invasions of harmful organisms that will inevitably come. In general, we know what needs to be done. In most cases, we do not need to develop whole new technologies. But we do need to face up to this problem squarely, and begin to take the steps that are necessary to deal with it.

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