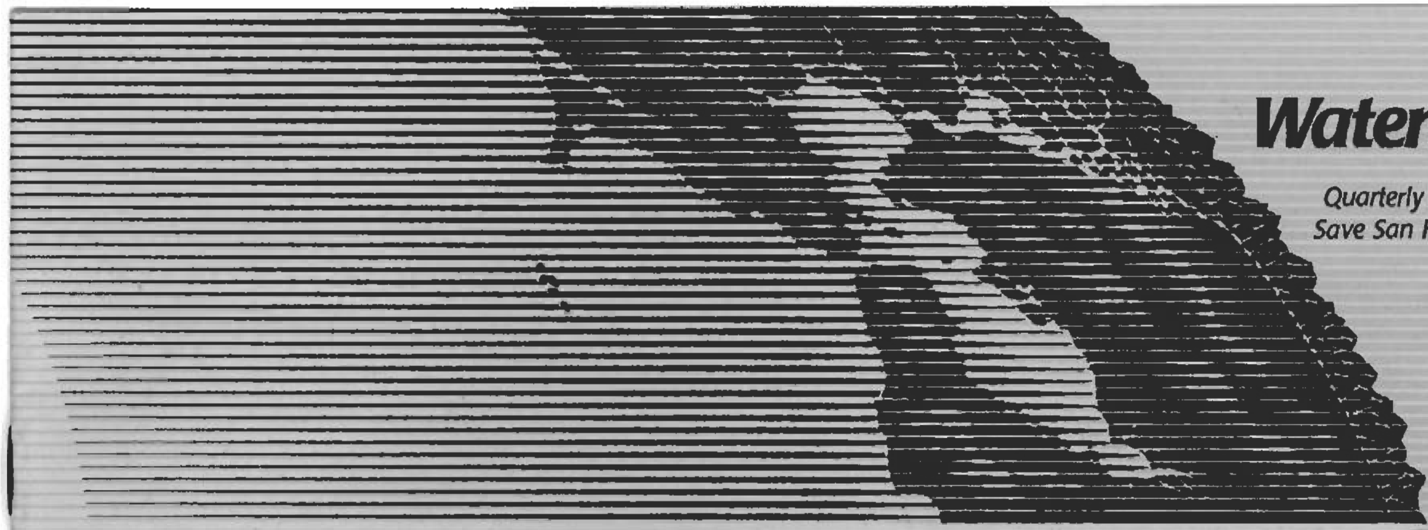

Watershed

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Intruders in the Estuary

by Andrew Neal Cohen and James T. Carlton

Last fall we led a group of biologists in a survey of marine life on the shores of San Francisco Bay. One of our sampling sites was Port Sonoma, a marina on the Bay's northwestern corner that has been filling up with mud. As the tide dropped, the marina's docks settled down into the accumulated ooze like hippos hiding from the noon sun, while shallow pools of brown, scummy water filled the slips between. Would we find *anything* living here?

To our surprise, the hand nets we dragged along the bottom of the pools emerged with staggering quantities of a dingy, half-inch-long, yellowish clam. Lifting our eyes, and adjusting our search image, we could now see that we were surrounded by little clams that covered the surface of the mudflats to the horizon: half-buried in the muck, shell touching shell, hundreds or thousands of clams in each square foot, millions of clams within a single glance.

We had heard of this clam. We had seen specimens, we had read reports, but until that day at Port Sonoma we hadn't really gotten the picture. Extending out of sight beyond the mudflats, out of the marina and under the waters of the Bay, the carpet of clams unrolled, thousands of acres in extent. Could we but walk under water, it would be a long day's hike before our boots came down without the crunch of little, yellowish clams underfoot.

It was hard to believe that only ten years ago there were none of these clams in the Bay.

Estuaries like San Francisco Bay are generally known to be highly productive habitats, where a combination of warm, shallow water and abundant nutrients flowing in off the land results in rapid growth of plants and animals. A portion of this estuarine growth supports life in ocean waters outside of the estuary. Thus, the biological diversity of the coastal ecosystems, and the size of coastal fisheries, may depend on the web of relations between estuary and ocean, and on the energy flowing from sunlight to plant to animal within the estuary.

San Francisco Bay's yellowish clam is one of many intruders in this web of relations, a non-native organism accidentally introduced from Asia, which threatens to alter forever the flow of biologic energy in the Bay. Gaining an accurate understanding of that energy flow, and of how the new clam is changing it, has challenged the best of the Bay's scientists.

In the northern portion of San Francisco Bay, where the largest rivers enter, a "bloom," or sudden growth, of the microscopic floating plants called diatoms used to occur during most summers. Diatoms are eaten by small floating animals called zooplankton, which are eaten by small fish, which are eaten by bigger fish. In the 1960s and 1970s, researchers believed that the size of the diatom bloom, and of the populations that fed upon it, was governed by river flows and water clarity— that high river flows, which carry a lot of sediment, limited the amount of light penetrating the water, in turn limiting the growth of diatoms; and that low flows, with less sediment and clearer water, caused greater diatom growth.

So, when the driest years on record, 1976-77, brought waters of exceptional clarity to the Bay, scientists expected a prodigious bloom of diatoms. Instead, there was no bloom at all.

Researchers quickly regrouped around an alternative hypothesis. In the Bay's northern channels, ►SEE PAGE 8

Intruders in the Estuary

➤ CONTINUED FROM FRONT COVER

as in many estuaries with large inflowing rivers, the lighter fresh water flowing downstream is deflected toward the surface while a return current of heavier salt water flows upstream along the bottom, creating an "entrapment zone" where the two flows meet. Solid matter carried in the water—including sediment, detritus, diatoms, zooplankton and young fish— collects in this zone at concentrations that may be several hundred times as great as those found upstream and downstream.

In 1978 James Arthur and Melvin Ball, two biologists with the U. S. Bureau of Reclamation, showed that the biggest diatom blooms had occurred when the entrapment zone was located in the wide, shallow waters of Suisun Bay. In shallow water most of the water column lies within reach of enough sunlight to support the photosynthesis needed for plant growth. Diatom populations thus multiply faster in the shallows than in deeper channels, because more of them receive the light they need.

In 1976 and 1977, extremely low river flows shifted the entrapment zone several miles upstream into the narrower and deeper channels of the Delta. Researchers concluded that the diatoms failed to bloom because they were concentrated in deep channels where they grew more slowly than in previous years. The theory and the data seemed to fit, and by the early 1980s most scientists agreed that diatom growth in the northern part of the Bay was controlled by the location of the entrapment zone.

Then in 1985 Frederic Nichols, an oceanographer with the U. S. Geological Survey, published a paper arguing that diatom blooms in the northern part of the Bay were really controlled by the presence or absence of large numbers of diatom-eating clams. Piecing together data from several sources, he showed that clams normally restricted to the saltier downstream parts of the Bay—especially an Atlantic soft-shell clam accidentally introduced into the Bay with shipments of Virginia oysters in the 1870s—moved into the northern reach during the 1976-77 drought. He calculated that in 1977 there were enough Atlantic clams in the northern Bay to consume all the diatoms from the water in less than two days, preventing a bloom from ever getting started. The return of normal river flows after 1978 pushed the clams back downstream, and diatom blooms returned.

Just a year after Nichols proposed that hungry clams were dominating dry year energy flows, a biology class from Diablo Valley College dredged up three specimens of the previously-mentioned yellowish clam, *Potamocorbula amurensis*, from the bottom of the Bay. *Potamocorbula*, native to the estuaries of China, Japan and Korea, probably arrived aboard a cargo ship, travelling as small, floating larvae in the ship's ballast water. Ships headed for the freshwater ports of Sacramento or Stockton often discharge ballast water as they move up the Bay, in such vast quantities that tens of millions of living exotic organisms can be deballasted from a single vessel.

Potamocorbula apparently found the Bay to its liking and, reproducing enthusiastically, within a year became the most abundant mollusk on the bottom of the Bay, reaching peak densities of over a thousand clams per square foot. *Potamocorbula* is also a more efficient diatom-feeder than the other clams in the Bay, and tolerates a wider range of salinities, maintaining immense populations in wet years as well as dry. Since the clam first became abundant in the summer of 1987, there has been no summer diatom bloom in the northern part of the Bay.

With the disappearance of the annual diatom bloom, the populations of diatom-eating zooplankton (which the clams eat as well) and of zooplankton-eating fish have also shrunk. Some researchers predict that *Potamocorbula* will permanently shift the estuary's energy flows, which once supported large numbers of water-column-feeding fish, to favor bottom-feeding organisms such as sturgeon, crabs and diving ducks. As yet, however, no boom in bottom-feeders has been detected.

Meanwhile, back at Port Sonoma, another sweep of the net brings up not only another thousand yellowish clams, but also several yellowfin gobies from Japan and, flipping about on the dock, dozens of excited little shrimp from Korea. Here and there a juvenile Dungeness crab, virtually the only native species that we are to see that day, gingerly picks its way among the crowds of foreign organisms. The Asian clam, the Atlantic soft-shell clam, the Japanese goby and the Korean shrimp are but a few of the more than 200 exotic animals and plants that have become established in the waters of San Francisco Bay since the days of the Gold Rush. Although the Bay has thereby gained in number of species, it has lost the distinctive faunal characteristics and the web of community relationships that it had developed since its post-Ice Age origin, and which distinguished it from the other great estuaries of the world.

Similar stories are unfolding in other water bodies around the globe, where introduced marine and aquatic organisms fundamentally have disrupted food webs and energy flows. The European zebra mussel, accidentally introduced into the Great Lakes in 1986, has sucked clear the waters of Lake Erie. In the Black Sea an introduced American comb jelly, feeding insatiably on zooplankton, has destroyed the anchovy fishery. At any moment of the day, millions of gallons of ballast water, containing thousands of species of phytoplankton, zooplankton, and the eggs, larvae or adults of clams, crabs, shrimp, worms and other marine organisms, are on the move across and between the world's oceans. Discharged without regulation at the end of their voyages, these organisms threaten to transform the world's coastal ecosystems as dramatically as *Potamocorbula* has changed the waters of San Francisco Bay.

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Congress Clashes Over Central Valley Water

➤ CONTINUED FROM PAGE 3

purchase as a budget savings, and lawmakers may still be tempted to support it despite the fact that it would result in a boon of billions of dollars to the Authority.

San Joaquin Valley agribusiness now is likely to throw its weight behind another Doolittle bill. H.R.1906 would gut key environmental provisions of the Act and irrevocably damage other government efforts aimed at achieving equitable use of California's limited water supply. The Act is also under attack on the appropriations front, as Central Valley Congressmen propose "riders" to deny funding for its full implementation. ➤ NEXT PAGE