

Proceedings of the National Forum on
Nonindigenous Species Invasions
in U.S. and Marine Fresh Waters

Sponsored by the Northeast-Midwest Institute

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Biological Invasions of the San Francisco Bay and Delta

Andrew N. Cohen, University of California-Berkeley

Of all the coastal aquatic ecosystems invaded by exotic species, the best-known is probably the San Francisco Bay/Delta Estuary. This estuary was most recently the subject of a two-year study on introduced species, conducted by myself and James T. Carlton of Williams College and Mystic Seaport, for the U. S. Fish and Wildlife Service.

We identified 212 exotic organisms that have become established in the Estuary. An additional 123 species are listed as representing perhaps half of the Estuary's cryptogenic species (species which, based on current knowledge, could be either native or introduced). Another 40 exotic species were discovered in the Estuary too recently to know whether they have become established, while another 36 are known from adjacent aquatic ecosystems but not yet reported from the Estuary.

More significant than the sheer number of exotic species is their dominance, in number of individuals and in biomass, in many of the Estuary's habitats. In numerous studies made since the 1940s, exotic species accounted for 40% to 100% of the common or dominant species in benthic and fouling communities at sites throughout the Estuary. Most of the common fish in the Delta were introduced from the eastern United States, along with their parasites. The zooplankton fauna in the northern part of the Estuary has, since the late 1970s, been increasingly dominated by Asian copepods and mysid shrimp.

In the past, many exotic organisms arrived attached to the hulls of wooden ships, in oyster shipments from the Atlantic or Japan, or with intentional introductions of fish. Although these transport mechanisms no longer operate, the pace of invasions has been increasing. Since 1850 an average of one new organism has become established in the estuary every 36 weeks; since 1970 there has been a new organism established every 24 weeks; and in the last decade perhaps as many as one every 12 weeks.

The increase appears largely due to ballast water-water pumped into a ship to achieve proper buoyancy and trim, transported across oceans, and then discharged on another coast before taking on cargo. Such ballast water may contain clams, crabs, shrimp, worms and other marine animals in great abundance, so that in a few hours time tens of millions of living exotic organisms may be deballasted from a single ship.

The notorious Amur River clam (*Potamocorbula amurensis*) arrived in San Francisco Bay in ballast water. Three clams were collected in October of 1986; within nine months, by the summer of 1987, it had become the most common clam in the Bay, reaching densities of 2,000 clams per square foot. These clams can filter the entire water column within a few days, depleting it of the tiny floating plants that form the base of the food web that sustains many of the estuary's fish and marine animals. Other organisms that recently arrived in ballast water include a predatory New Zealand sea slug, two Atlantic jellyfish, and possibly the Chinese mitten crab.

The introduction of these and other organisms has had both ecological and economic impacts. Through predation and competition, introduced species have contributed to the extinction or regional eradication of some native species and caused dramatic reductions in others. The Bay's food webs have been radically altered. Introduced cordgrasses threaten to overrun the mudflats, which provide key winter feeding sites for millions of migratory shorebirds on the Pacific Flyway.

On the economic side, one introduced wood-boring clam (*Teredo navalis*) caused an estimated \$615 million (in 1992 dollars) of damage to wharves, piers, ferry slips and other structures between 1919 and 1921. Hull fouling, which in the Bay consists primarily of introduced organisms, can increase the fuel consumption of boats and ships by 15 to 50 percent. California now spends \$400,000 each year to control exotic plants in the Delta, and spent over \$1 million to keep a single exotic fish from reaching the Delta. All three of these activities (control of exotic fouling, plants and fish) involve the release of substantial quantities of poisons into the environment, with additional environmental, occupational and possibly public health costs.

Another type of economic impact is demonstrated by the recently arrived Chinese mitten crab (*Eriocheir sinensis*) and the guild of other introduced burrowing organisms, which damage river banks, flood-control levees and irrigation channels. (One of these organisms also chews up the styrofoam blocks that keep afloat the docks in the Bay's marinas). When the mitten crab invaded German rivers in the 1930s, government authorities caught and destroyed tens of millions of crabs a year to try to keep the population under control. In Asia, the mitten crab also carries a human parasite, the oriental lung fluke, which, however, we have not yet seen in San Francisco Bay. On the other hand, in the Delta most of the organisms that parasitize sport fish are introduced.

The biggest economic losses, however, may be caused by direct and indirect impacts on the California water system. Direct impacts include the fouling and blocking of water intakes and pipes by introduced organisms, of which the worst is probably yet to come, if the zebra mussel should be introduced to California. Indirectly, exotic species appear to be a factor in the increasing number of endangered species in the Estuary, while the continuous arrival of new species makes the Estuary's ecosystem fundamentally unmanageable, by continually changing the cast of characters. These factors have led to increasing restrictions on water diversions, levee maintenance, channel dredging and other economic activities in and near the Estuary, with implications for the whole of California's economy. It is for this reason that California water agencies support legislation, such as currently applies to the Great Lakes, mandating the mid-ocean exchange of ballast water from foreign ports.