

The Tide Rises

David Sedlak, an environmental engineering professor at the University of California–Berkeley, stands on a levee near San Francisco Bay’s eastern shore. Manmade embankments extend for many miles, lining much of the bay’s edge, but Sedlak, a lean, intense guy, is fired up about this newly built one. Instead of the usual barren concrete, the bayward face of the levee slopes gently beneath a dense growth of native wetland plants. From muddy clumps of roots and rhizomes placed here only a year ago, the plants have sprouted into a lush palette of green, from the deep dark of Baltic rush to the bright tones of creeping wild rye.

Sedlak is part of a bold experiment. If it succeeds, the project may reshape the East Bay shoreline, restoring a vast acreage of lost tidal wetlands that will be nourished by treated wastewater. The hope is that vegetated levees (the official moniker for the concept is the Horizontal Levee) will save money and energy, recycle treated sewage to create habitat, and help the urbanized East Bay adapt to rising sea levels.

Conventional levees form steep concrete or earthen walls that armor roads and buildings against the bay’s powerful waves. The Horizontal Levee is a lovely contrast, a compressed version of a natural habitat long missing from the shoreline. The transition zones, or ecotones, between land and bay were biologically rich places that once hosted a diversity of native plants and animals. Since the Bay Area was settled, wetlands have been diked off from both the open bay and the surrounding land. Between 1800 and 1998, 92 percent of tidal marshes were lost to diking and filling.¹

“In San Francisco Bay, we’ve separated the contacts between the terrestrial and the tidal,” explains Peter Baye, a consulting ecologist whose deep knowledge of remnant natural wetlands acts as guideline for the creation of the Horizontal Levee. Habitats that once formed a continuous gradient from dry land to salt marsh have been boxed off, separated by dikes. The disappearance of what ecologists call the “back end” of tidal marshes has been a significant loss. Connection with the land once nourished brackish marshes with fresh water and sediment. The habitat created there provided cover for many marsh creatures, including the endangered salt marsh harvest mouse and Ridgway’s rail, when tides rose and pushed them out of the flat marsh plain.

Today, restoring both salt marshes and the ecotones that connect them to the land is not just a wildlife conservation technique. It's part of a larger plan to use natural ecosystems to protect the bustling urban zones of the Bay Area from rising waters. As measured by a gauge beneath the Golden Gate Bridge, the bay's level has increased by seven inches from 1900 to 2000. Climate forecasts predict that the rise in bay waters will accelerate in the mid-twenty-first century, climbing an additional fourteen inches by 2050,² and continuing to rise to fifty-five inches above current levels by 2100. The greatest immediate threat is from storms that coincide with high tides. Such storm events regularly push water over the top of existing levees, flooding roads.

As a wave crosses a salt marsh, its energy dissipates among the plants and mudflat. Reviving the bay's lost tidal marshes can create a resilient, low-maintenance barrier against storm surges. Rebuilding the back end of tidal wetlands adds another protective barrier, as well as creating a space where salt marshes can migrate inland as the bay level continues to rise.

The notion of the horizontal levee comes from Baye's insights into pre-settlement ecotones, which were fed by seasonal seeps of fresh water that allowed native plants to flourish. Now, levees block any fresh water that runs off during rainstorms—and the majority of the available fresh water is in the form of treated sewage effluent, which is piped past any potential restored wetland areas and into the deep waters of the bay. These deep-water discharges were required by the San Francisco Regional Water Quality Control Board starting in the 1970s.

Baye suggested the idea of redirecting wastewater flows so that treated effluent would filter through a restored land-marsh transition zone. This would have multiple benefits: A restored ecotone would provide plant and wildlife habitat, pump nitrogen out of the water and into the air through the action of denitrifying microbes, and build a layer of peat that would buffer the impacts of rising bay waters. The East Bay Discharge Authority, which pipes effluent from several treatment plants in the area to the bay, would be spared the expense of replacing its aging deep-water pipe, now corroded from decades in salt water.

The concept was embraced by geomorphologist Jeremy Lowe, now with the San Francisco Estuary Institute, who sees it as an inspired way to combine goals and funding. Wastewater managers have access to different sources of money than wetlands restoration advocates, so having both groups behind a project is a big advantage. For Lowe, the creation of the prototype Horizontal Levee at Oro Loma is an important first step on a long road of testing ways to restore wetlands while protecting the bay's shoreline.

"We've been waving our arms around for a long time, but up to now we haven't built anything," he says. "I see it as an experiment to provide scientific information, but also a way to focus the conversation about how we are going to adapt to sea level rise."

The experimental levee, which stands adjacent to the sewage treatment plant at Oro Loma, holds a series of parallel wetland cells. Rushes and sedges send their roots down into carefully prepared layers of substrate. Beneath a shelf of soil lies a layer of gravel mixed with wood chips. As wastewater flows through

this underground layer, anaerobic bacteria will transform its load of nitrate into N_2 gas, which dissipates into the atmosphere. This denitrification process takes an ample supply of carbon, which is why wood chips were added to the experimental wetlands. Sedlak hopes that within about ten years, the wetlands will have built up a layer of peat containing enough carbon to fuel denitrification for the long term.

The levee's wet meadows are lush, dense with an assortment of native plants. So far, there's been no significant problem with the invasive weeds common on much of the shoreline. "If we let the native flora reconnect to fresh water sources, that can take care of the weed problems," explains Baye. The theory is that native marsh plants can outcompete invasives when conditions are right—and a little over a year into the life of the Horizontal Levee, that notion is proving true. When I visited in March 2017, the levee was watered by abundant rainfall from the wet winter of 2016–2017. The big question is how the plant community will respond when treated wastewater starts flowing through the system in May.

For now, the water that flows out from the experimental system is routed back to the wastewater treatment plant to be discharged through the long pipe that extends into the bay—because the experiment is too new for regulators to allow actual discharge of effluent via shoreline wetlands. The hope is that if the Horizontal Levee concept can be shown to work, regulators with the regional board will be willing to trade the expensive deep-water discharge pipes of the past half-century for a series of restored shoreline habitats. The idea makes sense for a number of reasons: Throughout the bay, deep-water pipes will be increasingly susceptible to damage as the sea level rises. The long, plant-covered slope of the horizontal levee will provide a far more resilient protection against storm surges than conventional cement or earthen dikes. As time passes, the region's wastewater treatment plants, almost all of them built near the shoreline, will be in growing need of protection from the rising waves.

The Horizontal Levee, with its focus on bringing back lost ecotones, is a departure from decades of wetland restoration practices in San Francisco Bay. Some of California's earliest tidal restoration projects took place in the bay. These efforts were motivated by Section 404 of the Clean Water Act, which requires that developers who destroyed wetlands must restore habitat elsewhere in mitigation.³ They focused only on restoring salt marsh, the realm of cordgrass and pickleweed. Transition zones were not part of the calculus.

Phyllis Faber, then a consulting biologist, pioneered salt marsh restoration in the bay with the Muzzi Marsh project, begun in 1976. Construction of the Larkspur ferry landing in Marin County required dredging of Corte Madera Creek, an action that destroyed some wetland. In mitigation, Faber designed a restoration of the Muzzi property, which had been diked and drained in the 1950s, and used as a dumping ground for dredge spoils.

Faber's initial restoration plan was simple: Breach the dikes in a few spots to allow the tide to flow in and out. In the first year of tidal flow, she remembers the soil softening. By the second year, native pickleweed had begun to establish. "We were thrilled with how quickly the pickleweed came back," Faber recalls. To

accelerate the regrowth of native salt marsh plants, in 1979 a network of channels was dug to improve circulation of tidal waters through the marsh. Later, dredge spoils were deliberately placed at the marsh's edge to provide sediment.⁴ A supply of inorganic sediment is an essential ingredient for the establishment of healthy salt marsh; the accumulation of silt allows the marsh to build elevation, necessary for the growth of cordgrass and other native plants. This process has always been part of marsh formation. Over the past six thousand years, salt marsh has established and spread out when bay levels were low and sediment supply was high, then receded again when waters rose.

Faber spent twenty years monitoring the progress of Muzzi Marsh. She tracked subtle changes in the marsh's elevation, and corresponding shifts in plant growth. Pickleweed dominates at higher elevations, cordgrass in the areas that are more deeply flooded with the shifting tides. Now, like other restored and natural salt marshes in the north bay, Muzzi Marsh is eroding away. "When the tide comes in it brings sediment, and when it goes out it carries sediment away," she explains. As waters in the north bay have cleared of suspended sediment, they carry away more than they deliver. "As a result," says Faber, "our marshes are all threatened by the normal wear and tear of tidal action."

The bay now eats away at the earthen dike that was first built to cut the land off from the bay in the 1950s, and that has protected Muzzi Marsh since its restoration (Fig. 13.1). If the old levee collapses, the marsh will be drowned and will become one more patch of open water on the Marin County shore.

"I'm going to be ninety, so I'm not going to be around to offer my opinion, and I hope somebody's watching this," says Faber. If Muzzi Marsh is drowned, a part of her legacy will vanish. Once the marshland floods, the tides are likely to flood buildings that stand behind it—an outcome more likely to grab the attention of officials in the town of Corte Madera.

Sediment supply is a major issue confronting efforts to restore salt marsh in San Francisco Bay. The California Gold Rush reshaped the bay in multiple ways. One major influence was an intense pulse of sediment released by hydraulic gold mining in the Sierra Nevada during the mid-1800s. Whole mountainsides were ripped apart, and their remains eroded into the creeks and rivers of the Sierra, flowing into the Sacramento–San Joaquin Delta and out to San Francisco Bay. New salt marshes developed, often outside the levees that had separated prehistoric wetlands from the tides. At the few ancient, intact salt marshes that survive on the bay, a fringe of newer marsh appeared, fed by the heavy loads of Gold Rush silt.⁵ As dams were built to hold back the Sierra's rivers, sediment was trapped behind them and the amounts flowing to the bay declined. Bay waters cleared, and a 1999 analysis found that levels of suspended sediment would continue to decline.⁶

Federal and state regulations forbid the dumping of sediments on wetlands, part of an effort to protect the bay from a wave of filling and development that threatened its survival in the 1960s. Up until 1965, when a band of local activists triggered the establishment of the Bay Conservation and Development Commission (BCDC), the bay was routinely used as a dumping ground for trash and untreated wastewater.



Figure 13.1 Erosion of the levee surrounding Muzzi Marsh, Corte Madera, California. As upstream dams capture sediment and sea level rises, San Francisco Bay's surviving salt marshes are threatened. Photo by Sharon Levy.

Now, the end of the Gold Rush sediment pulse portends a new era for wetland restoration in the region, in which sediment, long disposed of in deep waters to keep it as far from sensitive wetlands as possible, will become a vital resource for marsh restoration.⁷

During her time as a restoration biologist, Faber emphasized that native marsh plants would revive from seed banks surviving in bay soils. Given enough time—sometimes several years—the plants did come back on their own. Limiting human interference seemed best, especially after the US Army Corps of Engineers introduced an Atlantic Coast species of cordgrass, *Spartina alterniflora*, which turned invasive, outcompeting the native Pacific cordgrass, *Spartina foliosa*.

Dense stands of Atlantic cordgrass took over marshes, coopting habitat for an array of native plants as well as birds and their prey. A decade-long effort coordinated by the California Coastal Conservancy used herbicide sprays along with volunteer labor to eradicate the invader. By 2016, Atlantic cordgrass had been removed from most of San Francisco Bay, at a cost of more than \$30 million.⁸ The lesson that restoration ecologists must be careful what they plant has been learned the hard way.

Yet those working to revive the bay's tidal wetlands now feel an unparalleled sense of urgency. Restored marshes may now need the boost of humans intervening to start native plant growth, especially the freshwater and brackish meadow plants that live in the transition from land to salt marsh. (In these areas,

unplanted earth can be quickly taken over by weedy invasives.) The bay's fate is tied to the rate of glacier melt in Greenland and Antarctica, which is accelerating. "If you follow the news over the last year, everything is happening a lot sooner and faster than expected," says Baye. "So we might see that spike in global sea level rise sooner than the expected date of 2050."

The South Bay Salt Pond Restoration Project, one of the largest wetland recovery efforts in the world, is a testing ground for new strategies. The project includes more than sixteen thousand acres of salt ponds, areas that had been diked off from the bay and replumbed to concentrate salt that was harvested by the Cargill company. When Cargill consolidated its salt works, it sold many of its abandoned ponds to the state. The goal now is to restore most of that area to salt marsh, while recreating the lost ecotone where the marsh meets the land.

John Bourgeois, executive project manager with the California Coastal Conservancy, is in charge. He's in a race to capture as much sediment as he can to raise the elevation of the former salt ponds. At Alviso, in the far southern reaches of the bay, groundwater extraction has caused the pond floors to sink by as much as eight feet. For now, the waters of the south bay still carry substantial amounts of suspended sediment. In the north bay, the water has cleared and the dissipation of Gold Rush-era silt is more obvious. It's only a matter of time before sediment depletion comes to the south bay too.

The levee surrounding one of the former salt ponds at Eden Landing Reserve, where there's been relatively little subsidence, was breached in 2006. As the tides flowed in and out, they deposited sediment that built lost elevation, allowing native cordgrass to flourish.

One great advantage is that the salt ponds have retained the sinuous tidal channels formed in ancient marshes before they were diked off from the bay (Fig. 13.2). In long-established marshes, these channels form an intricate pattern of dark water interlaced with the greenery of salt marsh plants. The channels are an integral part of a healthy marsh. They carry tidal waters deep into the habitat, deposit sediment, and build ridges at the channel edges where wildlife shelter among stands of cordgrass. One species particularly dependent on the channel system is the endangered Ridgway's rail, which forages and nests along channel edges (Fig. 13.3). Within eight years of the first dikes being breached at Eden Landing, a pair of nesting Ridgway's rails was found. Their population has grown steadily.

To build elevation in the more subsided areas of the restoration project, Bourgeois is seeking permits to pipe in a slurry of sediments dug up during dredging at local harbors. This will require a floating offloader to set up in the bay. Because of regulations governing the dumping of sediments in the bay, this kind of work must be done before dikes are breached. Getting the permits to add sediment to a diked-off salt pond is a challenge: It's just not possible to obtain a permit to add sediment to habitat that's already reconnected to the bay.

Bourgeois hopes to restore complete marshes, which will mean reviving the ecotones between dry land and wetland long ago lost to diking and urbanization. "We're going to have to do that in a somewhat artificial manner," he says,



Figure 13.2 Aerial view of tidal channels in a San Francisco Bay salt pond. Meandering channels can take many years to develop and are critical to the health of salt marshes. Aerial Archives/Alamy Stock Photo.



Figure 13.3 The Ridgeway's rail, an endangered species now breeding in parts of the South Bay Salt Pond Restoration Project. Photo by Leslie Scopes Anderson.

“because this isn’t the north bay where the shoreline is adjacent to rolling hills and farm lands.” There’s little space between the old salt ponds and the nearest buildings. So the plan is to recreate the lost transition zone on a manmade slope, like the one at Oro Loma’s Horizontal Levee.

That will mean using a tremendous amount of fill—hundreds of thousands of cubic yards of it, thousands of dump-truck loads. Bourgeois needs a lot of spare earth to create his transition zones, and that can be an expensive proposition. His plan, which he has tested before during a restoration project at Bair Island, is to use dirt dug up at construction sites. Dumping the soil at Eden Landing will be cheaper for construction firms than taking it to a landfill, which is normal procedure. A dirt broker acts as a middleman, testing the earth to make sure it’s not tainted with toxins. The restoration project ends up getting its fill for free. The tactic fits right in with the restoration ecologists’ ethic of recycling: old salt ponds into healthy marshes, treated sewage into a water source for wet meadows.

Bourgeois has submitted applications for a series of permits required to create the ecotone slopes he hopes will someday back up restored marshes at Eden Landing’s former salt ponds. “We’re going to be a huge guinea pig for this process,” he says. “I’m proposing several hundred thousand cubic yards of material to be placed in the bay. So it’s going to be a wait and see whether or not the agencies can adapt.”

Staffers at agencies like the San Francisco Regional Water Quality Control Board and the BCDC understand that circumstances have changed dramatically since regulations were established to protect the bay in the 1960s and 1970s. Adapting to those changes remains a work in progress. “We’ve been in discussions on our policies for sea level rise and sediment decline issues for two years,” says Brenda Goeden, sediment project manager for BCDC. So far, the most radical new permit requests are Bourgeois’ petitions to build a new back end onto a series of restored saltmarshes.

Even if by some miracle we halt our combustion of fossil fuels, the process of sea level rise has already been set in motion. Restored tidal wetlands will be an essential part of adapting. Yet wetlands, both natural and restored, coastal and inland, combat global warming in another important way: They lock up carbon that would otherwise be released to the atmosphere as the greenhouse gas carbon dioxide (CO₂).

Wetland plants—bulrush, cattail, or willow in a freshwater wetland, cordgrass or pickleweed in salt marsh—sink their roots into underwater sediments. There’s little or no oxygen in these marsh soils, so decomposition is slow. Over time, old roots die off and become incorporated into a layer of peat, rich in carbon, that can be stored for centuries. New generations of plants thrive, sinking their roots down into the peat, building it further.

When wetlands are drained, peat soils that may have accumulated over millennia are exposed to the air. The organic peat soils oxidize, releasing both carbon dioxide and methane (CH₄), a far more potent greenhouse gas, to the atmosphere. Drained wetlands can hemorrhage carbon stores accumulated over

thousands of years. The process begins with a rapid burst of carbon emissions, but can continue at lower rates for more than a century.⁹

Wetlands cover only 5 to 8 percent of the planet's land surface but hold 20 to 30 percent of the soil carbon on Earth.¹⁰ A recent analysis found that wetlands in the continental US contain 11.52 Petagrams (Pg, equivalent to 1 billion metric tons) of carbon. Worldwide, wetlands store an estimated 300 to 700 Pg of carbon.¹¹ For context, all of the living plants on Earth are estimated to store 56 Pg of carbon; the modern atmosphere, pumped up with greenhouse gases from burning fossil fuels, holds 750 Pg; the planet's soils hold 1,500 Pg.¹²

Given these facts, the notion of restoring wetlands would seem to be a no-brainer. There's been debate among scientists, however, because despite their ability to store prodigious amounts of carbon, wetlands are also natural sources of greenhouse gases, especially methane, which the International Panel on Climate Change has determined possesses twenty-five times the global warming potential of carbon dioxide.¹³ Wetlands have been identified as the source of about a quarter of the total methane in Earth's atmosphere, and their emissions are expected to rise as the climate warms.¹⁴ Some researchers have argued that while existing wetlands should be protected for their value as wildlife habitat, water quality filters, and flood protection, restoring more wetlands would be irresponsible in the age of global warming.¹⁵

Bill Mitsch, the wetlands expert and dreamer of landscape-level restoration, strongly disagrees. He and his coworkers analyzed carbon flux data from twenty-one wetlands in the tropical and temperate zones. They found that on average, the amount of methane released is equal to 14 percent of the carbon stored in a wetland's peat layer.¹⁶ This puts the ratio of carbon sequestration to methane release at 19:5. Because the result is lower than the 25:1 methane:carbon dioxide global warming ratio established by the International Panel on Climate Change, this casts wetlands as a net source of greenhouse gas pollution.

When time is added to the analysis, however, that initial conclusion is reversed. Methane decays in the atmosphere, morphing into carbon dioxide through the process of oxidation within eight to ten years.¹⁷ Carbon in the peat of healthy wetlands can remain locked away for millennia. Factor the atmospheric decay of methane into the equation, and long-lived wetlands—those that endure for a century or more—become net sinks of greenhouse gas. The team found that the carbon sequestration is highest in the temperate zone; tropical wetlands release more methane because decomposition happens faster in the heat, and boreal ones sequester less carbon because the Arctic growing season is short.

Methane is generated as anaerobic bacteria break down organic matter in peat. The lack of oxygen in the saturated soils of wetlands, the same factor that allows so much carbon to be stored there, makes methane production possible. For Mitsch, methane emissions are a natural side effect of the processes that make wetlands so important—and no reason to abandon the idea of restoration. In some of his studies, even young, newly restored wetlands have sequestered enough carbon to counterbalance their methane emissions.

Mitsch points out that the carbon in fossil fuels comes from ancient wetland peats, transformed over geologic time into coal, oil, or natural gas. It makes sense, he says, that wetlands are likely the most effective ecosystems on the planet for sequestering carbon.

While Mitsch has focused his work on inland, freshwater wetlands, that principle may hold especially true for tidal wetlands. In the past few years there has been a burst of interest in conserving and restoring coastal marshes, mangrove swamps, and seagrass meadows. These habitats all sequester significant amounts of carbon, and they have been disappearing fast: Estimates of the cumulative global loss of all three habitat types range from 25 to 50 percent over the last fifty to one hundred years.¹⁸ Conversion and destruction of coastal ecosystems has been estimated to release up to 1 billion tons of carbon dioxide every year.

The freshwater and brackish meadows and marshes at the back end of the tidal zone grow and store carbon fast. In the salt marsh flat, plants face the challenge of pumping excess salt out of their systems, so their growth is slower. In terms of carbon storage, both ends of the spectrum are important. Methane is not produced in salt marsh, because salt water is rich in sulfate, which kills off the microbes that release methane as a product of decomposition in freshwater wetlands.

Studies of what's become known as "blue carbon"—the carbon stored by coastal ecosystems—suggests that these habitats store carbon with far greater efficiency than terrestrial forests or prairies. Tropical forests, the justifiable focus of intense conservation efforts and a significant part of the global market in carbon credits, store about 2.5 metric tons of carbon per square kilometer per year. Salt marshes, seagrass beds, and mangroves capture and sequester an estimated sixty to 210 tons of carbon per square kilometer per year.¹⁹ The loss of these habitats has meant a failure to capture 434 billion tons of carbon over the past century.

Reviving these coastal habitats could make a significant dent in our carbon pollution problem, but that will take what marine ecologist Andrew Irving has called "industrial-scale restorations."²⁰ That's the kind of thing being attempted by the South Bay Salt Pond Restoration Project, with its sixteen thousand acres of existing former salt ponds and ambitions to create more acreage using fill to build ecotone slopes.

To understand the role of wetlands in a world overloaded with human-generated nutrients in water and air, one needs to consider time. Swamps and marshes were here long before we were, when our ancestors were small, timid primates scurrying through swamps we would later dig up and burn. The great wetlands of North America began to form thirteen thousand years ago, when glaciers receded at the end of the Ice Ages and left behind the Great Lakes, the Chesapeake Bay, and the grand delta of central California flowing into San Francisco Bay. Along the edges of these waters, wetlands grew up and soaked away vast stores of carbon. In only two hundred years or so, we humans have managed to rip apart and drain more than half of these ecosystems. We started the destruction using our own blood and sweat. Later we used machines fueled by the energy-rich remains of ancient wetlands.

The wetlands of the future must serve human ends, and bring nature into a manmade world to help mop up some of the mess we have made. We can't revive the vast wilderness of the Great Black Swamp, but strategically placed wetlands built into the Midwestern farmscape can do part of its job. The endless tule marshes of prehistoric California are lost, but a series of soggy meadows engineered into the edges of San Francisco Bay's urban sprawl can help the city and its people to thrive.

Out of sight, in the boggy soil and among the roots of the living plants, nitrogen and phosphorus will be absorbed, carbon locked away. Above, rushes and sedges will wave in the wind, their narrow, bright leaves gleaming in the sun. The breeze will carry the smell of wetlands: a combination of thriving growth and gradual rot. From the reeds will come the trill of a marsh wren, the splash of a frog, or the scurry of a mouse.

Enough obstacles stand in the way to make this seem an impossible dream. That's what the powers that be told Arcata's upstarts forty years ago—and they turned out to be wrong. This, too, is a wetland dream worth chasing.

NOTES

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