Small Creatures Big Ideas

by Martha Larson

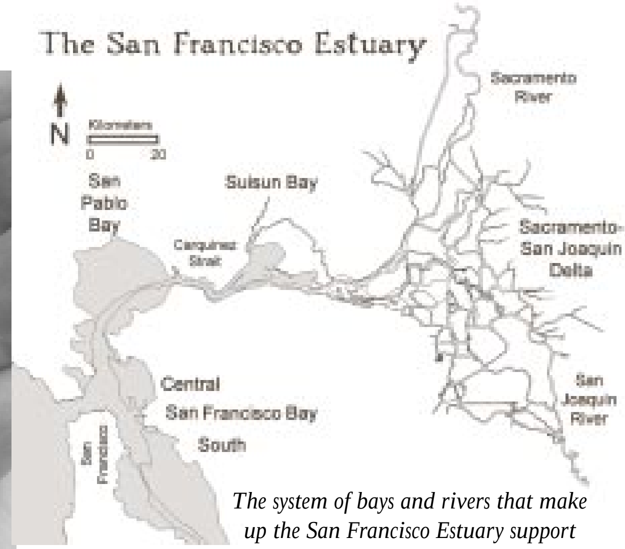
Starting in 1987, scientists noticed large drops in the amount of phytoplankton and zooplankton in the San Francisco Estuary. That same year, the population of a species of clam introduced into the Estuary from Asia was skyrocketing.

Under the microscope, a copepod looks like its distant insect relative—the silverfish. While the copepod's long, wispy antennae catch the eye, it is the five sets of feet that put this common water creature into motion, darting outside the microscope's field of view. The copepod's most recent meal is plainly visible within its clear body. Copepods play a vital role in the aquatic food web, feeding on miniscule plants and animals and being fed on by larger aquatic species. In the San Francisco Estuary, copepods provide up to 100 percent of the diet of most young fish. While copepods are usually plentiful in both marine and freshwater environments, the copepod population in the shallow waters of the upper San Francisco Estuary dropped suddenly in 1987.

The San Francisco Bay is only one part of a greater estuarine ecosystem that reaches up into the river deltas north to Sacramento and down into the San Joaquin Valley to Stockton. The Sacramento and San Joaquin rivers and their tributaries carry rainwater and snowmelt to Suisun Bay. Ocean tides mix saltwater with freshwater from the rivers in the connected Suisun, San Pablo, and San Francisco Bays. These bays comprise an estuary with over 750 species of plants and animals and 80 percent of California's commercial salmon fisheries. The San Francisco Estuary continues to support this ecosystem, despite the competition with human demand for freshwater, and the threat of invasive species brought by humans in their travels to the Bay Area.

In 1987, the ecosystem became home to a new invader that caused the population of most copepod species in the upper Estuary to crash—to fall by 50 to 90 percent.

Dr. Wim Kimmerer is a recognized expert in estuarine ecology, and a founding officer of the California Estuarine Research Society. Copepods have been Kimmerer's subject of study since he began work as a biological oceanographer at the University of Hawaii in 1973. Kimmerer is now a Senior Research



The system of bays and rivers that make up the San Francisco Estuary support over 750 species of plants and animals and 80% of California's commercial salmon fisheries. Map courtesy of Marc Vayssieres, California Department of Water Resources

Left: The Amur River clam, Potamocorbula amurensis

Scientist at the Romberg Tiburon Center, San Francisco State University's marine field research station. The Bay view from his Tiburon peninsula office provides inspiration for the ideas that keep the nine graduate students, Ph.D.s, and research assistants in his laboratory busy. Kimmerer's copepods have led him to look at how the food web, physical factors such as tides and freshwater flow, and introduced species affect viability of life in the San Francisco Estuary. As the co-chair of the Ecosystem Restoration Program Science Board for CALFED (the group of state and federal agencies responsible for management and restoration of the San Francisco Bay Delta), Kimmerer is responsible for thinking about the big picture — the workings of the vast and complex San Francisco Estuary and its watershed.

Starting in 1987, Kimmerer and other scientists noticed large drops in the amount of phytoplankton (small plants) and zooplankton, such as copepods, in the San Francisco Estuary. That same year, the population of a species of clam introduced into the Estuary from Asia, the Amur River clam (*Potamocorbula amurensis*), was skyrocketing. Kimmerer linked the two events, but as a scientist, he had to test his theory and determine how the clam was affecting the copepods. The dramatic decline in the Estuary's copepod species was distressing, but was also an opportunity to observe the effects of introducing a single invasive species on the existing ecosystem.

Kimmerer investigated two possible mechanisms for copepod decline. Because it is not possible to observe the interaction of the clam and copepod in their natural setting, Kimmerer used a combination of experimental work and deductive reasoning to tie the two species together. If the clams were competing with copepods for the same food, copepods would have fewer resources and produce fewer young. However, field measurements showed that females were producing the same number of eggs, so the clam must be affecting copepods at a different part of their life cycle. Kimmerer then looked at whether the clams were consuming the copepods themselves. Adult copepods are too large for the Amur River clam to ingest, but Kimmerer was able to show in the laboratory that the clam is capable of eating nauplii, a larval form of copepod, at a rate consistent with the population drop. In the Estuary, nauplii are present in the same geographic location and depth as the Amur River clam, so they would be available as food. Kimmerer determined that the Amur River clam affected the copepod population by eating copepod young. With its rapid feeding rate and sheer numbers (achieving densities up to 1,000 per square meter), the Amur River clam had taken a big bite out of the Estuary's food supply.

The Amur River clam, named for its Siberian river of origin, probably arrived in ship ballast water. (Ships fill their ballast tanks with water before leaving port so they will not float too high on the open ocean, and then empty the tanks upon reaching their destination.) Scientists believe the clam arrived in 1986, at the beginning of a drought. Drought conditions caused a die-off of existing clams in certain areas of the Estuary, creating open habitat into which the Amur River clam could move.

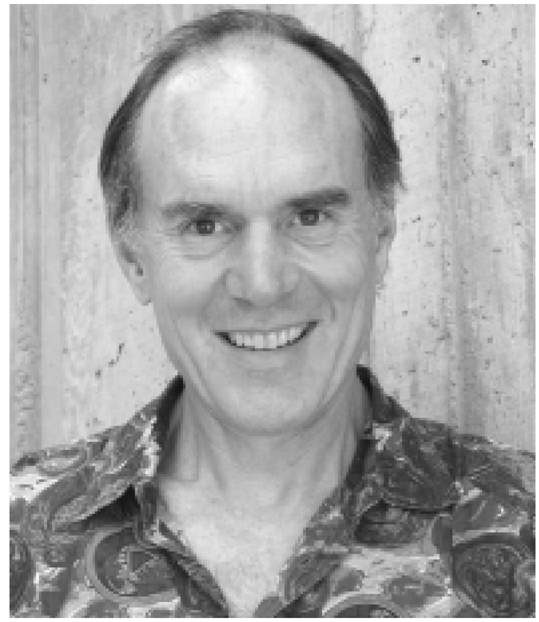
Mary Helen Nicolini, a research technician in Kimmerer's lab, has been studying the Amur River clam's success. Though not much bigger than a fingernail, the Amur River clam shows certain behavior and adaptations that gave it an advantage over other clams in the ecosystem. One key may be siphon position. Clams are filter feeders. They extract food by circulating water over their gills using two siphons (one to pump water in and the other for discharge.) Other clam species in the Estuary bury themselves in the sand, with only their siphons protruding. The Amur River clam sits higher in the sand, with its siphons reaching farther into the water. This position may give the clam access to more food. While other species of clams around the Estuary live either only in fresh or salt water, the Amur River clam can comfortably live in a wide range of salinities. These features give it an edge over other clams living in the system, and help explain why the Amur River clam spread so quickly throughout the Estuary.

After seeing a sharp falloff in a primary food source for young fish, Kimmerer decided to study the effect of copepod decline on the fish population in the Estuary using data collected by state and federal agencies. The results were unexpected. Kimmerer looked at several fish species, including striped bass and longfin smelt. These two fish are similar in their life cycles: they reproduce upriver, then hatch their eggs while floating downstream, stopping when they reach a certain salinity level. Both feed mainly on copepods during their larval and juvenile stages. While the longfin smelt has declined since 1987, the similar striped bass has not. Of the seven fish species that Kimmerer looked at, only two showed a decline after the introduction of the Amur River clam.

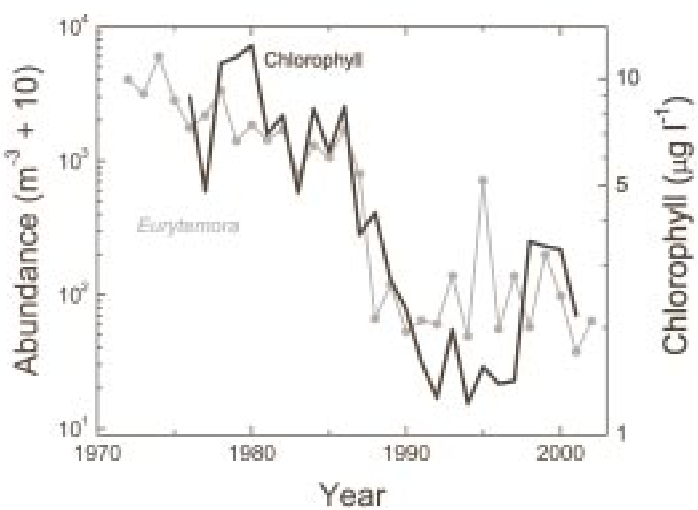
Kimmerer acknowledges that more studies are needed to understand his results. Says Kimmerer, "That's how science is, you get started on something, you get some answers, but the original question branches out. The trouble is, you can only follow one branch at a time." Kimmerer compared the clam's effect to other factors influencing fish survival rates, and found that the amount of freshwater inflow into the Estuary in a given year may be a more important variable. This is why it is necessary to understand not just the living organisms, but also the physical operations of the Estuary itself. While not the only factor influencing ecosystem health, the far-reaching effects that one species of clam has had on the Estuary point to the importance of halting further invasive species introductions.

Although it may be too late to control the widespread Amur River clam, Kimmerer is thinking about how to contain the introduction of such species in the future. Ships discharging ballast water have introduced many species into the Estuary. Controlling ballast water, however, is expensive. The lowest cost method is to change the ballast water at sea. Because estuarine species cannot live in the open ocean, there is no risk of contaminating the ocean. However, changing the ballast water may not completely remove all estuarine species before the ship arrives in a new estuary, which is why some are skeptical of the effectiveness of this method. Kimmerer is working with a post-doctoral associate, Dr. Keun-Hyung Choi, to test a hypothesis that even incomplete removal of non-native species from ballast water may provide adequate protection. They believe that in low enough numbers, the water's action will diffuse introduced species more quickly than they can find each other to reproduce. Kimmerer likens it to being "exposed to a cold virus. Your body can fight it off to a certain degree, but if there are too many, it overwhelms your immune system." The key is to know what level is too many. Choi is researching how near each other copepods have to be in order to find one another to reproduce. If there are not enough males and females to find each other and mate before they diffuse in the Bay, they will not create a viable ongoing population. If Kimmerer's and Choi's theory proves correct, introduction of non-native species may be controllable at relatively low cost.

Scientists do not completely understand how life in the Estuary responds to the introduction of nonnative species and to other natural and human-driven changes. Kimmerer's ongoing work will provide a better understanding of how to manage human impact on the Estuary in order to protect the life found in it. Kimmerer's interests have expanded to encompass not only copepods, clams, and fish, but also how the alteration of the Estuary's fresh and saltwater flows affects these populations. But for every question he resolves, his curiosity leads him to new areas of interest. Looking out from his office window at the herring boats plying the waters off the Tiburon shore, Kimmerer says, "I think the reason I have this view here, it's a source of humility. I can look out and say, what do I know about the Bay out there?"



Wim Kimmerer, Senior Research Scientist
Romberg Tiburon Center



Annual means of chlorophyll concentration (black line, right axis) and abundance of the copepod Eurytemora affinis *(gray line, left axis) in the Low-Salinity Zone of the San Francisco Estuary, usually in Suisun Bay. Chlorophyll concentration is a measure of the biomass of phytoplankton, which form the basis of the estuarine food web. The copepod* E. affinis *was formerly the most abundant copepod in this part of the Estuary, and is a key food for fishes such as the threatened Delta smelt. The sharp drop in about 1987-88 coincides with the spread of the introduced Amur River clam,* Potamocorbula amurensis, *which consumes phytoplankton and also the nauplius or larval stages of the copepods.* Diagram courtesy of Dr. Kimmerer