The San Francisco Bay-Delta Estuary

UNDER SIEGE

AQUATIC INVASIVE SPECIES

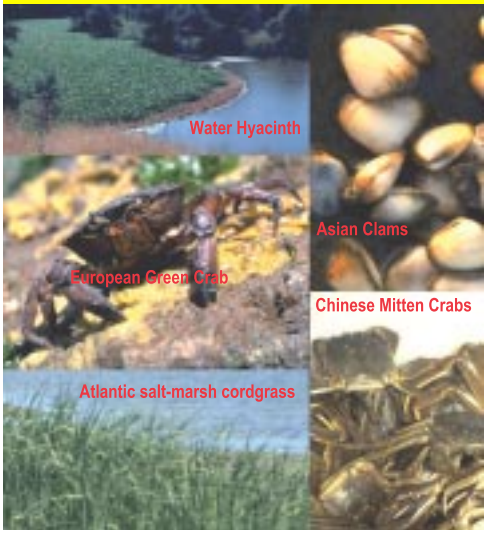
The San Francisco Bay Estuary is under siege by non-native aquatic invasive species that are destroying native flora and fauna and threatening to alter entire ecosystems. Whether introduced intentionally a century ago or arriving more recently in ballast water or attached to ships, culprits like the Chinese mitten crab and the Asian clam Potamocorbula are transforming the Bay. The San Francisco Bay-Delta Estuary is now the most invaded aquatic ecosystem in North America, home to more than 230 introduced species.

Aquatic Invasive Species: *What are They?*

The San Francisco Estuary is being invaded by increasing numbers of non-native species. Non-native aquatic species include a variety of organisms— fish, invertebrates, algae, plants, and pathogens such as cholera. These species may be harmless in their native environment, but once transported to another waterbody such as the Estuary they can dominate native species, disrupt the balance of the natural ecosystem and threaten commercial, recreational, and agricultural activities.

While many non-native invasive species cannot survive in a new environment, some are especially hardy. Given an environment free from their natural predators and competitors, they can become aggressive invaders. The Asian crab *Potamocorbula*, the Chinese mitten crab, the European green crab, Atlantic salt-marsh cordgrass, and water hyacinth are some of the non-native species that have been particularly destructive in the Estuary.

AGGRESSIVE INVADERS-



Water Hyacinth, Asian Clams (Potamocorbula), Chinese Mitten Crabs, Atlantic Salt-marsh Cordgrass photos courtesy of: Andrew Cohen, SFEI

European Green Crab photo courtesy of: Caroline Kopp, CA Academy of Sciences

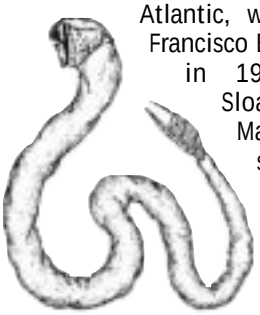
The Historical Perspective: *When did they get here?*

The Estuary's first known introduction was a white Atlantic barnacle, collected in 1853. It probably made its way to the San Francisco Estuary attached to the hull of a ship. It was the first of many new species that would migrate to the San Francisco Estuary following the discovery of gold in 1848. A huge influx of settlers, the establishment of maritime commerce, and a multitude of other human activities would change the face of the Estuary forever and become conduits for further species invasions.

In the 1870s, the transcontinental railroad brought the American oyster from the East Coast to the Bay Area. The oyster, prized for its flesh, was farmed in San Francisco Bay and soon replaced native California oysters in popularity. By the late 1890s, it had become California's most valuable fishery product. Although the American oyster never became permanently established here, other non-native organisms hitchhiking on the shells and in packing materials did establish in San Francisco Bay.

Many early introductions were deliberate releases that were performed or authorized by government agencies. Crayfish, bullfrogs, American shad, and striped bass were introduced as food sources. The dramatic success of striped bass and American shad led to commercial fisheries within 10 years. Annual yields of striped bass exceeded 450 tons between 1889 and 1915. Striped bass is still the primary sport fish caught in San Francisco Bay although numbers have dropped significantly in recent decades.

Some intentional releases— such as common carp — produced harmful results. Other non-natives arriving with authorized species or as a result of maritime commerce also caused serious problems. The shipworm, *Teredo navalis*, probably a native of the Atlantic, was found in San Francisco Bay at Mare Island in 1913. Commodore Sloat had chosen Mare Island as a suitable location for the Navy Department's western shipyard in 1852 because he thought the site was "safe from attack from wind, wave, enemies and marine worms." *Teredo navalis*, however, can tolerate lower salinity levels than most marine borers and was able to survive in the North Bay. The shipworm spread and destroyed some 50 major wharves, ferry slips, and other structures in the northern Estuary, causing damages of at least $2 billion (in 1992 dollars) between 1919 and 1921.



Teredo navalis

Whether intentionally or accidentally introduced, more than half of the fishes in the Delta and most of the benthic organisms in the Bay today are non-native species. While it can be difficult to separate the impacts of invasive species from those caused by habitat alteration, nationwide about 400 of the 958 species listed as threatened or endangered under the Endangered Species Act are considered at risk primarily due to impacts from non-native invasive species.

Every hour, an average of more than 2 million gallons of ballast water–containing potential invaders–is released into U.S. waters.

Photo courtesy of: Greg Ruiz

Chinese mitten crabs *(Erocheir sinensis)* have clogged power plant pipes and disrupted fish salvage operations at Delta pumping facilities.

Photo courtesy of: Andrew Cohen, SFEI

The Asian clam *(Potomocorbula amurensis)* has replaced native bivalve species and become the dominant benthic organism in much of SF Bay.

Photo courtesy of: Andrew Cohen, SFEI

Invasion Pathways

Non-native aquatic species are introduced and spread by a variety of activities including maritime commerce, sport fishing, recreational boating, aquaculture industry, bait business, aquarium trade, and horticultural practices.

Historically, ballast water has been a primary vector for introducing non-native aquatic species into the Estuary's waters. Ballast water is taken aboard in coastal ports along with large numbers of aquatic organisms, which are then released when the ballast water is discharged at the next port of call. It is estimated that on any given day 3,000 species of freshwater, brackish and marine protists, animals, and plants are traveling around the world in the ballast of ocean-going vessels. Every hour, an average of more than 2 million gallons of ballast water — containing potential invaders — is released into U.S. waters. Bulkers and tankers alone released an estimated 68 million gallons of ballast water into San Francisco Bay in 1991.

As a center of extensive international trade, the San Francisco Estuary has been exposed to continuous invasions of non-native species for the past 150 years. In recent decades, more species have been able to survive their voyages, thanks to faster vessels and shorter shipping times. The rate of invasions has accelerated from an average of one new species every 46 weeks between 1850 and 1970, to one every 14 weeks since 1970.

Aquaculture, aquarium industries, and fisheries also contribute to invasions. Live Atlantic bait worms shipped to bait shops and sport stores are packed in seaweed that often contains mollusks, worms, and other organisms. The bait, packing material and accompanying organisms are frequently tossed out into the water to become new invaders.

Invaders also come from home and school aquariums. Pet owners tiring of their new hobby may dump aquarium fish into the nearest waterbody. The goldfish, perhaps a released pet, is thought to be the first foreign fish species introduced to North America. Goldfish are now commonly found in low or medium elevation habitat in California and have completely overrun some small lakes. Goldfish compete for food and space with other fish.

Most species used today in aquaculture, agriculture, and horticulture are non-native species that were intentionally introduced. Water hyacinth, introduced for its attractive flower, is very invasive and requires expensive eradication measures. One of the problems with introducing non-native species into the Bay is that we cannot predict which of them will become unruly pests—until it's too late.

Recreational boaters and anglers can accidentally contribute to the spread of invasive water hyacinth and *Egeria densa*. Tangled in boat propellers, attached to vessel piping or hidden away in bait buckets, these unwanted pests hitchhike to new sites. The zebra mussel, the scourge of the Great Lakes region, has been found on the hulls of some out-of-state recreational vessels entering California but has not yet become established in the state.

The Invaders: Some of the Worst Culprits

Chinese Mitten Crab

(Eriocheir sinensis)

The Chinese mitten crab, named for the dense hairy patches on its white-tipped claws, is a burrowing crab from China and Korea. It was first collected in south San Francisco Bay by commercial shrimp trawlers in 1992. Since then, it has become established in San Francisco Bay and has rapidly spread to river areas upstream of the Delta. In Asia, the crab is a delicacy. Its introduction to the Estuary may have been a deliberate release to establish a fishery or an unintentional release via ballast water.

Migrating adult crabs have interfered with fish salvage activities at pumping facilities in the south Delta. Initially the crab population grew exponentially, and 775,000 crabs were collected at the pumping facilities at Clifton Court Forebay in the fall of 1998. By fall of 1999, the number had declined to approximately 90,000 at the site and was even lower in 2000.

The sharp claws of the crab cut the mesh of commercial fishing nets and damage catches. High densities of crab burrows can destabilize riverbanks and levees. The crab is also a potential health hazard, as it can be a host for the Oriental lung fluke, a parasite that causes tuberculosis-like symptoms in humans. At this time, no evidence of the fluke has been found in California crabs.

The European green crab *(Carcinus maenas)* preys on clams, oysters, mussels and smaller crabs, including Dungeness crabs.

Photo courtesy of: Caroline Kopp, CA Academy of Sciences

Water hyacinth *(Eichhornia crassipes)*, a free-floating perennial herb, grows rapidly and blocks navigation channels.

Photo courtesy of: Andrew Cohen, SFEI

***Egeria densa* is a submersed, aquatic plant that forms dense mats of vegetation that disrupt the natural ecology of the Delta.**

Photo courtesy of: CA Department of Boating and Waterways

It is illegal to import eggs or live specimens of any species of mitten crab to the United States under the Federal Lacey Act. It is also illegal to import, transport or possess live Chinese mitten crabs in California, Washington and Oregon.

ASIAN CLAM

(Potamocorbula amurensis)

The Asian clam *Potamocorbula* was probably introduced into San Francisco Bay from the western Pacific by the release of ballast water in the mid-1980s. The invader arrived at an auspicious time: A tremendous storm in February 1986 had removed most of the region's normal benthic animals, leaving an opening for the clam. The clam spread rapidly and by 1987 had become numerically dominant at shoal and channel sites in both Suisun and San Pablo bays as well as some South Bay sites. It has sustained average densities exceeding 2,000 clams per square meter and continues to be the dominant benthic organism in the North Bay and in the Bay's southern extreme during most years. Contributing to the clam's success is its ability to tolerate a wide range of sediment types and salinities.

Grazing rates of the clam show that it is capable of filtering the water column over the channels in the northern reach of the Estuary more than once per day and over the shallows almost 13 times per day. *Potamocorbula* feeds at multiple levels in the food chain, consuming bacterioplankton, phytoplankton, and zooplankton, to the detriment of native species. For better or worse, *Potamocorbula* has become so well established in the San Francisco Estuary that it is considered a permanent member of the benthic community.

EUROPEAN GREEN CRAB

(Carcinus maenas)

The green crab, which despite its name ranges in color from green to orange or even red, is a native of the Atlantic coast of Europe. It was first discovered in South San Francisco Bay in the early 1990s. Its numbers increased rapidly, and by 1994 green crabs could be found from the South Bay to the Carquinez Strait. Because its distribution is limited by salinity, the crab has not spread into the fresh waters of the Delta. It has, however, expanded northward up the coast as far as British Columbia.

The crab preys on clams, oysters, mussels and smaller crabs. Within three years of its introduction into the Estuary, the green crab had significantly reduced densities of native clams and native shore crabs. In laboratory and field enclosure experiments, green crabs have consumed Dungeness crabs of smaller or equal size. A large green crab population in the Estuary could decimate a Dungeness crab year class.

WATER HYACINTH

(Eichhornia crassipes)

Water hyacinth, a native of tropical South America, is a free-floating perennial herb with rounded, bright green leaves typically up to 10 inches in diameter. It forms dense, floating mats. Leaf stalks are spongy and help keep the plant buoyant. Water hyacinth is sold as an ornamental plant in garden stores and is prized for its large blue-lavender flowers. It was introduced to the U.S. in 1884 at the Cotton States Exposition in New Orleans, where it was displayed as an ornamental plant and distributed to visitors as a souvenir. The plant was first reported in California on the Sacramento River near Clarksburg in 1904.

Introduced into lakes and ponds for its beauty, water hyacinth is now a major pest in the Delta, blocking canals and waterways, affecting water quality, fouling irrigation pumps, closing marinas, and blocking salmon migration. The plant grows very fast, doubling within a couple of weeks. Controlling water hyacinth is difficult and expensive. Chemicals and mechanical removal are the primary weapons used on the weed. The Department of Boating and Waterways is responsible for controlling water hyacinth in the Delta. The Department has set up barriers to keep large masses of floating plants out of navigation channels and sprayed herbicides at a cost that has risen to nearly $500,000 annually.

EGERIA DENSA

Egeria densa, is a submerged, aquatic plant that is rooted. Small one-inch leaves are crowded in whorls of three to six around stems that are one to two feet, or longer. The plant has small, white flowers that grow on short stalks, one inch above the water. This native of South America was introduced into California more than 30 years ago and is a popular plant used in aquariums from which it may have been released into the

waterways. *Egeria densa* is sometimes confused with *Hydrilla*, another similar-looking, non-native aquatic plant. *Egeria* forms dense mats of vegetation that obstruct navigation and recreation, slow water flows, clog agricultural irrigation pumps and disrupt the natural ecology of the Sacramento Bay-Delta ecosystem.

In January 1997, the California Legislature enacted Assembly Bill 2193 enabling the California Department of Boating and Waterways to create the *Egeria densa* Control Program for the Delta, using an adaptive management strategy with a strong scientific base. The Department has been gathering the necessary information to complete an Environmental Impact Report (EIR) and will determine the most feasible *Egeria densa* control alternative to meet both the requirements of the California Environmental Quality Act (CEQA) and the needs of those who live, work and recreate in the Delta.

Economic Impacts

Federal officials estimate that the total cost of invasive species in the U.S. is nearly $125 billion each year. Nearly half of the species listed as threatened or endangered under the federal Endangered Species Act are at risk because of the negative effects from non-native invasive species.

The economic impacts of introduced organisms in the San Francisco Estuary are substantial, but poorly quantified. Few non-native species that were introduced to the Estuary, other than some intentional governmental releases, have produced economic benefits. Some of the negative economic impacts have come from the inability of water users and regulatory agencies to maintain healthy populations of native and anadromous fish, resulting in limits on and threats to water diversions, wastewater discharges, levee maintenance, and channel dredging and construction activities.

From 1919–1921, the shipworm, Teredo navalis, caused at least $2 billion (in 1992 dollars) of structural damage to maritime facilities.

Photo courtesy of: Hill, C. L. and Kofoid, C. A. "Marine Borers and Their Relation to Marine Construction on the Pacific Coast." San Francisco Bay Marine Piling Committee, San Francisco, 1927.

A few examples illustrate the enormous economic impacts. In one short three-year period, from 1919 – 1921, the shipworm, *Teredo navalis*, caused at least $2 billion (in 1992 dollars) of structural damage to maritime facilities. California now spends approximately $1,500,000 annually to control *Hydrilla* and close to $500,000 each year for control of water hyacinth. The newly arrived glassy-winged sharpshooter, an invasive insect, carries with it the plant bacterium, *Xlelia fastidiosa*, a disease that has caused nearly $40 million in losses to California grapes. The disease threatens the grape, wine, and raisin industries and related tourism, collectively valued at nearly $35 billion annually.

A New Threat – "Killer Algae"

In October 1998, a warning was issued to the Department of Interior (DOI) that an aquarium-bred clone of the tropical green seaweed, *Caulerpa taxifolia* could become established in U.S. coastal waters. The Mediterranean strain of *C. taxifolia* spreads rapidly, forming a dense mat that covers all kinds of bottom-dwelling life. When this strain was discovered in early 2000 in a coastal lagoon near San Diego, there was fear it would spread up the California Coast. Early detection and swift eradication measures may have stopped its spread for the present.

The Mediterranean strain of *C. taxifolia* reproduces vegetatively, and small cuttings or plant fragments are capable of regenerating whole plants. It displaces native vegetation and becomes the dominant plant life. Activities such as dredging, mechanical removal or control, anchoring, commercial fishing, and boating, as well as ocean currents and storms have all contributed to its spread in other regions. ***If found, it should not be disturbed. Sightings should be reported to local agencies immediately.***

The plant was placed on the Federal Noxious Species List in 1999, making it illegal to import into the country or transport across state lines. Some aquarium dealers still sell the algae to hobbyists. An informed and vigilant public plus cooperation from the aquarium and shipping industries is critical to preventing and controlling infestations.

Invasive Riparian/Salt Marsh Plants

Some very invasive, non-native plants live at the edges of the Estuary's waters.

Purple loosestrife *(Lythrum salicaria)* is a highly aggressive plant invader of wetlands, stream banks, marshes and canals. It displaces native vegetation, decreases water flow and quality, and disrupts irrigation systems. Each year it spreads across approximately one billion additional acres of wetlands and is now found in 42 states, including California.

Photo courtesy of: Joseph DiTomaso

Giant reed *(Arundo donax)* resembles a giant stalk of bamboo. It was introduced into California in the 1800s for erosion control along drainage canals. This water-guzzling reed smothers native riparian vegetation and is highly flammable. It spreads readily when pieces of the plant break off and wash downstream to re-establish new plants.

Photo courtesy of: Joseph DiTomaso

Smooth cordgrass *(Spartina alterniflora)* is a perennial saltmarsh grass that was intentionally introduced to south San Francisco Bay about 25 years ago to promote wetland restoration. It competes with native cordgrass and now threatens numerous newly-restored tidal marshes and mudflats. Large infestations can turn a wetland into a *Spartina* meadow.

Photo courtesy of: Andrew Cohen, SFEI

HIGH RISK ACTIVITIES

AQUACULTURE:

The culture of shellfish and fin fish is a significant pathway for both intentional and unintentional introductions. Early imports of oysters to San Francisco Bay brought unwanted species attached to shells and in packing materials. Abalone farmers accidentally imported and released into California waters a South African abalone parasite in the 1980s and 1990s.

ANGLERS AND BAIT SHOPS:

The use of non-native bait species and their packing material can result in intentional and unintentional release of invasive species. Occasionally, individuals have released a favorite aquatic species into public waters in hopes of establishing a viable fishery, sometimes leading to disastrous results. The Northern pike illegally planted in Lake Davis is an example: In 1997, the state Department of Fish and Game treated the lake with Rotenone to try to prevent these voracious fish from escaping into the Sacramento River. The treatment compromised the local water supply and an important fishery in the lake. While introductions have been beneficial in a few cases, the unintentional spread of a species or accompanying predators has often had detrimental effects.

AQUARIUM TRADE:

Importers, culture facilities and pet stores transport and sell non-native plant, fish and invertebrate species. Intentional and non-intentional release of species into waterbodies by the industry and from home and school aquaria has led to introductions. The common goldfish and "killer algae," *C. taxifolia,* are likely examples.

GOVERNMENT RELEASES:

State and federal government agencies intentionally release non-native species for biological control, to establish sport fisheries, or for erosion control.

NURSERY INDUSTRY:

Nurseries, garden centers and mail-order catalogs all sell non-native species for gardens and ponds. Unwanted plants are sometimes discarded into waterways or onto public lands. The water hyacinth is an example of a beautiful ornamental aquatic plant that has invaded Estuary waterbodies.

RESEARCH/EDUCATION:

Public and private research and academic institutions use non-native species for research and teaching. These organisms may sometimes escape, be carried out in water or otherwise unintentionally discarded, or be intentionally released for experimental purposes or as an act of good intention.

RESTAURANTS:

Live seafood shipments, such as East Coast lobsters, can contain packing materials and/or other living organisms that get tossed out and become a problem if they end up in the Estuary.

SHIPS AND RECREATIONAL BOATS:

Ballast water and ship fouling are primary vectors for the maritime industry. Recreational boaters can transport invasive species such as the zebra mussel or other species attached to their boat hulls. Aquatic nuisance plants are easily transported when fragments become tangled in boat propellers or fishing gear.

Zebra mussels clog water and power plant pipes, but have not become established in California.

Photo courtesy of: Andrew Cohen, SFEI

Caulerpa taxifolia spreads rapidly, forming a dense mat that covers all kinds of bottom-swelling life.

Photo courtesy of: Alexandre Menendez

Egeria densa, (shown above) is sometimes confused with Hydrilla, another similar-looking non-native aquatic plant.

Photo courtesy of: Joseph DiTomaso

Non-native bait worms and packing materials can result in the unintentional release of invasive species.

Photo courtesy of: Andrew Cohen, SFEI

WHAT YOU CAN DO

Non-native species can inflict horrendous damage on the environment, but the good news is that the public is becoming better informed and more involved in preventive measures. New state and federal legislation has been passed to prevent and control introductions; resource agencies are developing programs to control the spread of non-natives; and citizens are participating in a variety of prevention and eradication programs. Each person has a vital role to play. You can help prevent the introduction and spread of non-native species by taking the following steps.

Never release pets, plants or aquarium species into the wild.

Check with local authorities before transporting plants and animals to a new location.

Educate yourself about non-native species and their invasion routes.

Use native plants when landscaping.

Support state and federal invasive species legislation and programs.

Be on the alert for invasive species and report sightings to authorities.

Join a community group that is restoring habitat or removing invasive plants.

The San Francisco Estuary Project was established in 1987 by the US EPA and State of California (State Water Resources Control Board) under Section 320 of the Clean Water Act – the National Estuary Program. Its purpose was to develop through a consensus process a Comprehensive Conservation and Management Plan (CCMP) for the Bay-Delta Estuary and now is to implement that plan. The CCMP presents a blueprint of 145 specific actions to restore and maintain the chemical, physical and biological integrity of the Bay and Delta.

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