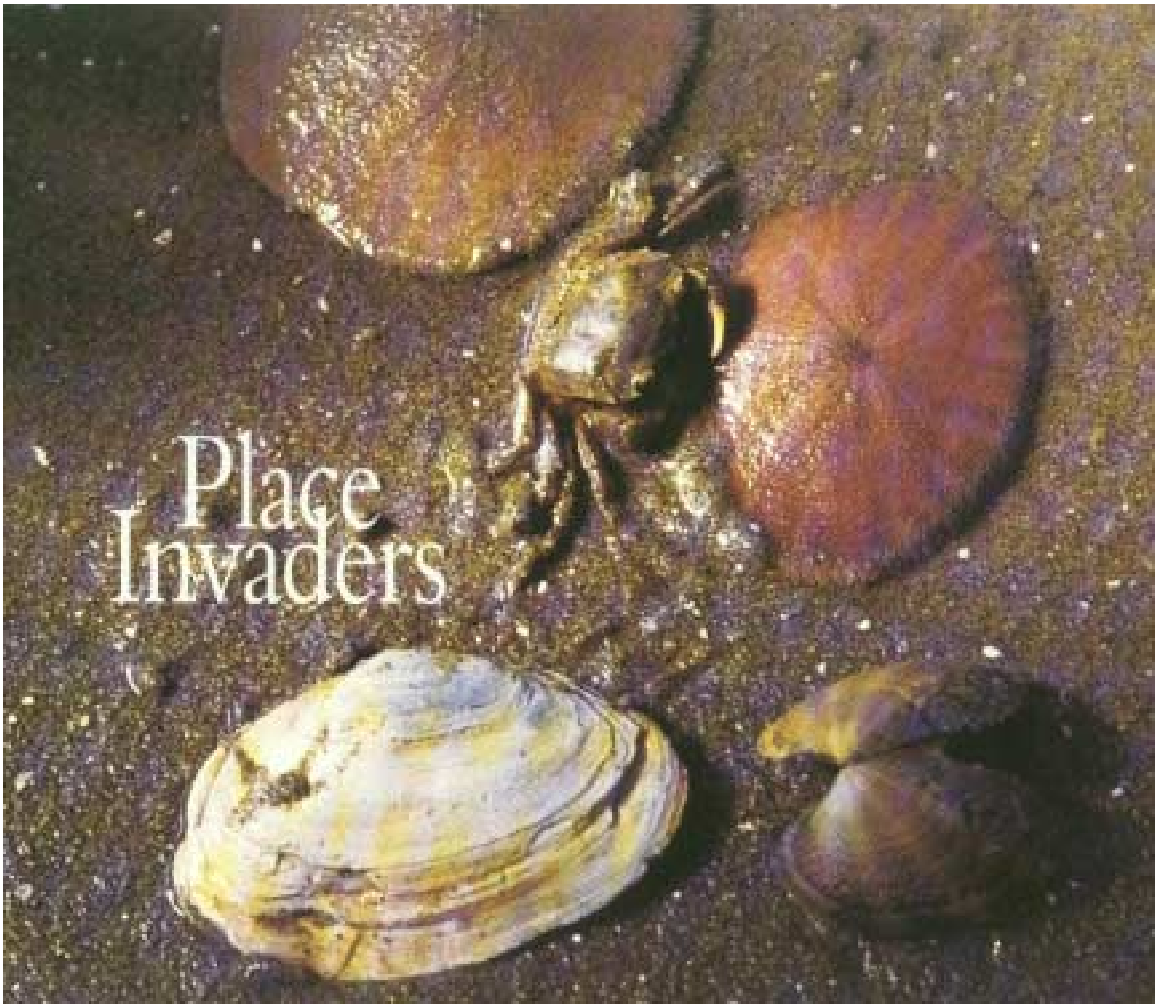

*A native yellow shorecrab (*Hemigrapsus oregonensis*) scurries among its more sedentary fellow inhabitants of a San Francisco Bay intertidal flat. Though the sand dollar (*Dendraster eccentricus*) is also indigenous to the West Coast, the soft-shell clam (*Mya arenaria*) and the littleneck clam (*Venerupis philippinarum*) were brought here in the last 130 years, probably clinging to oyster shells.*

Place Invaders: Intruders in San Francisco Bay

by Andrew Neal Cohen

On the Richmond shoreline in San Francisco Bay, the bay's muck-bound creatures play out their lives. Among them are a native yellow shorecrab and a horde of species that did not evolve here and many believe do not belong. These descendents of travelers from distant shores include a soft-shell clam and a tiny gem clam from the Atlantic; a littleneck clam and a orange-stripped anemone from Japan; and two Australian isopods, the burrower *Sphaeroma quoyanum* and, clinging to its belly, a minute associate, *Iais californica*. All of these arrived here within the past 130 years. And as I poked about among them in the summer of 1991, I was startled to find evidence of yet another newcomer.

This was the molted shell of a crab about two inches across and roughly hexagonal, with five prominent spines along each forward edge. Neither I, nor my colleagues, nor the guidebooks or invertebrate keys had ever noted its like in the bay before. When weeks later I got in touch with Dusty Chivers in the Invertebrate Zoology Department of the California Academy of Sciences, he identified the crab as the bay's latest successful invader, the European green shorecrab (*Carcinus maenas*).

Many of the plants and animals in the bay--the fish that swim and the tiny organisms that float in its waters, the invertebrates living on and in the mud, the plants in the marshes and the seaweeds on the bottom--are not native to the region. Though no one knows the precise number, at least 150 are "introduced species": plants and animals that have travelled here with intended or inadvertent human assistance, and established reproducing populations.

Some have become so abundant that they dominate whole sectors of the bay's ecosystem. For example, in parts of the bay, introduced species account for more than 90 percent of the total weight of bottom-dwelling mollusks. Some of these additions to the local fauna have brought significant benefits, including several fish and shellfish that temporarily supported large commercial fisheries, while other have caused considerable harm, such as the shipworm, *Teredo navalis*, which riddled pilings with its borings and, within a few years of its discovery, caused the sudden and wholesale collapse of piers and wharves. But whatever their impact on human activities, introductions have irretrievably altered the ecosystems they've invaded, and reduced the biotic distinctions that made each ecosystem unique.

The bay's history of frequent disturbance provided ample opportunities for new species to become established. To a naturally high rate of disturbance from seasonal and yearly changes in river flows and salinity, and the erosion and redeposition of mud by tidal currents, wind, waves, and storms, add a long list of human disturbances: the diking or filling of marshes and mudflats; the alteration of shoreline and the creation of new types of habitats with seawalls, pilings, riprap, and man-made lagoons; the dredging and dumping of dredge spoils; the damming and diverting of freshwater flows; the pollution from factories, refineries, ships, farms, and cities; and the historic increases in sediment from mining and farming. Such disturbances, individually and together, can eliminate or reduce the existing populations of organisms, creating an opportunity for a new organism to secure a home. According to James Carlson, director of the Williams College-Mystic Seaport Program in Maritime Studies, for nearly 150 years this highly disturbed and vulnerable environment has been subjected, "to both multiple and massive innoculations of exotic species," through mechanisms dominated by commercial shipping and oyster farming. The first infusion followed the discovery of gold in 1848, as thousands of ships arrived from all over the world, many to be abandoned or sunk when their crews fled to the gold fields. Their wooden hulls were encumbered with healthy growths of exotic harbor fauna, some of whose descendents can be seen today fouling the pilings and docks of the bay. Shipworms and gribbles bore into pilings, thick encrustations of barnacles, mussels, tube worms, tunicates, seaweeds, anemones, and sponges cover the available surfaces, while a mobile epifauna of small crustaceans and polychaete worms cling and nestle among them.

Over the years, incidental shipments of exotic biota continue to arrive at the bay's ports. With the disappearance of wooden cargo ships and the development of efficient antifouling paints, along with faster hull speeds and shorter time spent in port, the global transport of living ship-bottom assemblages has surely declined. Instead, modern cargo ships carry most of their maritime hitchhikers inside the hull, where immense number of tiny organisms float comfortably in ballast-water tanks.

Other exotic invertebrates arrived in the carloads of live Virginia oysters that were planted in San Francisco Bay after the completion of the Transcontinental Railway in 1869, and with shipments of Japanese oysters in the early twentieth century. "A single oyster shell," writes Carlton, "may have upon it representatives of ten or more invertebrate phyla, comprising dozens of species, and these numbers can be greatly increased when oysters are packed together for shipment with associated clumps of mud and algae." Today, researchers report far more species of exotic invertebrates in San Francisco Bay than in any other West Coast location.

The arrival and phenomenal spread of the Asian bivalve *Potamocorbula amurensis* attracted public notice. This homely little clam was first collected in the bay in October 1986, having probably arrived as planktonic larvae in ballast water discharged from a cargo ship. Within eight months, it became the most abundant mollusk in the northern reaches of the bay, growing in concentrations of up to 1,500 clams per square foot.

Above: A native of the East Coast, the cordgrass Spartina alterniflora *was originally brought to the Bay Area as part of a saltmarsh "restoration" project. It now grows prolifically in part of the West, turning mudflats into cordgrass islands.*

Potamocorbula is also a highly efficient filter-feeder, straining large quantities of phytoplankton out of the water column. These microscopic floating plants form the base of the pelagic food web, and populations of certain fish and other marine organisms may ultimately depend on a good crop.

In drought years, phytoplankton concentrations in the northern part of the bay have typically been very low. According to Fred Nichols, an oceanographer with the Water Resources Division of the U.S. Geological Survey, the low concentrations may be due to increased numbers of filter-feeding clams, which move into the northern bay from saltier areas during droughts. In the past, the return of normal weather and normal river flows has driven the clams out and the phytoplankton have recovered. But *Potamocorbula* is more tolerant of fresh water than other clams, and appears to be unharmed by this year's high flows. If it survives and continues to decimate the phytoplankton, *Potamocorbula* could dramatically and permanently alter the bay's northern food web.

Although the exotic invertebrates in the bay appear to have been introduced accidentally, most of the exotic fish in the bay and delta were purposefully brought in by government agencies to increase sport and commercial fishing. Beginning in the 1870s, state and federal agencies have successfully established 29 nonnative fish in these waters, with some of them showing phenomenal growth, at least for a time. Just two decades after 432 striped bass were transplanted to the bay from New Jersey, commercial fishermen were harvesting over a million pounds a year. Introduced catfish supported a fishery so successful that by the turn of the century the surplus catch was being shipped back to Mississippi.

*Above: James Carlton has studied nonnative species in San Francisco Bay for 30 years. To gauge the age of this recently-introduced European green shorecrab (*Carcinus maenas*), he measures its size.*

Peter Moyle, professor of Fisheries Biology at the University of California at Davis, has studied the effects of these introductions on California's native fish. He has found that new fish generally take over in waters that have been altered or disturbed, and through predation or competition restrict native fish to the remaining patches of relatively pristine water. In the delta's tributary rivers that drain the Sierra Nevada, healthy poulations of native fish, unable to coexist with the introduced species in the highly altered rivers of the Central Valley, are found only in the relatively undisturbed foothill reaches. Moyle fears that the remaining native populations, isolated from each other by lowland reaches now occupied by introduced fish, are in danger of extinction.

Above: Casts of the native lugworm, Arenicola *sp., left behind after the animal digests thesubstrate to extract nutrients. Water seeping through the burrows prevents the worms from suffocating.*

Within the delta as well, introduced fish have contributed to the decline of native species, with predation playing a major role. The inland silverside (*Menidia beryllina*), introduced by the California Department of Fish and Game to control gnats in Clear Lake, has spread to the delta, where it may now be a major predator on the larvae and eggs of the Delta smelt, a threatened species.

Probably the best-known introduced fish in the bay is the striped bass (*Morone saxatilis*). Although celebrated by environmental and fishing organizations as the bay's "indicator species," Moyle says that the voracious striper may have been responsible for eliminating two native fish: the Sacramento perch, now extinct in its native waters, and the thicktail chub, which is globally extinct.

According to Moyle, fish introductions and habitat changes generally occurred simultaneously, so that it is often hard to say which was responsible for an extinction. But in this case, the two native fish were tolerant of a wide range of habitat conditions, they were omnivorous, and they were extremely abundant--their remains are frequently found in Indian middens around the delta. Because habitat change alone seems unlikely to have done these fish in, Moyle is "convinced that they are gone due to introduced species. Their disappearance was coincident with the introduction of striped bass and black bass."

Although taken all together introduced species have changed large portions of the system's biota, most individual introductions have simply settled into life as yet another species among the many already here. Native species are sometimes displaced, but this has generally occurred without any obvious change in the way the ecosystem functions. For example, millions of shorebirds still migrate here each winter to feast on the mudflat's invertebrates, although few of the species that they pluck from the muck were present 150 years ago.

A few introductions have had a larger impact: striped bass because they were prolific predators, and the super-abundant *Potamocorbula* because of its effect on the bay's northern food web. Another big impact introduction may be the Atlantic cordgrass, *Spartina alterniflora*, which could radically transform one of the bay's most important habitats.

Above: A Japanese orange-striped sea anemone, Diadumene lineata*, found in Lake Merritt in Oakland, probably was first transported to the East Coast attached to the hull of a ship, and then across the country to San Francisco Bay on the back of an oyster*.

Ironically, *Spartina alterniflora* arrived in the bay as part of a "restoration" project. In the early 1970s, it was planted in a saltmarsh in Hayward to mitigate for wetlands destroyed by a nearby flood-control project. A robust plant which appears to out-compete the native species of cordgrass, *Spartina alterniflora* has since spread to five additional sites on both sides of the bay. In at least one of these cases, it was transplanted to the new site as part of yet another restoration project.

According to Donald Strong, professor of Biology at the Bodega Marine Laboratory, this "pushy New York *Spartina*" grows both higher and lower in the tidal zone than the native cordgrass. Because the bay's broad mudflats are built on such a gentle gradient, the ability to grow at even a slightly lower elevation means that tens of thousands of open mudflat acres may eventually be choked by dense growths of nonnative cordgrass, which is likely to accrete sediment at a rapid rate. "In Willapa Bay in Washington," reports Strong, "*Spartina alterniflora* has turned hundreds of acres of intertidal and subtidal mudflats into cordgrass islands."

Above: Two interlopers from the east, now well-established in San Francisco Bay, are the Atlantic mud snail, Ilyanassa obsoleta*, left, and the Atlantic oyster drill*, Urosalpinx cinerea. *In between are the oyster drill's egg cases.*

How concerned should we be about the potential transformation of mudflats into cordgrass marsh? On the one hand, some researchers hope the new cordgrass will provide additional habitat for the severely endangered California clapper rail. On the other hand, the mudflats are home to great numbers of clams, snails, worms, crabs, and other crustaceans, many of which are provide food for shorebirds, wading birds, and gulls when the tide is out, and for dabbling and diving ducks and bottom-feeding fish such as bat rays and leopard sharks when the tide is in. In contrast, relatively few creatures live or forage in the cordgrass.

We might get lucky with *Spartina alterniflora*, but since in most cases it will prove impossible to control or eliminate an introduced species once it's established, successful regulatory efforts must focus on prevention. The Australian government, convinced that many of the periodic "red tides" that make shellfish toxic are caused by exotic phytoplankton, has issued voluntary guidelines to control ballast water discharges. The U.S. government, responding to the invasion of the Great Lakes by the European zebra mussel (*Dreissena polymorpha*), which caused millions of dollars of damage in blocked water pipes and fouled boat and harbor structures, recently enacted the world's first mandatory ballast-water regulations. In 1992, California established a state policy aimed at preventing the introduction of "aquatic nuisance species" and pathogens via ballast water--but without any regulations or enforcement. (Note: Since this was written, California, later followed by Washington and Oregon, passed laws requiring ballast water from overseas to be exchanged at sea. Such exchange, if vigorously pursued, is generally viewed as only a partial solution to the problem of ballast water introductions, as the exchange of water is generally less than complete and sometimes, for reasons of ship safety, cannot be done at all. These laws also provide for very limited monitoring and weak enforcement.)

In the meantime, the European green shorecrab has spread to sites throughout much of San Francisco Bay and has been collected from Bodega Harbor. This crab is another species which is likely to have a big impact, for it is highly prolific (each female produces an average of 185,000 eggs a year), lives in nearly all types of coastal habitats, tolerates a wide range of salinities, and eats virtually anything. Its been blamed for damage to shellfish, shrimp, and eel fisheries in Europe, and for the near-destruction of the Maine soft-shell clam fishery. (Note: The green shorecrab has since been collected as far south as Morro Bay and north to British Columbia, though it is only established over part of this range.)

And new species continue to arrive. While wandering about on the edges of the bay a few years ago, I found colonies of a brilliant orange-and-black bryozoan forming lichen-like encrustations on the rocks, and several shells of a southern California moon snail cast up on the beach at Alameda, neither organism having been reported from the bay before. That summer, the Department of Fish and Game netted a new, probably Asiatic mysid shrimp in the northern bay.

In recent years scientist have paid increasing attention, and raised increasing alarm, about the effects of introduced species on fisheries, commercial activities, and marine ecosystems. But not all researchers share these concerns, and a few continue to propose additional introductions of fish and shellfish for commercial or sport fishing, as well as introductions of predators and parasites for use as biological controls. In their view, introduced species have provided sizable benefits. The striped bass may have killed off a few native species, but it also created a multi-million-dollar commercial and sport fishery. In lakes, marshes, and irrigation ditches, mosquitofish and silversides have eliminated troublesome clouds of insects. *Spartina alterniflora*, though changing the mudflats, might yet save the clapper rail. Overall, introductions of marine and aquatic organisms have increased the region's biodiversity as it is usually measured.

One oft-cited reason for concern that may outweigh the benefits is what Carlton calls "the roulette theory." Since there's no way of knowing if the next introduction will be one that produces costly fouling, destroys a fishery, eliminates a native species, or transmits a human disease, we should simply resist all introductions.

For me, an even more compelling reason begins with the recognition that native ecosystems are made up of finely-tuned relationships between coevolved organisms, and are not simply a random collection of plants and animals. Each ecosystem provides a unique educational and aesthetic appeal. Unregulated global transport of marine organisms threatens to transform the world's variety of bay and estuarine ecosystems, wherein each may contain more species than it did originally, but all will be dominated by a similar small set of aggressively invasive organisms. This loss of the distinctions between ecosystems is akin to replacing all the volumes in the library with a single book, or turning all the restaurants into town into McDonald's.

Only worse, since this homogenizing is utterly irreversible. With other ecosystem impacts--oil spills, over-fishing, water-diversions--if you stop the disturbance the system will, over time, more-or-less recover. But with introductions the change is fundamental and absolute. As Carlton warns, "Once you introduce a species, you've forever altered the natural environment. There's no going back. Ever."