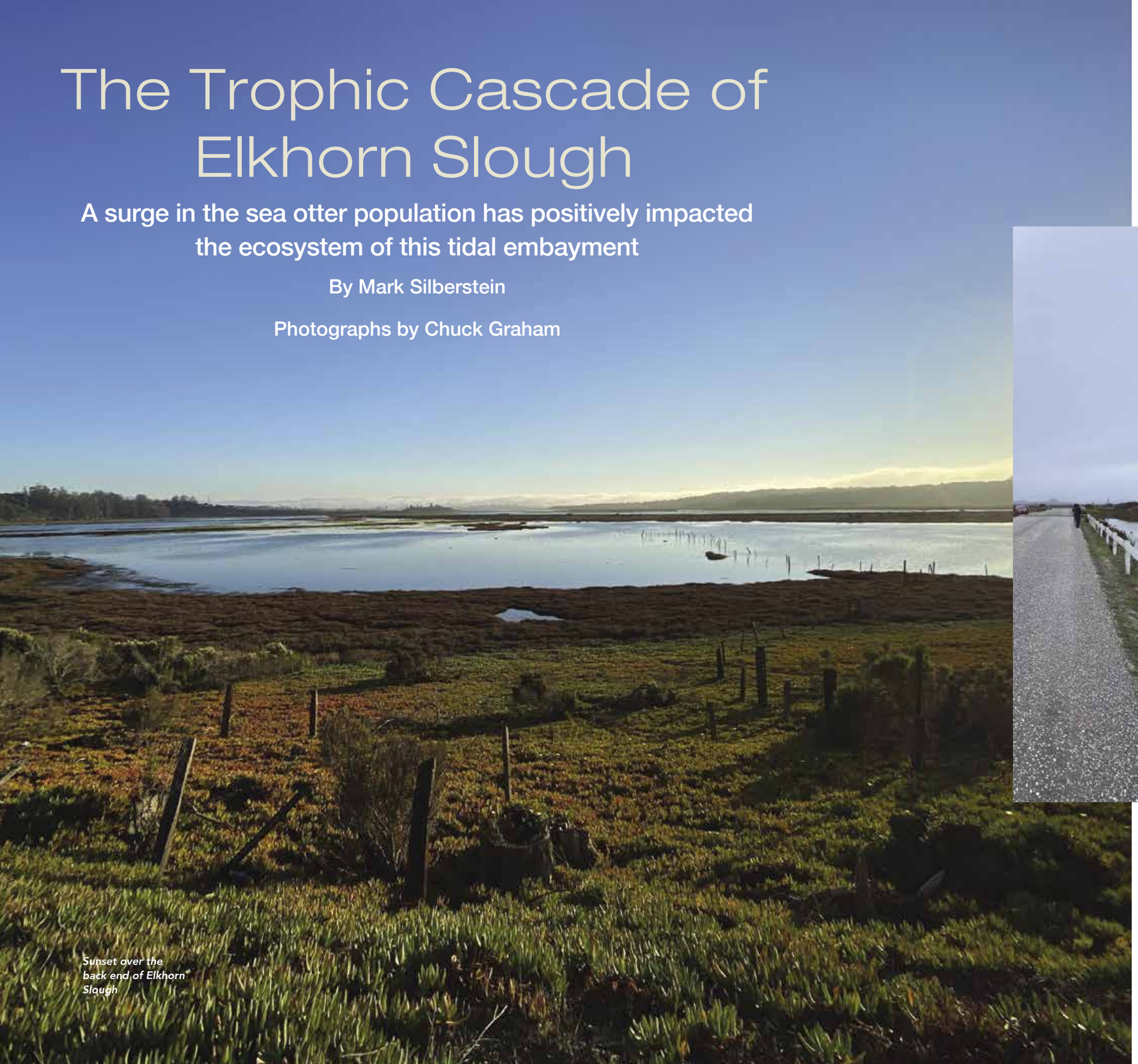
The Trophic Cascade of Elkhorn Slough

A surge in the sea otter population has positively impacted the ecosystem of this tidal embayment

By Mark Silberstein

Photographs by Chuck Graham



Sunset over the back end of Elkhorn Slough

There are few places in the world where, in the span of less than ten miles, you can travel from rocky chaparral-covered ridge tops to the deep sea and in between encounter oak forests, coastal prairies, tidal marshes, mud flats, sand dunes, and beaches. Elkhorn Slough, in the geographic center of Monterey Bay, California, is one of these places. Elkhorn Slough is a tidal embayment perched at the head of the largest submarine canyon in North America. The juxtaposition of this diversity of habitats harbors a remarkable array of species. The estuary itself supports over a hundred species of fishes, well over 500 species of invertebrates, the densest concentration of sea otters (*Enhydra lutris*) on the California coast, and, in a fifteen-mile radius of the slough, 340 species of birds have been identified—leading to its designation as a Globally Important Bird Area and a Western Hemisphere Shorebird Reserve.

The natural history of Elkhorn Slough has been explored scientifically for over a century, notably early on by marine biologists George MacGinitie (1889–1989) and Nettie MacGinitie (1899–1993), of Stanford University Hopkins Marine Station, and Edward F. Ricketts (1897–1948) and his marine supply company, Pacific Biological Laboratories. Millenia before the MacGinities studied the fauna of Elkhorn Slough tideflats in the 1920s, indigenous tribes lived in villages along the shore and harvested the rich resources of the estuary. Archaeological studies have revealed over eight thousand years of occupation and evidence of the indigenous people's diet of fish, shellfish, fowl, and mammals that were once abundant in the area. Today, sea otters are the iconic charismatic megafauna in the slough. A little digging, however, reveals other creatures that were first identified by the MacGinities and remain key elements in this coastal ecosystem.

The "fat innkeeper worm" (*Urechis caupo)* is one of Elkhorn Slough's icons and an example of the unsung role that invertebrates play in tideflat and estuarine ecology. George MacGinitie described the worm as looking like a large pink cigar. It was classified in the phylum Echiuroidea, but more recently recognized as belonging in the Annelida phylum, a large and diverse group of mostly segmented worms. The moniker "innkeeper" derives from the biology and habits of *U. caupo*—it creates U-shaped burrows in sand and muddy marine sediments that host a coterie of other species. Innkeeper worms spin a fine-mesh mucous net at the entrance to their burrow and with serial peristaltic contractions along their bodies, bring a flow of water in through the net and out through the other end of the burrow. The net traps particles of food; when it clogs, the worm swallows it and digests the enclosed tidbits. MacGinitie described three common commensals living in *Urechis* burrows: a scale worm, the polychaete *Hesperonoë adventor*; a crab, *Scleroplax granulata*; and even a fish, the arrow goby (*Clevelandia ios),* takes temporary refuge. In Elkhorn

Fat innkeeper worm burrow surrounded by eelgrass

Gaper clam

This small sea slug (Phyllaplysia taylori) helps keep epiphytic algae from overgrowing and blocking photosynthesis in eelgrass.

Slough, a small clam, *Cryptomya californica* has also been found tapping the water currents of the innkeeper with its short siphon. The innkeeper is a tolerant host—not apparently benefitting from the guests, but not suffering either.

Innkeepers inhabit tideflats and nearshore benthic sedimentary environments. They can occur in densities of half a dozen animals per square meter and, in a classic clash of the icons, are often a part of the diet of sea otters inhabiting the slough.

The invertebrate fauna of bays and estuaries is rich and varied and Elkhorn Slough provides a window into the diversity and structure of these communities. Extensive clam beds, and concentrations of polychaete worms, such as the "rubber band worm" (*Notomastus tenuis)*, provide food for a variety of predators, from sharks and rays to shorebirds and otters. Areas of the slough that have been restricted from full tidal action by culverts and roadways harbor a greatly reduced diversity of invertebrate species, but sometimes produce great density leading to large flocks of feeding birds. Waterboatmen, and brine fly larvae in these tidally restricted areas occur in tremendous numbers and attract such seasonal migrants as red-necked phalaropes (*Phalaropus lobatus*), two species of sandpipers, western (*Calidris mauri*) and least (*Calidris minutilla*), and many species of larger shorebirds.

Like most coastal environments in the continental United States, Elkhorn Slough has gone through dramatic changes wrought by development and changing land-use patterns.

When the MacGinities studied Elkhorn Slough, the hydrology of the slough had not yet been modified by the construction of Moss Landing Harbor or by diking and draining wetlands. There were extensive beds of eelgrass (*Zostera marina*) in the lower reaches of the slough that hosted a great diversity of invertebrates and fishes. Between the time Moss Landing Harbor was created 1945–47, by dredging a deep-water channel to Monterey Bay, and the establishment of the Elkhorn Slough National Estuarine Research Reserve in 1980, eelgrass beds in the slough had all but disappeared.

Enter the otters. The winter of 1982–83 brought the strongest El Niño conditions yet observed in the eastern Pacific. The beaches at Moss Landing, flanking the mouth of Elkhorn Slough, saw sustained waves of twenty-five feet. The combination of storm waves, torrential rains, and high tides eroded coastal dunes back fifty feet. Prior to this event, sea otters were associated with open coast kelp beds and rarely visited the quiet waters of Elkhorn Slough. During this turbulent winter, however, the slough became a refuge for a number of otters. They discovered a full buffet with extensive beds of Washington clams (genus *Saxidomus*) and gaper clams (genus *Tresus*). In the mid-1990s, a surge in otter numbers was observed in the slough. About this time, the Monterey Bay Aquarium began releasing into the slough rescued otters that had been rehabilitated. While numbers have fluctuated, there has been a general trend of increasing numbers of otters living in the slough. The aquarium program found that the otters released in the slough did very well and reproduced at rates comparable to their wild counterparts. Biologists have seen high counts of over 150 otters in the slough, with fluctuating numbers as animals move in and out to Monterey Bay.

A long-billed curlew (Numenius americanus) wading through pickleweed

In early 1995, another El Niño storm system stalled over the California central coast/Monterey Bay area, leading to sustained precipitation falling on already saturated watersheds. Devastating flooding occurred throughout the area. The Pajaro River breached its banks, flooded the lower Pajaro Valley, and flowed into Elkhorn Slough. This historically unprecedented flow deposited a tremendous load of sediment in the mid-reaches of the slough. The shoals that formed were subsequently colonized by sparse eelgrass. By 2010, researchers observed a dramatic increase in cover of eelgrass in the slough. Subsequent research showed a coincidence of increasing numbers of otters and the expansion of eelgrass beds. Through a series of field experiments, a remarkable story emerged. There are several small invertebrates that graze the blades of eelgrass, keeping it free of fouling algae and increasing the growth and health of the plants. Two of these, *Phyllaplysia taylori*—a small cryptically colored sea slug the width of an eelgrass blade and perfectly camouflaged—and an isopod, *Idotea resecata*, are effective leaf-cleaners, keeping epiphytic algae—whose growth is typically stimulated by the high nutrient level of the slough—from overgrowing the eelgrass. Several species of crabs prey on these two grazers and can reduce their populations to the extent that epiphytic algae can cover the photosynthetic surfaces of eelgrass, reducing health and growth.

Research showed, however, that increasing otter populations in Elkhorn Slough and their consumption of crabs led to the dramatic reduction in crab numbers, thereby reducing their predation on the grazers. Increasing numbers of grazers led to cleaner and healthier eelgrass and to the ultimate expansion of meadows. The trophic cascade described in this research parallels in some ways the resurgence of kelp bed density and health on the open coast in the presence of otters controlling herbivory by grazing invertebrates, such as urchins, which can otherwise eliminate kelp stands (*see "Underwater Barrens" by Doug Simpson,* Natural History*, February 2017*).

Today in Elkhorn Slough, there is a concerted and coordinated effort to restore the habitats and functions of this coastal environment "from the ridgeline to the tideline." Recent work has seen the successful planting of eelgrass in plots that have taken root and the expansion of this rich habitat continues. Seagrasses, such as *Zostera*, are part of the trifecta of plants in coastal environments that are known to sequester disproportionally large quantities of carbon—the so-called blue carbon—and include mangroves, salt marshes, and sea grass meadows.

Recently reported research from British Columbia has shown that sea otters foraging in eelgrass beds along that coast fragment the rhizomes and shift the reproductive

A southern sea otter wraps itself in eelgrass to stay in place.

mode of the plants from vegetative growth to flowering, thereby increasing the genetic diversity in the eelgrass populations. This shift has important implications as global climate changes—the more genetic diversity, the greater the likelihood that plants will adapt to new conditions. This novel research expands our understanding of the role top predators, such as sea otters, play in structuring communities and, in this case, in potentially impacting the future trajectory of populations through direct genetic shifts.

There is a parallel effort to restore the native oyster, *Ostrea lurida*, in Elkhorn Slough. This work includes hatchery-reared spat from Moss Landing Marine Laboratories aquaculture facility and the research team at the National Estuarine Research Reserve. Thousands of young oysters have been outplanted in the slough, and their growth and survival is closely tracked. One of the goals is to reestablish the oyster beds that once were abundant in the slough as evidenced by the deposits in archaeological middens. To outplant and monitor the oysters, researchers at the slough are working with the Amah Mutsun Land Trust Native Stewardship Corps of that tribe, whose ancestors were among the groups of indigenous inhabitants of these lands.

From the ridgeline, conservation interests have purchased steep eroding fields above the estuary and are restoring coastal prairie, maritime chaparral, and oak woodlands, and in the process reducing the inputs of sediment and nutrients into the estuary. This work includes collaboration with local farmers who are installing catch basins, biodigesters for trapping and transforming nutrients, pulling back cultivation from wetland edges and restoring marshes.

The tidal salt marshes of Elkhorn Slough have a dynamic history. They started growing as sea level rose from the last low stand about 18,000–20,000 years ago and eventually flooded the river valley that became Elkhorn Slough. Over thousands of years, sediments accumulated and were colonized by marsh plants. Paleoecological cores of these marshes record thousands of years of ecological history and reveal marshes dominated by pickleweed (genus *Salicornia*)—an indicator of saline conditions—with some brief periods of freshwater incursion. Tidal marsh acreage in the slough has declined up to 50 percent from what was a historic high two centuries ago. The loss is ascribed to the changing hydrography that included diversion of the Salinas River sometime in the first decade of the twentieth century and the dredging of the aforementioned harbor in 1946. In addition, historic diking and draining cut off hundreds of acres of tidal marsh from regular circulation, and led to subsidence of the marsh plain by as much as three to six feet. As the levees separating these lands from the tides failed, the former marshes were too low in the tidal frame to support marsh vegetation and led to depauperate mud flats.

Beginning in 2004, a team of scientists, managers, and conservationists organized the Tidal Wetland Program in Elkhorn Slough with the goal of understanding the causes of marsh loss and developing and implementing work to conserve and restore them.

Harbor seals and cormorants bask inside the slough at low tide.

A border of prickly pears planted decades ago stand guard at the edge of an abandoned field overlooking the newly restored tidal marsh. The Hester Marsh Project is the largest active tidal restoration effort in Elkhorn Slough. Over 120 acres of diked and drained tide lands are being restored to an elevation that will sustain vascular marsh plants and be resilient to 100 years of sea level rise. The newly excavated channels are visible in the middle ground.

The most recent effort is the restoration of 120 acres of diked and sunken tidelands to habitat that will support vegetated marsh and will be resilient to rising sea level. To ensure marsh plants can colonize and survive in these areas, over 300,000 cubic yards of soil was placed to raise the elevation in the tidal frame. The first phase of this work is completed and a sixty-acre area is already being utilized by otters and a host of other estuarine species. Researchers are measuring the carbon sequestration of this area as a unique opportunity to study the process starting with a clean slate and tracking the evolution of a vegetated marsh from bare soil. An array of experiments is designed to measure the effectiveness of different plant restoration approaches; tens of thousands of plants have been planted on the site.

Elkhorn Slough is distinguished by its designation as one of what will soon be thirty National Estuarine Research Reserves established along the nation's shores. The program is overseen by the National Oceanic and Atmospheric Administration (NOAA). In each of the states where a reserve is established, a state or local entity is responsible for management. At Elkhorn Slough, the California Department of Fish and Wildlife is the management authority. NOAA and the Department work closely with the Elkhorn Slough Foundation, a community non-profit and Accredited Land Trust, to conserve, restore, and manage the Slough.

Over the past forty years, the Elkhorn Slough Reserve and Foundation have protected about 15 percent of the 45,000-acre watershed. California State Parks, Monterey County, and The Nature Conservancy have protected hundreds of acres of additional lands in the watershed. The team of scientists, land stewards, educators, and managers have contributed to a deeper understanding of the biology and ecology and continue to lead conservation and restoration of this estuary. The tidal waters of the slough are further protected by designations as a State Marine Protected Area and as part of the Monterey Bay National Marine Sanctuary.

Elkhorn Slough provides a microcosm of issues facing coastal environments around the globe. The juxtaposition of industry, agriculture, residential development, transportation corridors, harbor, fishing, and recreation in one of the truly remarkable wildlife habitats in the country provides a setting to answer the question: How do we do conservation in a working landscape? People have made their living here for thousands of years. To ensure that people will be able to continue to do so, a team doing the research and experimentation to care for this biologically and ecologically rich place.

Likewise at the other twenty-eight National Estuarine Research Reserves and on lands conserved by state, federal, and local agencies and by land trusts across the nation, people are restoring, managing, and balancing uses to ensure the sustenance of nature in the face of our current challenges. Perhaps, *U. caupo*, the "fat innkeeper worm" and humble tideflat denizen can be a model for us all—living with diverse co-inhabitants, all getting along, sharing resources in an accommodating way and waiting for the tide to turn.

Mark Silberstein, *executive director of the Elkhorn Slough Foundation, is a marine zoologist who has worked on the study and conservation of coastal wetlands for three decades. He is known for pursuing collaborative approaches to conservation and for a fondness for mud. For more information and references:* www.elkhornslough.org. Chuck Graham, *freelance writer and photographer based in Carpinteria, CA, is a guide at the Channel Islands National Park for Channel Islands Outfitters. He is a frequent contributor to* Natural History. *His latest piece was an "Endpaper: Cache as Cache Can" in the April 2020 issue.*