SAN FRANCISCO

ESTUARY

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FISH TALES

Stories of fins and scutes, smelt and salmon, gut rot and egg loss, and the myriad fishes tracked, tagged, trawled, and hatched in the San Francisco Estuary.

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EDITOR'S DESK

Better Living Through Fish

ARIEL RUBISSOW OKAMOTO

I come from a long line of fisherfolk. My grandparents had a tiny cabin on a Quebec lake. We visited some summers. My grandfather let me drive the big white speedboat at a snail's pace while he smoked cigars and trolled for trout off the stern. Once, when I caught one bigger than his catch-of-the-day, he "accidentally" knocked it back into the lake with the net. On the dock, we'd sunbathe while he cast lines overhead with a precision worthy of the movie *A River Runs Through It*. At the lake, we ate trout and eggs, trout salad, baked trout. I survived on spoonfuls of Cool Whip.

Editor as teenager with bass catch and grandmother, Kay Rubbra.

I've not only fished off my grandfather's dock, but also in ice-cold Sierra lakes with my backpacker dad, and with my own kids. Once we sent my tween daughter and godson out with a professional guide and they came back with a beautiful salmon, which our friend then gutted and served up as sushi right there on the shore. I get chills thinking of their experience, catching and eating something of such natural perfection on a wild river, not a supermarket in sight.

This issue of ESTUARY is all about fish, not fishing. But I mention fishing here because of the way it connects us to our food and our ecosystem. When we fish we interact directly with water and wildlife. But the study of fish, right here in our own Bay and Delta, also affords this intimacy. There are scientists in California who know more about steelhead gills and smelt otoliths and sturgeon scutes and salmon eggs than they do about Britney Spears, Jimmy Garoppolo, extra virgin olive oil, or any other thing or person of celebrity.

As an editor, dedicating an issue to fish feels like centering the region's relationship with its waterways and waterbodies. Forget the fires, the floods, and the harmful algal blooms, and think about the basics: without our interest in fish, as a challenge to catch, as a symbol of the wild, as an indicator of current health or slow planetary death, as a miracle that lives underwater where we can't live, so much of our work would occur without a reference point.

In this issue, we share both the heroics of saving a fish near extinction as well as the secrets of some sturdier, healthier natives. We detail how South Bay fish are faring now that so much fish-food-producing marsh habitat has been restored in their environs. We examine how our incessant habit of driving everywhere is not only warming the planet but also leaving behind shreds of rubber that are creeping into fish guts and poisoning Pacific Coast coho.

Our stories discover fish in bone-dry streams under boulders, and tally steelhead in two entirely different watersheds: one urban, one valley, but both often starved of flows by human diversions. And we even take a moment to drill down, once again, into the perpetual failure of the best-laid plans and policies to actually protect our beloved salmon, especially in drought when there isn't enough water to go round. In this sharing of fish tales, we invite you to marvel at the swimmers off our shores and riverbanks. Good fishing.

MEMORY LANE

Bluegill Blues

JOE EATON, REPORTER

Growing up in Arkansas and Georgia, I used to go fishing with my father. Just hook and line, for bluegill, crappie, and the like. It was a challenge to my attention span; I tended to get distracted by birds and forget to watch the bobber. I remember losing one fish because of an anhinga that flew over. But I enjoyed the result, dredged in cornmeal and deep-fried. Lunch on the fishing trips was always Vienna sausages, straight out of the can, and saltines. Once when I wasn't along, my father caught a largemouth bass of sufficient size that he decided to have it mounted, which was probably a relief to my mother who would otherwise have been expected to cook it. He had heard from a coworker that there was a taxidermist somewhere in the vicinity, and drove the bass, on ice, down the backroads of Thomas County, Georgia, looking for him, getting lost repeatedly. He finally broke down and asked somebody who was working on his car where the taxidermist was. "I don't know about no taxidermist, but there's a guy down the road a piece that stuffs fish," was the response. The fish was duly stuffed, and it's still somewhere in my storage unit.

Fresh from the Freezer

ALETA GOERGE, REPORTER

I never fished as a kid. In fact, my first time fishing was last year when my husband and I joined a Fish Emeryville charter aboard the *Sea Wolf*. We left the harbor at dark o'clock and headed out the Golden Gate with the sun rising behind us. It was a treat to be out on the water at dawn among those enmeshed in maritime culture. The sea was too rough to go to the Farallones as planned, so we headed north and fished for rock cod and lingcod in deep pockets of water along the coast. I caught plenty of fish, all of which were stunningly kaleidoscopic. After a few hours I turned my attention to watching birds, observing the surface of the water, and motoring below that beautiful bridge. We ate fresh Pacific cod from our freezer for months.

Hatchery-raised Delta smelt staged for loading in barrels before traveling by truck and boat to the waters of their genetic origin. Photo: USFWS

ENDANGERED

Hatchery Delta Smelt Released to Wild

ROBIN MEADOWS, REPORTER

On a mild day between rainstorms in mid-December, wildlife biologists outfitted in rubber boots and orange lifejackets load drum after drum of precious cargo onto a small boat docked in Rio Vista, a town on the Sacramento River in the Sacramento-San Joaquin Delta. There is little fanfare but the occasion is nonetheless momentous. The shiny silver drums contain thousands of Delta smelt — finger-size imperiled fish unique to the Delta — that were raised in a conservation hatchery. Today marks the inaugural release of captive smelt into the cold, murky waters of their native home.

"For the first time, we're seeing if it's possible for hatchery-raised Delta smelt to be released into the wild, survive, and successfully reproduce," says Katherine Sun, a biologist with the U.S. Fish and Wildlife Service (USFWS) who co-leads the multi-agency effort that also includes the California Department of Fish and Wildlife, the California Department of Water Resources, the U.S. Bureau of Reclamation, the U.S. Geological Survey, and UC Davis.

Delta smelt were once plentiful. "You could pull up a net and expect to see a good handful of them," Sun says in a recent USFWS Fish of the Week! podcast. Added to federal and state endangered species lists in 1993, the Delta smelt is now close to extinction. "We're talking in the hundreds," Sun continues.

This slender, nearly translucent fish may be tiny and all but gone, yet its influence on California water is huge. Much of the water flowing through the Delta is pumped south, providing drinking water for 25 million people and irrigating nearly 4.5 million acres of Central Valley farmland. Protections for Delta smelt include periodically curtailing these exports to keep the fish from being sucked toward and even into the pumps.

"The Delta smelt ... has become a flashpoint for significant resentment, frustration, and lawsuits," note the authors of a September 2021 commentary in the journal Environmental Law Reporter, including Karrigan Börk, an associate director at the UC Davis Center for Watershed Sciences.

Tensions over the water supply could be eased by reversing the Delta smelt's decline, giving wildlife and water managers alike a shared interest in the welfare of this at-risk species.

The immediate intent of the Rio Vista hatchery smelt release is not to bolster the barely-there wild population, but rather to determine the best way to get these captive fish into the Delta and thereby optimize future releases. It's taken decades to get to this point.

"Some may say it's too late but I'm glad we're finally putting the fish out," says Tien-Chieh Hung, who directs the UC Davis Fish Conservation and Culture Laboratory that raises hatchery smelt.

The conservation hatchery began figuring out how to breed and raise Delta smelt in captivity in the mid-1990s, soon after the fish was formally listed under the federal Endangered Species Act. To keep hatchery fish as similar to the wild population as possible, the captive population is managed to preserve genetic diversity, aided by an annual influx of up to 100 wild-caught smelt.

It's getting hard to reach that quota. The hatchery last caught its full allotment of wild Delta smelt in the winter of 2017-2018. Over the next two winters, the catch dipped to 28 and then rebounded to 93. Last winter, the hatchery caught just two fish. "We're struggling," Hung says. "We're still catching some but it takes much more effort to find them."

The hatchery raised 40,000 smelt for this winter's releases near Rio Vista, with 12,800 set free in the mid-December kickoff. Winter is a good time to put hatchery smelt in the wild because this is when they start migrating upstream toward the freshwater where they spawn. In summer the young smelt then migrate downstream to the brackish waters where they grow up.

Delta smelt are so sensitive to human handling that the researchers think it will take three years to figure out the best way to move and release them. For example, the team has learned that the fish need to be transported in round containers. "They're relatively weak swimmers," Sun explains in the podcast. "Delta smelt have been known to get stuck in corners, they get stressed out, and they die."

This winter the researchers are comparing two ways of releasing this fragile species from the transportation drums: letting the smelt swim straight into the Delta immediately versus holding them in cages for up to three days so they can get used to their new home. The process is

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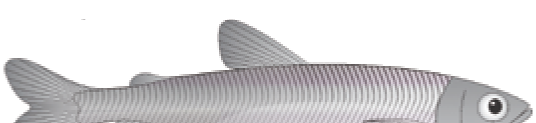

as gentle as possible. One by one, the drums are carefully hoisted and lowered into the water, pried opened, and gradually tipped to let Delta water in and hatchery smelt out. The small fish vanish immediately into the turbid water that helps them hide from predators.

For now, the goal is simply to see if the hatchery smelt can stay alive in the Delta. Future goals include seeing if hatchery smelt will breed in the wild, and if they can survive when released in other parts of the Delta such as the Sacramento Deep Water Ship Channel, the Cache Slough Complex, and Suisun Marsh. The eventual plan is to use hatchery Delta smelt to boost the wild population.

Hatchery fish alone will not be enough to save the smelt, however, because the Delta ecosystem is severely degraded. "Habitat restoration is a huge part of the effort," says Ken Paglia, a California Department of Fish and Wildlife spokesman. "You don't want to release fish into an ecosystem that isn't doing well."

Delta smelt require water that is cool and neither too salty nor too clear, making them dependent on freshwater from the rivers that flow into the Delta and also sensitive to the vast volumes of water exported south for drinking and irrigation. Another threat to these fish is that the Delta produces far less of the food they eat. The early 2000s saw a precipitous decline of Delta smelt that coincided with a drop in zooplankton, minuscule aquatic creatures that make perfect fish food.

Simultaneous declines were observed in several other open-water (pelagic) fish in the Delta, including the threatened longfin smelt and the non-native striped bass. This alarming multi-species decline sparked regular surveys for these pelagic fish, which serve as indicators of ecosystem health. While none of these fish have rebounded, longfin smelt are still breeding in the South Bay (see p. #) and striped bass are still breeding in Suisun Marsh.

Biologists hope the released hatchery Delta smelt will benefit from habitat restoration in the Delta, including tidal marshes and floodplains where zooplankton thrive. Previous experiments with captive smelt in cages in restored habitat confirm that these sites produce plenty of food for fish.

The survey crews that track Delta smelt and the other indicator pelagic fish will be able to distinguish smelt born in the hatchery from those born in the wild at a glance. The conservation hatchery marked every single one of the captive-born fish by clipping their adipose fins, small flaps on the back that don't grow back. Some of the hatchery smelt also have silicone tags injected under their see-through skin. "It makes a one-centimeter line under the dorsal fin and you can vary the color," Hung explains. For hatchery smelt released this winter, these subcutaneous tags are red.

Peter Moyle, a UC Davis biologist who witnessed the Delta smelt's decline firsthand over more than half a century of studying them, is skeptical of the prospects for hatchery fish in the Delta: "If the wild smelt have not made it, what makes them think there's good habitat now?" He also worries that hatchery smelt will lose the capacity to live in the wild. "The longer you keep them in captivity, the more domesticated they become," he says. "We're in a desperate situation with smelt."

Rather than releasing hatchery smelt directly into the Delta, Moyle favors first putting them in ponds on Delta islands. This intermediate step could help captive smelt become accustomed to the natural world. That said, he agrees that taking action to save the Delta smelt is essential. "No matter what we try to do, it's risky," Moyle says. "But the alternative is for the smelt to go extinct."

And there are signs of hope for hatchery smelt in the Delta. Since the first batch was let loose, survey crews have spotted more than a dozen swimming in the lower Sacramento River. "This means they weren't just a buffet for predators and that they're moving in the Delta," Hung says. "They're out there and hopefully doing well."

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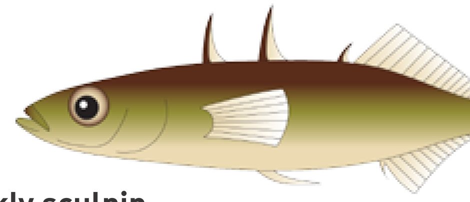
Loading smelt for mid-channel release in December 2021. Photo: USFWS

Release into natural habitat. Photo: USFWS

S U R V I V A L

Natives Who Can Rough It



NATE SELTENRICH, REPORTER

Name a native fish. One that spends lots of time in the Delta. One that's not a salmon, smelt, or sturgeon. One whose population isn't plummeting, and in fact seems to be doing just fine.

By now the list of possibilities has been shortened severely — though not exhausted. A number of native fish still ply Delta waters in stable numbers, but precisely because there are no restoration projects, monitoring programs, or conservation efforts designed to save them — or perhaps because they're not game fish, or particularly large, or traditionally "charismatic" — theirs are not household names.

To the extent that they are recognized by the general public at all, some are even referred to, somewhat derisively, as "rough" fish: essentially, not a desirable catch. But they are winners in their own way, living reminders of a pre-development Delta, still playing an active role in this highly modified ecosystem.

Who are they, and more importantly, what's their secret?

Tule perch

These small yet deep-bodied, often yellowish, barred fish are native to Clear Lake, the Russian River, the San Francisco Estuary, and the low-elevation rivers and streams of the Sacramento-San Joaquin watershed. Tule perch survival in the Delta seems to stem from a few key factors. They give birth to young that are like miniature adults, able to swim away immediately and to feed freely on the same food as their parents. They have a robust physiology as estuary dwellers that allows them to live in a range of salinities. Perhaps most critically, they eat invertebrates that are not favored by other fishes, particularly on the bottom and among the tule reeds, including some non-native amphipods.

"The fish don't care, as long as it's nutritious," says Peter Moyle, distinguished professor emeritus at the UC Davis Center for Watershed Sciences. "It's an abundant food source that not many other fish are exploiting."

Dylan Stompe, a fisheries researcher and PhD student at Davis, notes that since tule perch can tolerate totally fresh as well as mixed-salinity water, the Delta population benefits from a stable source upstream in tributary river systems. "More fish are constantly getting fed into the system," Stompe says. "I think that's another thing that's helped them."

Top to bottom: Tule perch, prickly sculpin, threespine stickleback, and Sacramento sucker. Photos: James Ervin, South Bay Fish Survey

Prickly sculpin

In addition to a name that tumbles off the tongue, prickly sculpin are fortunate to possess a devil-may-care attitude about housing. They're happy as a clam in riprap, which lines much of the lower Delta, finding it a perfect place to live and spawn. They've also been seen living among old car bodies and other large boulders and stones.

"There's a variety of invertebrates that live in that environment, and they're less susceptible to predation when they're in deep cover like that," says Moyle, who somewhat famously once wrote that prickly sculpin will even use beer cans as nesting habitat.

Prickly sculpin can deal with a range of temperatures and salinities, including in rivers above the Delta. In fact, these adaptable fish are found up and down the Pacific Coast from Alaska to Southern California, and classified as a species of least concern. "They're all over the place," Stompe says.

U.S. Bureau of Reclamation biologist Brian Mahardja notes that prickly sculpin population trends in the Delta aren't fully understood due to a lack of targeted monitoring. "But because their larvae are pelagic, and we do a lot of pelagic [open water] sampling," he says, "we at least know that their larval numbers are still relatively high despite all the changes that have happened to the Delta."

Threespine stickleback

The tiny threespine stickleback, usually measuring about 1 to 1.5 inches in length, is commonly found in the Suisun Marsh. There it loves weedy tidal ponds, such as those produced by duck clubs, for both feeding and rearing.

The fish plays an interesting part in a novel foodweb in the marsh, which is populated by both native and non-native species, Moyle says. Sticklebacks happily feed on non-native plankton and are in turn an important food of non-native striped bass, which also eat non-native gobies. "These fish behave almost like they've been living together forever, even though this relationship is more recent," Moyle says.

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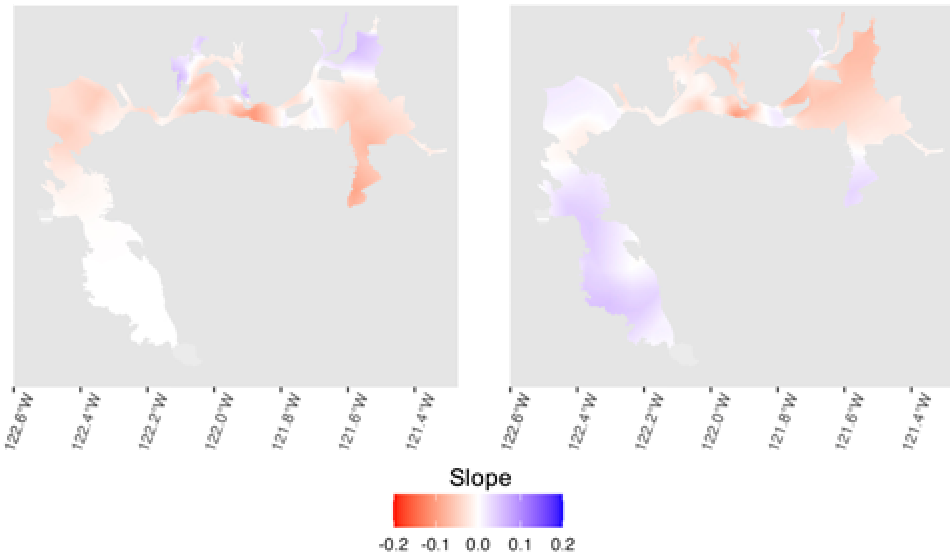
SACRAMENTO SPLITTAIL **THREESPINE STICKLEBACK**



Detection probability of Sacramento splittail and threespine stickleback in the San Francisco Estuary based on eight surveys between 1980 and 2017 (and expressed as spatial slopes). Red indicates regions of decline, and blue regions of increase, in detection probability. Source: Dylan Stompe

Beyond Suisun, stickleback can be found in decent numbers throughout the Delta and San Francisco Bay, Mahardja notes. In fact, the fish are so adaptable that they are of high interest to researchers studying evolution. "I see this species as being less dependent on the estuary and perhaps more resilient to climate change as a result," he says.

Sacramento sucker

Known for its fleshy or "swollen" lips, the slender Sacramento sucker, which can grow to almost two feet in length, is a long-lived benthic omnivore that hangs along the stream or channel bottom, where it feeds on algae, invertebrates, and detritus — "whatever is down there," Stompe says.

Its success is further aided by productivity. In spring, suckers migrate upstream from the Delta to spawn — often in streams that are low or dry in summer, Moyle notes — and females can lay tens of thousands of eggs per spawning period.

Sacramento sucker populations in the Delta and Suisun Bay are also supported by a healthy base higher in the Sacramento River, which, as with tule perch, is perennially feeding fish back into the system.

And similar to stickleback, Mahardja suggests, Sacramento suckers' lower reliance on the estuary itself may help it better withstand climate change and further modifications to the Delta ecosystem.

Sacramento splittail

Of all the fish on this list, the Sacramento splittail, a large minnow, is most at risk. Though currently listed as a species of least concern by the International Union for the Conservation of Nature, it was previously classified as endangered. Similarly, Sacramento splittail were considered threatened by the U.S. Fish and Wildlife Service until 2003; in 2010 the agency ruled that the fish did not warrant protection under the Endangered Species Act. It is currently listed as a species of special concern by the California Department of Fish and Wildlife.

Sacramento splittail. Photo: Teejay O'Rear.

Sacramento splittail's vulnerability lies in the fact that to reproduce it depends on the floodplain, a Delta habitat that has been heavily modified and largely lost. "When they're ready to spawn they swim upstream and spawn on floodplains," especially in the Yolo Bypass and the Consumnes River floodplain, Moyle notes. "Juveniles rear for a short period of time there, then they bail out when flood recedes, then head downstream to Suisun Marsh to grow up and repeat that lifecycle."

The challenge for splittail, Stompe adds, is that since most historical floodplains in the Delta are gone, they're reliant on big outflow events to create suitable reproductive habitat. "They need to be able to weather the bad years in order to have a spawning stock and produce a bunch more fish." Climate change is likely to further challenge the fish through longer droughts and less frequent, more severe flood events.

The Big Picture

No working Delta scientists specialize in studying these fish on their own, since the research money goes toward other species — imperiled fish, sport fish, problematic non-natives. What we know about their populations is gleaned from surveys targeting other fish, or, as in the case of the monthly Suisun Marsh Fish Study, now in its 42nd year, the entire community.

Though these five species don't necessarily live together, looking at them as their own little group reveals common keys to survival. None are pelagic, or open-water fish, like Delta smelt; instead they spend their lives along the bottom or the shore. "There's no decent water cool-water pelagic habitat left in the Delta," notes Teejay O'Rear, a field supervisor in Moyle's lab at Davis who leads sampling and data collection for the Suisun Marsh survey.

Another commonality is that they can tolerate different salinities and temperatures, allowing them to inhabit not only the estuary but also rivers and reservoirs, and rivers above the reservoirs. "Fish can tumble out of there and repopulate when conditions are right," O'Rear says.

And finally, O'Rear adds, none are "domesticated" (raised in hatcheries) like many local salmon: "They actually know how to find food and how to evade predators and things like that."

Granted, these fish likely aren't as abundant in the Delta and upstream habitats as they once were. But they're not in trouble as far as we can tell, either. Against all odds — despite the alterations to their habitat and a lack of focused efforts to protect them — they're still hanging in there, in relatively good numbers. "They're to be paid attention," Moyle says. "They're survivors."

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Twelve Years of Trawls Suggest Restoration Good for Fish

JOE EATON, REPORTER

Twelve years ago, scientists at UC Davis began a survey of the southern end of San Francisco Bay — the Lower South Bay — to see how fish responded to the South Bay Salt Ponds Restoration Project. They discovered an unexpectedly diverse and robust aquatic community and a previously unknown spawning ground for the longfin smelt (*Spirinchus thaleichthys*), listed as endangered in California and a candidate for federal protection because of its declining numbers.

The team, led first by Jim Hobbs and now by Levi Lewis, has compiled an invaluable long-term dataset and enhanced our understanding of the surprising ecosystems of the bottom of the Bay. In addition to journal publications, their findings have been shared in blog posts by amateur naturalist Jim Ervin, who rides with the sampling crews and documents which fish the trawl brings up: "Every single month is a memorable experience," he reflects (see p.10).

The team is based in the Otolith Geochemistry & Fish Ecology ("OG Fish," informally) Laboratory in UC Davis' Department of Wildlife, Fish, and Conservation Biology. Hobbs, who originally ran the project, studied with fish scientist Peter Moyle at Davis and returned there as a research scientist in 2009 after postdoctoral work at UC Berkeley. He met Lewis ("a close colleague for 20 years; super-smart") at the UC Davis Bodega Marine Laboratory.

Lewis grew up near the ocean in San Diego and spent a lot of time fishing. "I wanted to go into fisheries science — something related to conservation," he recalls. After undergraduate work at Davis, he got involved with coral reef ecology, a specialization with limited opportunity for fieldwork in California. Hobbs recruited him for the OG Fish Lab, where he became principal investigator for the South Bay surveys when Hobbs moved to the California Department of Fish and Wildlife (CDFW) in 2019. Hobbs continues to collaborate with the project.

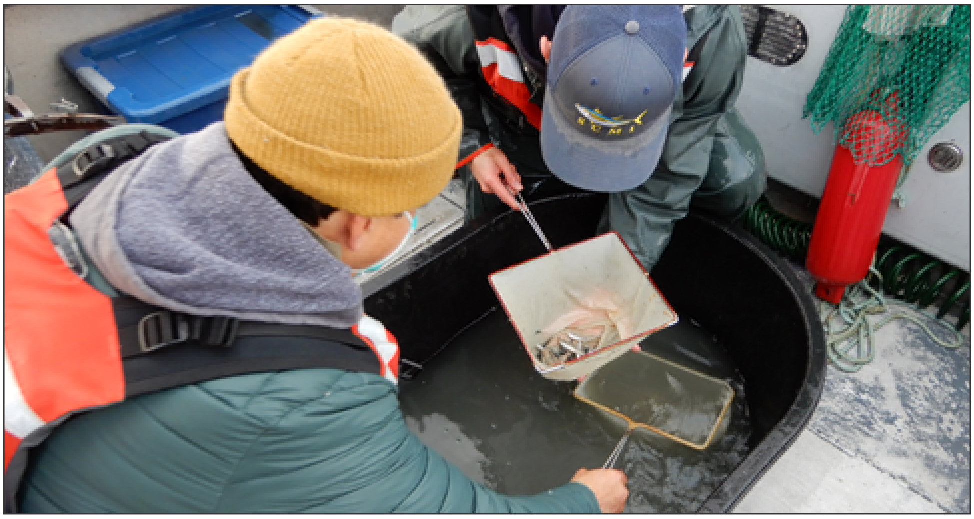
The southern end of San Francisco Bay has taken a lot of abuse in the last couple of centuries. Long before the conversion of tidal wetlands into salt-production ponds, the Lower South Bay became a repository for raw sewage, a major culprit in the local demise of oyster farming at the end of the 19th century. Later, waste from the Santa Clara Valley's fruit canneries overwhelmed tidal sloughs, causing massive fish kills.

As the city of San Jose grew, its sewage discharge became the largest stream flowing into the South Bay. By the 1970s, the neighboring city of Milpitas had become known as "the armpit of the Bay." Conditions changed with the passage of the federal Clean Water Act in 1972 and the development of improved wastewater treatment technology. When the restoration of 15,000 acres of former salt-production ponds to a more natural state began in 2006, marking the largest wetland-restoration project ever undertaken on the West Coast, no one considered the South Bay a particularly healthy habitat for fish.

Trawling for Insight

The fish survey began in 2010 in three of the restored salt ponds, later expanding to 20 stations for broader coverage of the Alviso Marsh Complex. Crews use an otter trawl, whose

Launching LONSME (the six-character "alpha" code for longfin smelt), a 23-foot workskiff specially designed for shallow water sampling such as the South Bay fish survey requires. Photo: James Ervin



Crew sieves and sorts fish that came up in the trawl net for ID before returning to the Bay. Photo: James Ervin

name may be an ironic tribute to the fish-eating mammal, to catch fish and the larger marine invertebrates. At each station, they measure key environmental parameters: dissolved oxygen and the temperature, salinity, and clarity of the water.

The otter trawl is well suited for catching juvenile and small adult fish; larger, more mobile fish like striped bass and leopard sharks often evade it. Even with that limitation, and without sampling habitats other than navigable tidal sloughs and ponds, the 2,400 trawls through 2021 yielded 66 species of fish and 30 of invertebrates. The same set of species used the restored ponds and the adjacent sloughs. Sixty-eight percent of the fish and 58 percent of the invertebrates were native species. When compared with four years of data from comparable trawls in San Pablo Bay, the Lower South Bay had ten times the abundance of fish and twice the species diversity.

What accounts for those differences? "The upper and lower estuaries are very different types of estuary," Lewis observes. "The upper estuary is a classic estuary with a salt wedge and major freshwater flows. The Lower South Bay is a Mediterranean-type lagoon with seasonal flows from winter rains and relatively dry summers." In that respect it's more like estuaries to the south, from Morro Bay to San Diego. Hobbs says that high-salinity conditions in the South Bay bring in more marine species, increasing the species count. Both also point to the influx of nutrients from the South Bay's wastewater treatment plants as a stimulus to food production, which is lacking in the Delta and northern Estuary.

As the researchers looked for patterns in how fish responded to dissolved oxygen (DO) and other environmental parameters, it became clear that there was no such thing as a typical fish. Almost all fish get the oxygen they need from the water they swim in; conditions of hypoxia, with extremely low oxygen, can be lethal. Above those extremes, responses can be all over the place.

In the South Bay, different species responded positively, negatively, or not at all to DO levels. For most species, abundance showed stronger associations with seasonal changes in temperature and salinity, weaker with DO and turbidity. Longfin smelt and American shad numbers correlated with high DO and cooler temperatures. Overall, catches were higher during the summer in warmer, fresher waters with low DO, a trend driven by native northern anchovy and non-native yellowfin goby; species richness was lower in those conditions. California halibut catches correlated with higher DO.

Longfin Nursery

"Our most significant finding is the fact that longfin smelt were reproducing down there," says Hobbs. The species was caught in surveys by the South Bay Discharge Authority in the 1980s, but spawning wasn't detected. (Jim Ervin unearthed the data from those surveys in an office basement.) The Davis team found large aggregations of smelt in reproductive condition from 2011 on. In 2017, one of the wettest years on record, larval longfins confirmed local spawning and were observed again after another wet year in 2019.

It's unclear how the larvae fare after hatching. According to recent studies, South Bay larvae are feeding better than their North Bay counterparts, but that doesn't translate into a higher growth rate. In the language of population biology, is the Lower South Bay a source or a sink for longfin smelt? "It's too early to tell," says Hobbs. "I'm probably more concerned it could be a sink." The South Bay can warm up fast, and longfins are sensitive to warmer temperatures.

Dr. Levi Lewis, who runs the UC Davis OG Fish Lab, with striped bass. Photo: James Ervin

Longfin smelt. Photo: James Ervin

Unlike the Delta smelt, the longfin isn't endemic to the San Francisco Estuary. Its range extends north to the Gulf of Alaska, with landlocked freshwater populations in Washington State. "We know very little about those other populations," Hobbs notes. "We've been trying to connect with other researchers." Longfins move among freshwater, brackish, and saltwater habitats, some dispersing into the ocean. There are indications of gene flow between Estuary longfins and their northern kin. Hobbs says the status of the northern populations could be a big issue if the US Fish and Wildlife Service lists the longfin under the Endangered Species Act; a status assessment by USFWS is currently out for public comment.

Most of the team's catches are returned to the water, but not some of the longfins. For the last three winters, adults have been collected as brood stock for UC Davis' Fish Culture Conservation and Culture Laboratory in Tracy, where captive rearing is being attempted as a hedge against extirpation. Others are harvested for analysis of their otoliths (the ear bones whose chemical signatures help trace a fish's movements), livers, and stomach contents.

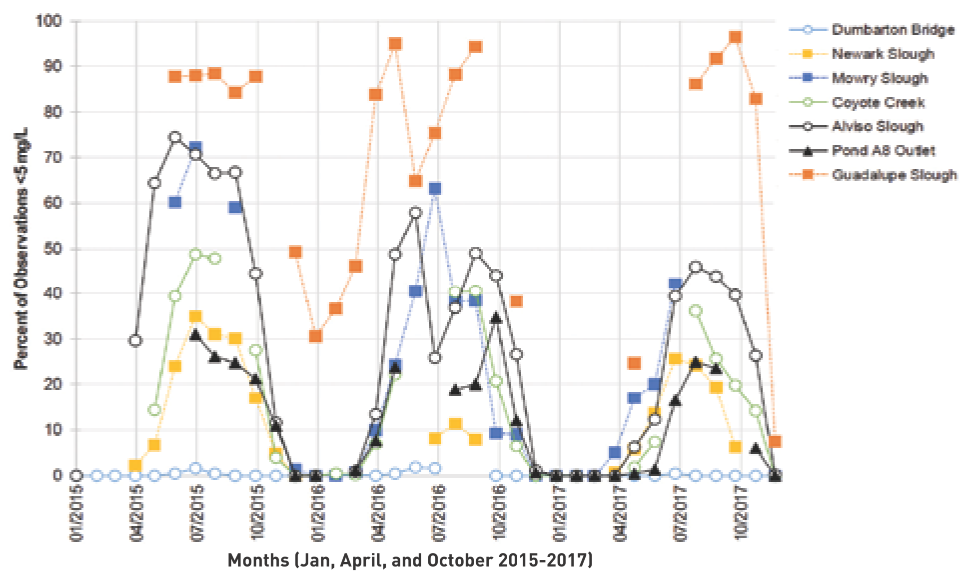
Changing Environment

Although native fish species predominate, the Lower South Bay has its share of non-natives, including striped bass and several Asian goby species. The inland silversides, a relative of the native grunion and topsmelt, may be the most problematic. Silversides from Oklahoma were introduced to Clear Lake in 1967 to control gnats. They weren't particularly good at that, but their burgeoning population altered the lake's food webs and may have helped drive the endemic Clear Lake splittail to extinction. Silversides had reached the Estuary in 1975. Although they weren't caught in the Lower South Bay until the 1980s, they're present there now in alarming numbers; thousands are being caught in the managed ponds alone.

These innocuous-looking fish are as fecund and voracious as Star Trek's tribbles. Fish biologist Carl Hubbs calculated that a female could produce 15,000 eggs in a single summer, at a rate of 200 to 2,000 per day. They're short-lived, but capable of reproducing in their hatching year. "They'll eat everyone out of house and home," says Hobbs. "They've caused havoc in the Delta, short-circuiting production for native fish by eating zooplankton that's food for baby fish." Their diet includes eggs and larvae of other fish, particularly those that spawn in nearshore shallows like the longfin smelt and the endangered Delta smelt.

The fish community isn't the only thing that's changed in the South Bay. Dams have stoppered the creeks and rivers that freshened the Bay, and the ground has subsided up to 12 feet in some areas due to groundwater depletion. The wastewater treatment plants are now the South Bay's only major source of fresh water, contributing 100 million gallons per day. "Treating and returning wastewater is a pretty good use of that effluent — a beneficial use," Lewis reflects. "It produces an estuarine gradient that otherwise wouldn't exist."

SEASONALITY OF LOW OXYGEN CONDITIONS IN THE SOUTH BAY



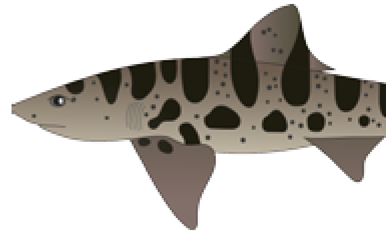
Percent of time each month for which hourly average of dissolved oxygen was less than 5 mg/L. Months with incomplete data not shown. Source: SFEI, MacVean et al 2018

Treated effluent is high in nitrogen that stimulates phytoplankton growth, but it can also cause hypoxia — dangerously low oxygen levels. "Nutrients can be a blessing and a curse," says Hobbs. "The system is right on the knife edge of being overproductive. It's not in a really bad spot yet. We haven't seen hypoxia persisting for many days, unlike in Chesapeake Bay where good chunks of the system are hypoxic for the whole summer."

Low-oxygen waters may provide a temporary refuge from predators for sticklebacks and sculpins. The researchers recommend studies of how native fish respond to DO levels. "A lot of the standard hypoxia criteria are based on fish species that aren't in our estuary," Lewis points out.

One red flag is that occasional fish kills — of species including striped bass, sturgeon, and leopard sharks — have been observed in the managed ponds like A16 and A18 in late summer and fall when wind conditions change and water and fish are trapped. Because of that, Hobbs says he has challenged salt pond restoration objectives that called for equal numbers of tidal and managed ponds: "When you put in water-control structures you're responsible for water quality and all the biota. It takes persistent management." Managed ponds may be good for waterbirds, less so for fish — another dilemma of managing for a whole ecosystem.

Since San Jose attained its present city limits in 1969, its population has roughly doubled: from 495,000 then to more than 1 million today. Santa Clara County followed the same trajectory. "The Lower South Bay's ecosystem is really good, considering [that increase in population]," reflects Lewis. "One big intervention that significantly reduced our per-capita impact on the ecosystem was going to a really high standard of wastewater treatment."



San Jose has, in fact, become a model for other cities like Sacramento, now overhauling its own treatment system. "There are still impacts, but if the ecosystem has improved that much since the 1950s, we're doing something right," he continues. "Fish biomass and diversity in the Lower South Bay are high. There are abundant forage fish populations and striped bass and sturgeon fisheries. And we're restoring more and more tidal wetlands every year. The story of San Francisco Bay is a story of hope."

Monitoring fish, other wildlife, and environmental conditions is essential to continuing to do things right. It's been a challenge to keep the Lower South Bay project going. "It's on a shoestring budget," says Lewis. "The researchers really sacrifice themselves." Hobbs put up his own money to plug a year-long gap between contracts with the South Bay Salt Ponds Restoration Project. The last two years of monitoring were supported by the San Jose-Santa Clara Wastewater Facility, with supplemental funding from the National Oceanic and Atmospheric Administration (NOAA) and CDFW. The San Francisco Estuary Institute has contributed funds for special studies, analysis, and fieldwork.

Hobbs says federal money may be forthcoming if the longfin smelt is listed. But the future of the long-term monitoring program itself remains uncertain. Such programs are vital to successful management of the Estuary, he notes: "We don't get a broader picture of what's happening with the ecosystem without those."

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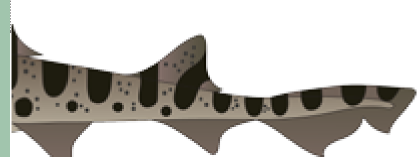

PEOPLEPROFILE

Eyeballing the Fish

Longfin smelt were what hooked Jim Ervin when he first learned about the UCD South Bay Survey through a presentation at the 2012 Bay-Delta Science Conference. "They were catching them right there in our effluent channel!" recalls Ervin, a self-trained naturalist and former compliance manager for the San Jose-Santa Clara Regional Wastewater Facility.

Intrigued, he contacted the researchers, rode with them on their next survey, and has been part of the project ever since, devoting more time to it after retiring from his wastewater facility job in 2018. "I have a free ticket to ride on the boat with fish experts who've been doing this for years," he says. He began his *Fish in the Bay* blog in 2016, posting spreadsheets and photographs of the catch.

Ervin has photographed and posted about such unlikely creatures as guitarfish, pregnant male pipefish, tonguefish (small flatfish the size and shape of the human tongue), red Irish lords, and parasitic copepods infesting the bodies of leopard sharks. His interests have grown beyond fish to include what he calls the "bugs" — marine invertebrates like shrimp, amphipods, snails, and sea slugs — as well as the harbor seals that haul out in the sloughs and the Bay ducks that may be keeping the *Corbula* population down. In January, he posted about catching a slew of non-native mud shrimp, probably flushed out of their burrows upstream by the previous month's heavy rains, and immediately heard from a shrimp specialist in Oregon.

To Lewis, Ervin is a naturalist in the tradition of Charles Darwin and the late E. O. Wilson. "They went around and made observations," Lewis says. "We've devalued people who do that. What Jim Ervin is doing is the absolute foundation of science. He's much more than a photographer. He's the Lorax of the Estuary — he stands for the fish." **JE**

Photo: Lonny Meyer

STRESSORS

West Coast Salmonids All Tired Out?

ALASTAIR BLAND, REPORTER

West Coast salmon and steelhead populations have declined steeply in the past century – a plight that biologists have primarily blamed on habitat loss. Dams, for instance, block adult fish's access to historic spawning grounds, and juvenile survival is impacted by streamside development and water diversions.

Now, it turns out, microplastic pollution may be a much bigger factor than anyone knew just several years ago.

In 2019, scientists with the San Francisco Estuary Institute and the Los Angeles-based nonprofit 5 Gyres published findings indicating that car tire particles are one of the most prevalent forms of microplastic pollution flowing into San Francisco Bay. Then, in 2020, a team of West Coast scientists discovered that a chemical in these particles is extremely toxic to coho salmon at miniscule concentrations, apparently responsible for abrupt die-offs of adult fish observed over many years in Puget Sound streams. The researchers published their results in the journal Science.

"The hard part was that our instruments identified more than 2,000 chemicals in the mixture that could have been causing the mortality," says Ed Kolodziej, a chemist at the University of Washington and a lead investigator on the research.

Through many trials and mass spectrometer runs, they isolated 6PPD-quinone as the primary causal toxicant that was killing coho salmon in urban and suburban streams. The molecule is a transformation product of a manufactured chemical parent, 6PPD, an antioxidant used globally to protect tire rubber from exposure to ambient ozone gas, which can cause rapid rubber breakdown.

6PPD-q is extremely toxic to coho, lethal at minute concentrations. Jen McIntyre, a Washington State University fish biologist and aquatic toxicologist who collaborated with Kolodziej, says concentrations as low as about 65 nanograms per liter of 6PPD-q — think two or three drops of water in an Olympic-size swimming pool — killed coho salmon within hours of exposure in laboratory tanks.

The scientists observed that exposure to the chemical was followed quickly by a breach in the cohos' blood-brain barrier — what they call vascular leaking and which can allow foreign chemicals to enter the brain. That, McIntyre says, is as close as the scientists have gotten to identifying the exact cause of death for the fish. "We don't know if 6PPD-q is entering the breach or if something else is getting in [and killing the salmon]," she explains.

One striking aspect of the findings, McIntyre says, is that roughly one coho in 30 was more or less unphased by 6PPD-q: individuals that the scientists dubbed "super-coho."

Beyond coho, other salmonid species seem more tolerant of exposure to tire leachate and stormwater. In lab testing, McIntyre says, the same exposure rates that quickly killed coho did not cause death in chum and sockeye salmon. In steelhead and Chinook, some of the fish died after exposure. Some of these findings are yet to be published.

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Male coho salmon. Photo: Lane Maguire

Left: Coho that died before spawning. Photo: Jen McIntyre. Center: Shredded tire. Right: Tire particles ingested by mysid shrimp (fish prey item) following lab exposure to particles of 20 um in size. Researchers observed effects on growth and behavior within 7 days (and within 4 for newly hatched fish). Photo: John Dickens.

But fish that survive exposure to 6PPD-q, McIntyre points out, don't necessarily swim away unharmed. "There could be sublethal effects that aren't as obvious as sudden death," she says.

The toxicity of the tire preservative in Pacific Northwest coho raises the question of whether fish species elsewhere may be similarly affected, and research is underway to find out. Scientists are tracking its presence and effects in the Great Lakes as well as waterways in Saskatchewan.

As for coho salmon, it's a likely bet the fish are affected by 6PPD-q throughout their West Coast range, especially in the urbanized watersheds of the California coast. Here, coho salmon once spawned in most rivers and streams. The fish were abundant, with hundreds of thousands swimming inland each year to lay and fertilize their eggs. As late as the 1970s, coho salmon remained an important component of California's commercial and recreational salmon landings. However, their numbers have since plunged, and the fish are endangered today — and extinct in many watersheds. Habitat loss, drought, and agricultural pollution have reduced their reproductive success. So has the diversion of water from streams for wine grapes and marijuana.

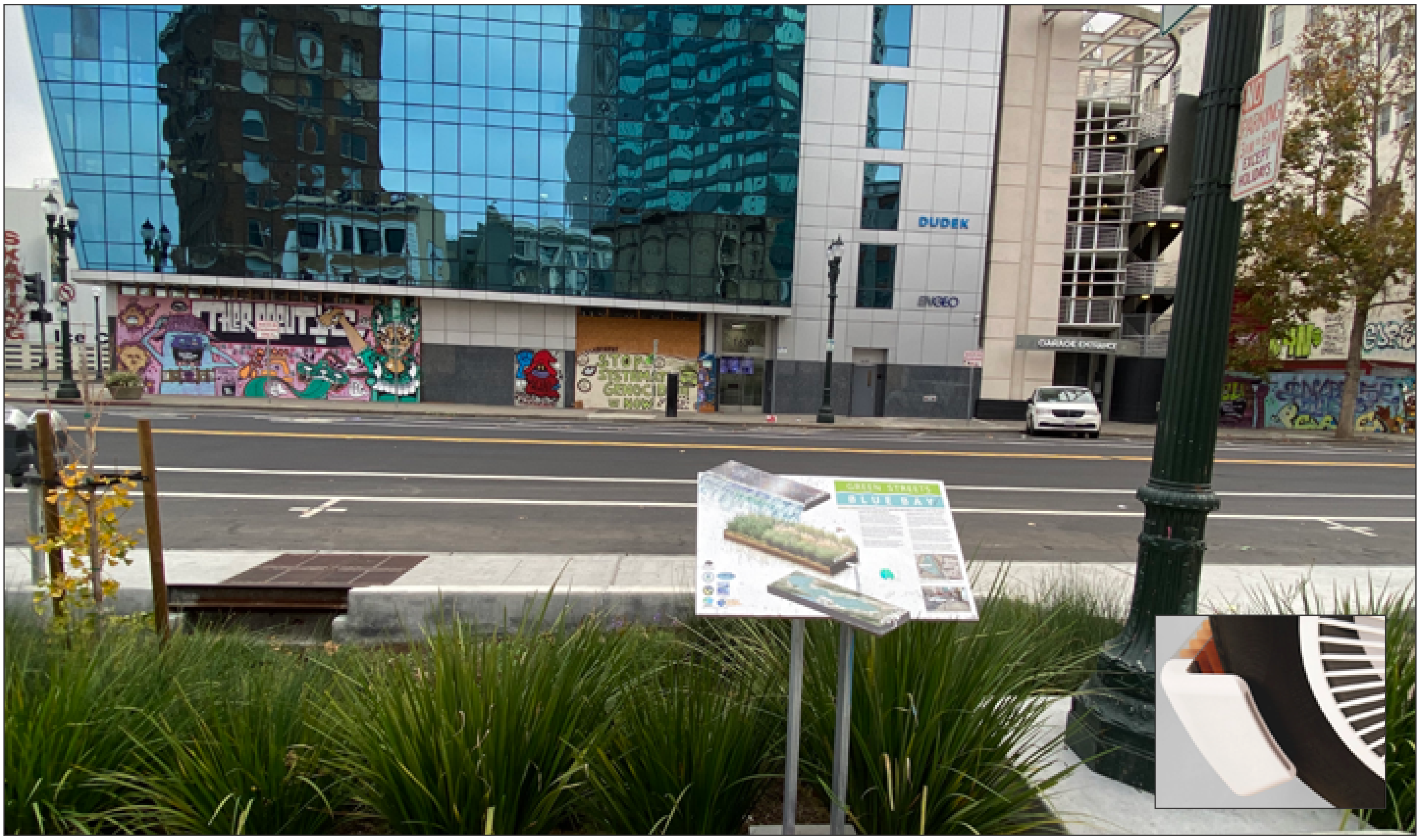
Now, it's safe to reason that increasing runoff of toxic tire wear particles is at least partially responsible for the coho's decline. Eroded tire particles are estimated to be the world's most common form of microplastic pollution, with every American responsible, on average, for 7-12 pounds of the material every year. In the Bay Area's bustling economy, where roadways host more traffic now than probably ever before, these figures translate into as much as 80 million pounds of vehicle tire waste annually released into the environment.

Sieve used to find microplastics in runoff. Photo: SFEI

But until recently, tire particles were water under the bridge, essentially undetectable. "We've known for a long time that car tires wear down, but microplastics research studies were always looking at relatively large pieces of plastic," says Kelly Moran, a senior scientist with SFEI who has led recent microplastic studies.

Tire wear particles are typically so small that they slip past conventional sampling sieves, and SFEI's 2019 report outlined the first surveys in which scientists got a good look at this particular form of pollution in San Francisco Bay. To sample for tire wear particles, SFEI downsized from larger to smaller sieve sizes and, Moran says, sampled below the water surface. Each was a novel approach compared to past sampling programs, which have focused on surface water, since microfibers — another major form of microplastic — tend to float.

Their gritty findings were alarming. They found that tiny black particles, suspected to be rubber, constituted 48 percent of all microparticles flowing into the Bay.



San Pablo Avenue's green verges in Oakland, which filter street runoff. Photo: SFEP. Inset: Tire guard pilot to catch particles. Photo: The Tyre Collective.

One reason that tire particles are so toxic is their miniscule size, which creates proportionally more surface area relative to their mass. "[S]maller particles typically have greater total surface area per unit mass," SFEI scientists explained in a 2021 report. This allows chemicals in the tire particles to more rapidly enter the surrounding water.

But the toxic preservative is not the only problem with tire wear particles, says Susanne Brander, an Oregon State University toxicologist and co-chair of a recent California Ocean Science Trust and Ocean Protection Council science advisory team on microplastics in marine ecosystems. "The tire particles themselves can be ingested and take up space in the gut and block nutrient uptake," she says, adding that this is a problem associated with other microplastics.

And with ingestion of plastic, size matters. Big is bad because the particles can choke small creatures, but the smaller pieces, approximately 80 microns and smaller, Brander says, may offer their own insidious threat: movement from the gut into other tissues. This is called translocation, and it's a growing problem as vast flotillas of plastic corrode into smaller and smaller pieces. This shrinkage process essentially never ends.

The flow of tire wear particles and other microplastics into the environment has so thoroughly polluted every ecosystem on the planet that future generations will never mitigate the mess they inherit. On the brighter side of the crisis, the overwhelming evidence that 6PPD-q causes almost instant death in coho salmon is driving regulatory action. The California Ocean Protection Council is now studying a path toward controlling microplastic pollution, with an eye specifically on tire wear particles. So is the California Department of Toxic Substances Control, which has started the process of officially listing motor vehicle tires as an environmental concern. Anne-Cooper Doherty, an environmental scientist with the department, says that in 2023 tire manufacturers must begin searching for a replacement chemical for tire production.

While that's a good start, the process could take years and there's no guarantee that the industry will come up with a safe and effective substitute. "They could come back and say there is no alternative," Doherty says.

But the road would not end there. Novel filtering devices, already available and showing effectiveness in pilot studies, can be fitted behind the wheels of vehicles, where they capture most of a vehicle's rubber emissions. Planting extensive rain gardens along roadways at key locations could also slow the migration of tire particles and leachate from roadways toward waterways. Moran suggests even simpler solutions: people might replace driving cars with taking transit, walking, and riding bicycles — and, for their cars, buy tires rated for longer life and more road miles.

Even without specifically sampling for 6PPD-q in waterways everywhere, Kolodziej says it's "reasonable to assume it's everywhere in the world that cars are." He says research is now underway to understand the lifespan of this chemical and, once it's loose in the environment, "if there might be some way to scrub it out."

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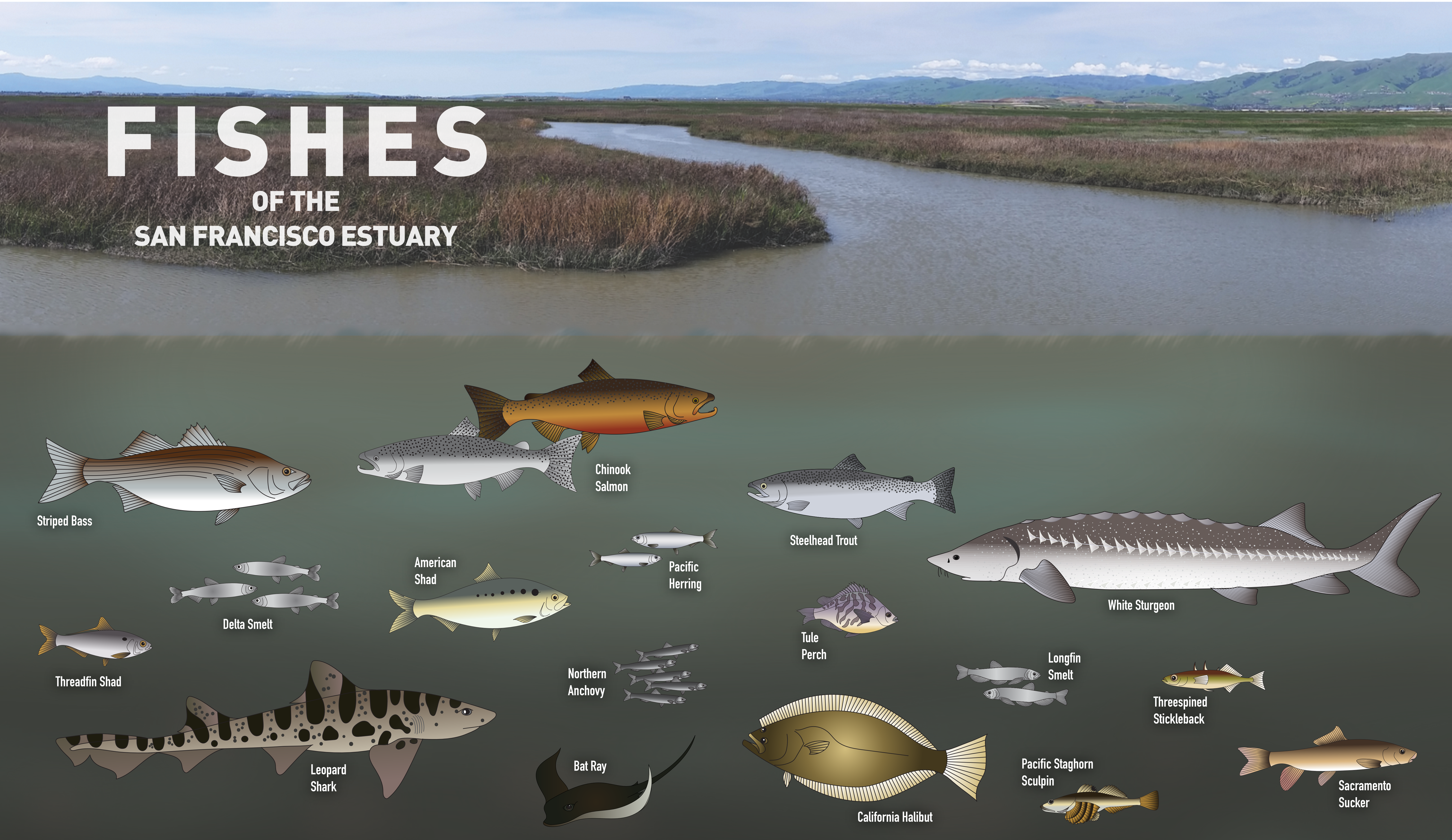

A selection of diverse fish species representative of those present in the San Francisco Estuary. Illustrations by Adi Khen; background photo by Levi Lewis.

Adi Khen

COYOTE CREEK

Big Boulders, Big Benefits

KATHLEEN WONG, REPORTER

As a source of flowing water, upper Coyote Creek is unreliable at best. Though storms swell its banks in winter, Mediterranean-climate summers shrink this South Bay stream to a series of isolated pools by August.

"By October right before the rains come, we're down to these really small pools that have all the fish in them," says retired Environmental Protection Agency ecologist Rob Leidy.

Leidy and UC Berkeley fish ecologist Stephanie Carlson began monitoring the annual dry-down of upper Coyote Creek in 2014, with the help of Hana Moidu and other graduate students. The creek itself originates in Henry W. Coe State Park and flows to the Bay through Coyote and Anderson lakes south of San Jose.

The scientists have found that while the intermittent reach of creek above Coyote Lake appears to be a death trap for aquatic organisms, it is actually dominated by native fishes and other wildlife. This makes Coyote Creek a rarity among California's highly invaded, diverted, and degraded waterways. In dry times, the pools are a West Coast version of the Serengeti's famous watering holes: they teem with wildlife ranging from lizards and snakes to mountain lions and deer ("The intermittent riches of Coyote Creek," Estuary 2017).

Across six years of surveys, the scientists have also noticed another peculiar detail: the pools that persist are always in the same locations. Given the importance of the pools for wildlife, the researchers wondered why some endure while others tend to evaporate. The most reliable, they found, had several features in common. Many were adjacent to massive, sometimes house-size boulders. Landslides had tumbled the boulders into the river from the steep banks.

"The thought is that the high-water flows of winter will scour deep along the boulder and form deep pockets for water," says Moidu. "Often at the end of the summer season, this is the only surface water that remains." The boulders also offer shade, slowing evaporation.

Scientist Mike Bogan sampling a deep pool. Photo: Rob Leidy

The most persistent pools also possess a secret source of water: an underground spring. The five-kilometer study reach begins just downstream of Gilroy Hot Springs, which flows even through the driest summers. Yet this hidden water supply only became clear after the extraordinary rains of 2017. "It was only in that really wet year that we saw surface connections to several springs along our study reach," Carlson says. "It made us realize that perhaps in drier years, there was a subsurface spring connection that might have been contributing to the persistence of those pools."

The springs arise from the fact that Coyote Creek lies in earthquake country. A fault runs along the creek's length. Cracks in the bedrock underlying the creek bed allow groundwater to fill the pools.

"These pools are disconnected from the annual rainfall because the water that comes into many of the pools is from deep aquifers," Leidy says. "This decouples them in the short term from the effects of drought."

Conditions within pools depend heavily on their size. The largest, deepest pools are cooler and have more dissolved oxygen, enabling them to host larger adult fishes, as well as species such as the endangered red-legged frog. By contrast, temperatures in shallower pools can go from the 50s at night to the 80s on hot afternoons, pushing animals to their thermal limits. The most common vertebrates in these puddles tend to be small organisms such as juvenile southern coastal California roach.

The team has even found one native fish that doesn't require open water to survive. The Pacific brook lamprey can wriggle its wormlike body into the few centimeters of water around the cobbles and gravel lining an otherwise dry pool. Within this hyporheic zone, the lamprey can lay low for weeks until rain returns.

"It seems many native species have adaptations that allow them to tolerate these very harsh conditions," Carlson says. The more natural flows in intermittent streams, the

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WATERSHEDS

Scaling Steelhead Monitoring

JACOBA CHARLES, REPORTER

Snorkeling survey for steelhead on the Stanislaus River, a San Joaquin River tributary. Photo: FISHBIO

For more than two decades, steelhead — listed as federally threatened in 1997 — have been monitored throughout the state. However, until recently that monitoring has been a haphazard affair. Each local jurisdiction has established a different system, using different methods with different degrees of intensity, according to a 2018 study examining monitoring within the Central Valley and its environs. In some areas, primarily the Sacramento River watershed, which drains the vast northern part of the valley, data has been collected more comprehensively. In other areas, such as the San Joaquin River system to the south, more gaps remain. And in general, monitoring tended to focus solely on migrating numbers and not more detailed life history demographics.

"We need to improve our understanding of the population status throughout the Central Valley — not just in terms of abundance but also demographics such as age, sex, and size," says Michael Beakes, senior fish biologist with the U.S. Bureau of Reclamation Bay-Delta Office Science Division.

A look at watersheds at two different ends of the Estuary reveals two different monitoring stories: one from the nearly 330-mile-long San Joaquin river, which has its headwaters in the snow-capped Sierra Nevada mountains; and one from three small watersheds in the arid and urbanized South Bay hills of Santa Clara, which center on 66-mile-long Coyote Creek.

From Mountains to Valley

The word that keeps coming up when discussing steelhead monitoring in the San Joaquin watershed is: complicated.

The landscape itself is complex. Draining nearly 20,000 square miles and yielding an average annual surface runoff of about 1.6 million acre-feet of water a year, the San Joaquin is a massive system with many tributaries, which traverses many ecosystems and runs through many jurisdictions. It has over 80 dams with a total storage capacity of more than 7.7 million acre-feet on the San Joaquin, Merced, Tuolumne, and Stanislaus rivers. The basin's many rivers and streams not only sustain countless species and landscapes — both wild and developed — but also provide humans with water supply, recreation, and hydroelectric power.

The fish, too, are complicated. Different individuals in *Oncorhynchus mykiss* may remain in freshwater their entire lives, and be known as rainbow trout,

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Map: Amber Manfree

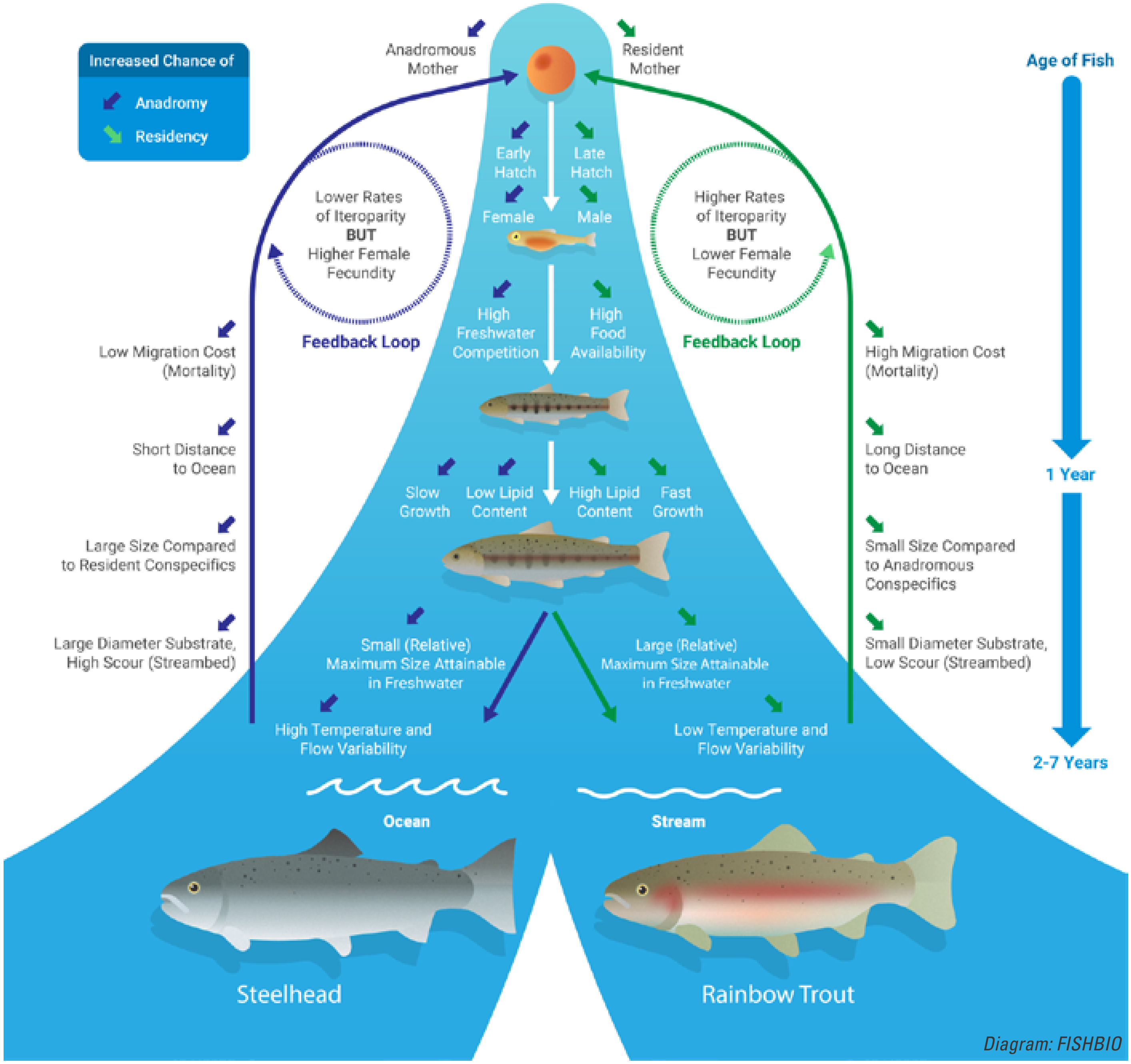

Diagram: FISHBIO

while others from the same population — even from the same parents — will become anadromous and outmigrate to spend some years of their life at sea. Neither are the migratory individuals on a set schedule as far as when they will leave for and return from the saltwater portion of their lives, as other anadromous salmonids are. That flexibility likely gives them an adaptive advantage. When oceanic conditions are unfavorable, they may return inland; when life in the river is better or worse than usual, they can choose to stay or go. Some few individuals will even make the trip more than once, spawning in freshwater each time they return.

"There is still a lot that we don't know, genetically and environmentally, about what dictates which of those pathways the fish ends up on," Beakes says. "So because of that we

Tiny tot steelhead. Photo: FISHBIO

also don't know what management actions we should take to boost the anadromous portion of the population. If we want to move towards steelhead recovery, we need to get a better handle on how much life-history variation there is and what factors drive fish to take on one life-history type over another."

Since 2020, the Bureau of Reclamation has been working to ensure that its monitoring program will be able to answer some of these questions. In addition, a new multi-agency steelhead monitoring plan currently being developed for the San Joaquin basin aims to make all this complexity more man-

Wier where fish passage monitoring occurs on the Stanislaus River near Riverbank. Photo: FISHBIO

ageable. Last January, a three-day online workshop on steelhead monitoring in the San Joaquin basin was hosted by the Delta Stewardship Council, with the goal of facilitating this process. It was attended by roughly 200 people.

"This is a specific goal that we are pursuing — participation by the other agencies is optional, but obviously, they are supportive of this conservation effort," says Beakes, the plan's lead author. "'Plan' is a bit of a misnomer, since there is no regulatory mechanism. It really is more intended to be a well-organized informational packet: here is what we know, and here are the best tools and approaches that we can use to evaluate this species."

He added that a similar plan, developed by the California Department of Fish and Wildlife, already exists for the Sacramento River system. "We are trying to create a complimentary plan, expand on some of the concepts, and reach out to stakeholders on the Sacramento side as well. It makes sense to leverage our collective knowledge and work together on some of these management issues."

Meanwhile, out on the rivers, the boots-on-the-ground work continues to unfold and expand.

On the Stanislaus alone, researchers are collecting scale and genetic samples to find out which adults are effective at reproducing, how much gene flow occurs between systems, and how old the fish are. They're using this data in combination with an existing PIT (passive integrated responder) tag program, in which microchips are implanted in fish and later scanned as the fish swim over an antenna installed in the river channel. In-stream spawning surveys, where researchers look for active spawning and also collect carcasses, are conducted by boat. Researchers also capture outmigrating fish using rotary screw traps. Steelhead that reach the Delta are monitored by the U.S. Fish and Wildlife Service.

In the future, more changes will be made to the monitoring program, Beakes adds. On the Stanislaus, they hope to install a new rotary screw trap and modify its configuration to target steelhead. And they are in the early stages of a partnership with Oregon State University and the U.S. Geologic Survey to develop a lifecycle model using the steelhead data being collected on the Stanislaus.

"Steelhead have a lot of cultural relevance, so they serve a lot of anthropogenic needs and ecosystem needs," Beakes says. "That complexity is fascinating, but it presents a major challenge from a management standpoint. We're just starting to understand exactly how complicated this species is."

Where the City Fish Dwell

Much farther to the south, in Santa Clara's Guadalupe River, Coyote Creek, and Steven's Creek watersheds, local scientists are also centering steelhead — but in a very different way. Draining just shy of 500 square miles combined, these watersheds have many tributaries that are affected by summer low flows and droughts. Downtown San Jose straddles the lower reaches of the

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Steelhead sampling sites on the Stanislaus (left, with rotary screw trap) and Guadalupe Rivers (right, with net fence) underscore the variety of Northern California conditions in which steelhead persist. Photos: FISHBIO & Valley Water



Pit tagging and sampling in Guadalupe Creek. Fish ladder at the Alamitos Drop Structure on the Guadalupe River, including Vaki RiverWatcher at left (with elevator enabling the raising and lowering of scanner plates and camera for maintenance). Photos courtesy Valley Water.

Guadalupe Watershed, so migrating steelhead — and the humans monitoring them — must navigate detritus and effluent from homeless camps before reaching their destination.

"Some seasons we will detect very few steelhead," says Clayton Leal, senior water resources specialist in the Environmental Mitigation and Monitoring Unit at Valley Water, formerly known as the Santa Clara Valley Water District. "We are very arid and the drought has hit our systems hard."

With small numbers of detection, it is hard to generate outside interest in the program. "We've been told by some research organizations that our county isn't scientifically interesting because we have small populations," Leal says.

Photo: Valley Water

But to Leal and his team, every steelhead is important to the degree that, when the first monitoring effort ended in 2013, they applied to not only continue but also expand the program, collecting a wider range of data from a greater number of creeks.

"These are a federally threatened species, and they are a keystone species in the environment," Leal says. "These fish need good water quality; if they persist then we know we are maintaining a healthy ecosystem."

The water district's early monitoring program — launched in 2004 — focused on habitat conditions and numbers of juvenile steelhead within the mainstem of the Guadalupe River, and in Guadalupe Creek. The new program includes the Stevens Creek and Coyote Creek watersheds. They now not only collect data on juvenile rearing, but have expanded to include adult and juvenile migration, fish condition, and survival. "We want to know about all portions of the fish's life history," Leal says.

They added an automatic fish counter called a Vaki River Watcher to three creek systems. Leal likened the counters, which are mounted within fish ladders, to copy-machine scanners for fish. And as in the Stanislaus system, Valley Water uses PIT tags, as well as conducting other habitat surveys.

"Really the only difference that you'll see in monitoring in these small urban watersheds versus bigger rivers is scale," Leal says. "We use a lot of the same technology."

In this watershed, the fluctuations in returning steelhead can be dramatic, largely based on environmental conditions: abundant in wet years, diminished during droughts. "In 2015 we actually caught zero juvenile steelhead, which was a shock," Leal says. In 2016 they caught two, and in 2017, after record-setting rains, they caught 30.

"With the monitoring, we're also trying to understand what we can do – for example, how water from reservoirs can be released in a more beneficial way for the fish, all while still providing water to the two million people who depend on it," Leal says. One thing the water district has tried is to maintain a "cold pool volume" so that the reservoir will remain deep enough to stay colder, thereby making the released water more beneficial to the steelhead.

In addition to drought, human degradation is also a big factor in fish health and creek quality. In Santa Clara County, the lower reaches of creeks are often urbanized, stripped of riparian vegetation, fished, and occasionally even informally dammed.

"The level of degradation is really extreme," Leal says. "When you look at what these fish have to swim through — I tip my hat to them every time. It's a tough life to be a fish in Santa Clara County, and they make it work. It's pretty impressive."

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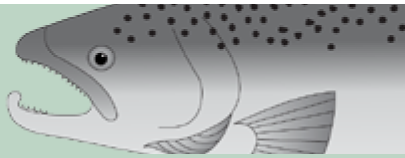


INTERVENTIONS

Will Salmon Simmer Again?

CARIAD HAYES THRONSON, REPORTER

After two critically dry years that coincided with Trump-era rollbacks to environmental protections, some iconic Delta fish are closer than ever to the point of no return. Last fall, for the second year in a row, the fall midwater trawl found zero wild Delta smelt, while a coalition of environmentalists and fishermen is asking a federal court to help prevent a repeat of 2021's near-obliteration of endangered winter-run Chinook salmon. Their lawsuit is just one of the balls to watch this spring as several projects and processes that could radically affect how much water flows through the Delta, and when, percolate.

"There's a lot going on right now, kind of bubbling just below the surface," says the Natural Resource Defense Council attorney Doug Obegi. NRDC is one of the parties to the lawsuit seeking to ensure that State Water Project and Central Valley Project operations protect salmon and other species. Last year, the projects released water from Lake Shasta early in the year, and did not leave enough cold water behind Shasta Dam to maintain cool water temperatures in the Sacramento River Basin during the winter-run spawning season.

"The spawning grounds overheated, just exactly as predicted," says John McManus, president of the Golden State Salmon Association (GSSA), which advocates on behalf of fishermen and others. Salmon require water temperatures below about 54 degrees Fahrenheit for successful spawning, but river temperatures exceeded that level by five degrees or more for several crucial months. Fisheries biologists estimate that only 2.6% of the roughly 31 million eggs laid hatched into fry that survived outward migration as far as Red Bluff; only 0.4% are expected to survive as far as the Delta. "The hot water conditions that took out the winter run undoubtedly also took out much of the natural fall-run spawn that we would be relying on to produce a future crop of fall-run fish," McManus says, referring to the backbone of the state's salmon fishing industry. There is evidence that high temperatures also led to poor survival of migrating spring-run salmon.

The carnage was made possible by new federal Biological Opinions — Endangered Species Act-required rules that govern water project operations — developed in 2019 under then-Interior Secretary and former Westlands Water District lobbyist David Bernhardt. The rules stripped away critical protections for salmon, smelt, and other species and allow for more pumping from the Central Valley Project. Subsequently, and to nobody's surprise, evidence emerged that science had been suppressed and scientists silenced while the new rules were developed.

Low lake levels at Shasta Dam in late October 2021. Photo: DWR

Both the State of California and the coalition of NGOs — including the Pacific Coast Federation of Fishermen's Associations (PCFFA), GSSA, NRDC, the Bay Institute, and Defenders of Wildlife — filed suit to invalidate the 2019 Biological Opinions, and soon after President Biden took office, the new administration flagged them for review. But in the meantime, the Bureau of Reclamation has been operating under the Trump administration rules. In 2021, the Bureau "let too much water go," says McManus. "They did cut back some water deliveries. But some senior water right holders still got quite a bit of water. And that water could have been used to keep salmon alive. But it wasn't."

Last fall, the Bureau of Reclamation announced a reinitiation of consultation on the Biological Opinions, which will result in new, presumably more protective rules by 2024. But what happens in the meantime may determine the fate of the winter-run Chinook and other imperiled species.

The state and federal governments have together proposed an Interim Operations Plan for the two water projects that PCFFA plaintiffs say does little to protect species. "It is very similar to the Trump administration's biological opinions," says Obegi. "They added some provisions regarding Shasta storage and water temperatures that are woefully inadequate to protect winter-run, or fall-run if this year is critically dry."

Declining to comment on the litigation, Russ Callejo, the Bureau's deputy regional director, says, "We're going to continue ... to coordinate with our state, federal, and local partner agencies, on measures that we can take this year, if it is dry ... to explore scientifically based, as well as feasible, options to improve the health of our fishery. Those conversations are ongoing; they're still very early stage." He adds that a healthy fishery is important to the agencies running the water projects, as well as to the wildlife agencies: "A healthier fishery helps us to operate more flexibly."

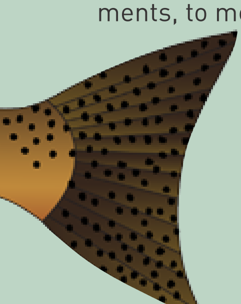
The plaintiffs have filed a motion for preliminary injunction requiring more protective operations in 2022. Although the Biden administration is not defending the 2019 Biological Opinions in court, a number of water districts have intervened in the litigation, arguing that until the new Opinions are developed, the 2019 rules should govern operations.

continued on next page

Beyond the immediate impact on salmon, the case could fundamentally reshape the way water is allocated in California. "Our proposed injunction would require the Central Valley Project and State Water Project to reduce their allocations to what's needed for human health and safety, prohibiting water allocations for agricultural and commercial uses unless they ensure adequate water temperatures for spawning salmon and meet Delta water quality objectives," says Obegi. A hearing was scheduled for February 11.

Adult fall-run Chinook salmon near hatchery on American River. Photo: Andrew Innerarity, DWR.

Obegi and others note that the federal rules would be much less central to species protection efforts if the State Water Resources Control Board were to complete and implement a long-delayed update to the Water Quality Control Plan for the Bay and Delta (Bay-Delta Plan) that would increase flows through the Delta. In 2018, as part of the update, the Board adopted instream flow objectives for the lower San Joaquin River and its tributaries (known as Phase One), calling for 30% to 50% of unimpaired flows, and released the framework of a similar plan for the Sacramento River and flows into and through the Delta (Phase Two). Those objectives have since been on hold while the Brown and Newsom administrations attempted to reach "voluntary agreements" with water users that permit lower instream flows in exchange for "non-flow" measures, such as habitat improvements, to meet environmental goals.



In December, the state Secretary of Resources and CalEPA notified water users that they were giving up on the voluntary agreements for tributaries to the San Joaquin and moving ahead with implementation of Phase One, updated flow standards for the Stanislaus, Tuolumne, and Merced rivers. The new standards would be implemented no sooner than the summer of 2023. No such announcement has been made regarding Phase Two, and no new agreements have been proposed since 2020. The delay irks advocates for fish.

"If we had a water quality control plan that actually protected fish and wildlife there wouldn't be a need for Endangered Species Act protections," says Obegi. "ESA protections were triggered because the agencies repeatedly concluded that the water quality standards were not adequate to prevent the operations of the state and federal water projects from driving species towards extinction."

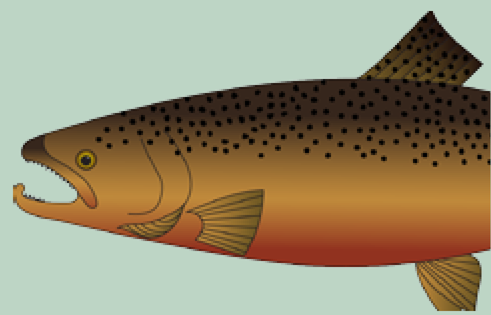
As tragic as it would be to lose one of California's native fish, the stakes are even higher than saving a species from extinction. The outcome of these conflicts will directly affect water quality in the Delta.

"This isn't a fish versus farm situation," says Regina Chichizola of Save California Salmon, a grassroots organization working with tribal communities. "This is the water that millions of people rely on. The salmon are like the canary in the coal mine; if the salmon go extinct, because there's not enough water, what does that mean for all the people that actually rely on that water for their drinking water supply?"

Two new massive water infrastructure projects threaten to put even more pressure on Delta water supplies. In November, the proponents of Sites Reservoir released revised environmental documents for public review and comment. The project, a privately owned — though publicly subsidized — off-stream storage facility near Willows, is strongly opposed by tribal and environmental groups. "The project as proposed would hammer migrating salmon and worsen conditions in the Delta," says Obegi.

Elsewhere in the Delta, the Department of Water Resources (DWR) and the U.S. Army Corps of Engineers are preparing to release environmental documents for the latest manifestation of the long-argued-over Delta tunnel. Now called the Delta Conveyance Project, the facility would include new north Delta diversion intakes with a capacity of 6,000 cubic feet per second. DWR maintains that operating rules for the facility will include restrictions on the amount of Sacramento River flow that can be diverted. However, so far little is known about those rules, and there are still open questions about how the project will be paid for.

All of these court fights, negotiations, and planning efforts are taking place against the backdrop of another looming drought year. Although major storms last fall stirred some hope for a wet winter — and enticed DWR to increase its promised water deliveries from 0% to 15% of contracts — January was one of the driest on record and February doesn't look much better. As climate change brings ever-more-frequent dry years, California needs to plan ahead if it is to have enough water for both people and fish. An updated Bay-Delta Plan is crucial, say Baykeeper's Jon Rosenfield and others.



"An updated water quality control plan, based on the best available science, with standards that are appropriate to protect the public trust, would prepare water contractors for how much water is going to be available," says Rosenfield, adding that the Board would also have to be prepared to enforce those standards, rather than waiving them during dry years as it often does. As for DWR and Reclamation, he says that rather than behaving as though dry years are anomalies, they "should always act as though next year is going to be a critically dry year."

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STURGEON

Long Live the Centenarians

ALETA GEORGE, REPORTER

A 90-year-old Australian lungfish at San Francisco's Academy of Sciences has received a lot of press lately, but there is a wild fish species living in the San Francisco Bay that has the potential to live that long or longer — or so we think.

While one white sturgeon caught in the Columbia River Basin was estimated to be 104 years old, the life expectancy of white sturgeon, *Acipenser transmontanus*, which includes the Central Valley population endemic to the San Francisco Bay, is hard to pin down. "There are old ones out there, but it's really hard to give a number because we just don't have it," says John Kelly, statewide sturgeon coordinator for the California Department of Fish and Wildlife (CDFW).

Sturgeon are often referred to as living fossils. Armored with bony scutes, not scales, they have been swimming in global river systems since before T-Rex. Of the 27 extant sturgeon species in the world, those in the Bay (and other self-sustaining populations in Oregon and Washington) are doing the best. "There are two sturgeon species in the estuary, which are managing to maintain populations despite everything," says UC Davis distinguished professor emeritus Peter Moyle. "Most species of sturgeon around the world are headed for extinction in the short term."

A Matter of Green and White

The two sturgeon species that rely on the San Francisco Bay watershed for their survival are the white sturgeon and the green sturgeon, *Acipenser medirostris*. The latter, listed as threatened under the federal Endangered Species Act, spends most of its life in coastal Pacific Ocean waters from Ensenada, Mexico to the Bering Sea, except for when it spawns in large rivers, like the Sacramento, and feeds in the Bay in summer.

White sturgeon is the larger and longer-lived of the two species. White sturgeon can reach 20 feet in length and weigh more than 1,000 pounds. Except for the occasional wanderer, white sturgeon spend their entire lives in Suisun and San Pablo bays apart from spawning every few years, primarily in the Sacramento River. Biologists estimate that between 30,000 and 56,000 white sturgeon within the legal size limit (40 to 60 inches from the tip of the snout to the fork in the tail) reside in the Bay. Elsewhere on the West Coast, there are also self-sustaining populations in the Fraser, Columbia, Snake, and Kootenai rivers.

Although it is possible for white sturgeon to be centenarians, it's difficult to determine their age, let alone their life expectancy. One of the ways to ascertain a sturgeon's age is to bisect its otolith, a smaller-than-marble-sized bone in their ear that helps them detect sound waves and maintain balance. While scientists can count the growth rings in this bone, the only way to obtain it is from a dead fish. "We don't want to be killing fish just to find out how old they are," CDFW's Kelly says.

Another way to determine age is to remove a one-centimeter seg-

continued on next page

Small white sturgeon caught in a recent otter trawl of the South Bay fish survey (see story p.7), and later returned to the water. Photo: James Ervin

White sturgeon being measured and tagged by CDFW. The tags are the white discs on the rack above the fish. Photo: CDFW

ment of the pectoral fin ray and look for growth rings in that slice. But this works best for fish younger than 30 because as the fish age, the rings grow closer together and become harder to read.

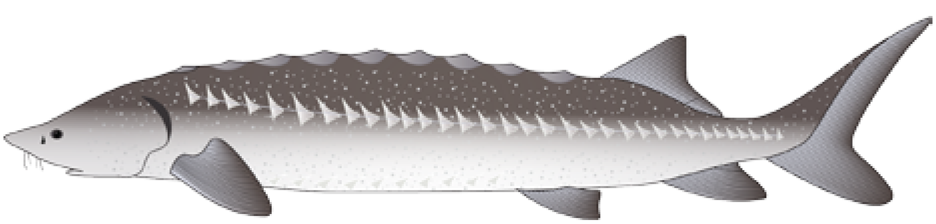
"Sturgeon are always kind of cryptic. They're just tough to study," says Kelly. The information obtained by annual CDFW monitoring that includes three months of catching, measuring, and tagging, is skewed by the size of the nets the scientists use to capture the fish, he notes. "We don't catch a lot of smaller fish or the very, very big fish. There's a huge risk of injuring those big fish, so we really try to focus our efforts on the fish targeted in the fishery," those that are 40 to 60 inches long, and for the most part no more than 20 years old.

Steak of Sole

White sturgeon lived in the Bay for thousands of years before the California Board of Fish Commissioners reported on their status at the end of the 19th century. An 1880 Commission report said that sturgeon, some recorded as reaching 12 feet in length and weighing 600 pounds, were so plentiful that the meat was cheap and appeared on menus as "steak of sole."

Just ten years later, sturgeon became one of the highest-priced fish in markets due to low catches. In 1901, the Fish Commission prohibited all sturgeon fishing to allow the species to recover — but it didn't. In 1917 they closed the fishery. "The State has seen the commercial extinction of the sturgeon," a report read.

The Commission reopened recreational sturgeon fishing in 1954, and for many years, an angler could take a fish a day with no annual limit. Restrictions tightened, and today an angler is allowed one fish a day, but with a limit of three per year. Anglers are required to fill out sturgeon report cards and tag all harvested white sturgeon. Poaching, the illegal take of female white sturgeon for its valuable black caviar, is a challenging problem for wildlife officers.



As for their life expectancy, while they may have the potential to live 100 years, they likely are not. "It's not a biological change, but risk exposure," says Kelly. "It's simply that there are things preventing them from surviving."

Consider an 80-year-old white sturgeon in the Bay today, says Kelly, one that would have been born in 1940. By the time it matured 14 years later, the recreational fishery had reopened with no annual limits, and the era of big-dam building was in full swing, reducing habitat and changing flows. Added to these threats were fertilizers, PCBs, and selenium in the water. "That old fish would've had to go through a lot to still be here."

While our local white sturgeon are doing better than other populations around the world, their numbers are lower than what they once were, and they need our protection. CDFW recommends that help come via reductions in pollution and chemicals in the water, improvements to habitat and stream flows, and more resources to deter poachers and those who buy illegal caviar. Perhaps then we can help our sturgeon live up to their life expectancy potential.

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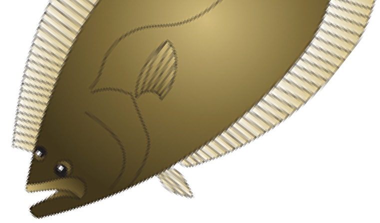

FISHERIES

Murky Herring Future

ALASTAIR BLAND, REPORTER

This winter, herring spawns in San Francisco Bay – visible from land as frenzies of birds and pinnipeds and even water discolored by herring milt – have been few and far between, according to recreational fishers who pursue the fish each year using hand-thrown cast nets. With few other eyes on the resource, it seems reasonable to assume that the downward trend in biomass documented through the 2019-2020 winter has continued.

But nobody knows for sure. For decades, the California Department of Fish and Wildlife has carefully monitored and assessed the Bay's herring runs. The research used a variety of surveys to produce annual biomass tonnage estimates almost every year since the 1970s. But in recent years a new herring Fishery Management Plan, developed by both regulators and fishers, is taking a more nuanced approach.

"We now use a tiered framework that scales management effort to commercial fishery effort, in terms of both participation and catch rate," wrote agency staffers in a response to email questions from Estuary.

At the end of the 2019-20 season, CDFW noted "low effort, low landings, and a below-cutoff biomass estimate," according to a follow up email. This triggered a closure of the SF Bay fishery and progression to a different, less intensive, monitoring protocol which continues to this day, and until different conditions kick in. As a result, data once shared with the public look a little different.

Tiered decision-making provisions in the same plan then allowed San Francisco Bay's commercial gillnetters a yearly quota of 750 tons of herring for the 2021-2022 season (up from zero tons the prior season). The way some see it, the department increased the fishing limit precisely when, in the name of precautionary management, they should have maintained the moratorium and full-on survey efforts.

Pacific herring. Photo: James Ervin

"Right now is the critical time to be managing this fishery and monitoring it," says Geoff Shester, California campaign director for the nonprofit ocean-conservation group Oceana. The organization spent years collaborating with state biologists to set new guidelines for regulating the commercial fishery and establishing a recreational daily take limit, which previously did not exist. Some of that work is reflected in the new fishery management plan.

Whatever the plans, herring seem to be in trouble. For the past eight years, San Francisco Bay herring biomass has been trending toward record-low levels. According to department data, the average annual biomass over more than 40 years is about 47,000 tons, but in the past several years, the biomass has averaged around 10,000 tons. In the most recent winter of the herring biomass survey (the 2019-2020 season), the biomass was just 6,427 tons.

Theories to explain the long-term decline range across the books, with possible causes including overfishing, climate change, reduced Delta outflow, and pollution.

Shester believes the region's herring population could dwindle further if it is too intensively fished. Environmental factors, like ocean and habitat conditions, may also dictate their future. He warns that so-called forage fish – small species like herring, sardines and anchovies – are susceptible to natural ups and downs in their population size and that fishing pressure during abundance lulls can be devastating. The plight of the West Coast sardine fishery, Shester says, illustrates the potential to fish one of these resources into the ground. The estimated biomass of the Pacific sardine has dropped by 98 percent since 2006, and federal fishery managers continue to allow fishing. Shester says it may take decades for sardines to recover, and he warns that a similar future could await San Francisco Bay's herring.

"We need to let the herring stock recover to healthy levels before resuming fishing," Shester says.

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California halibut, another species important for local recreational and commercial fishing, held by UC Davis' Micah Bisson. Photo: Levi Lewis

EXPERIENCE

Gone Fishing

SIERRA GARCIA, REPORTER

As the weekend dawns and California slumbers, the sportfishers descend, like clockwork, on the banks and waves of the San Francisco Bay and Sacramento-San Joaquin Delta.

They carry nets for herring or poles for sturgeon, heavy and light tackle, bloodworms or anchovy or any number of delectable morsels to attract the desired target. They tread industrialized East Bay shorelines and marshy Delta banks, hop aboard sporty six-pack boats for more ambitious trips or humbler craft for a leisurely solo excursion. They catch (and often release) a smorgasbord of species: halibut, kingfish (white croaker), or sturgeon around the Bay, or striped bass, salmon, and black bass in the many tendrils of the Delta.

"Here, you get both worlds, fresh and salt," explains Hamilton Lai, a lifelong fishing enthusiast who has trolled the Bay and Delta for nearly 40 years.

Like many people who fish for pleasure, Lai recalls a time when fish were so abundant in the Bay that he'd catch his daily limit within 15 minutes. Today, "you're lucky to catch your limit at all," he says. Lai, a San Franciscan who grew up in Vietnam, "is a foodie of the practical kind, who likes to joke and cook, and arrives at a barbecue with a sack of oysters, not half a dozen," according to Estuary's editor, a family friend.

Fishers like Lai have been on the quiet frontlines of witnessing transformations to the region's fisheries since the late 20th century. Jim Cox, a retired charter-boat captain with four decades of experience fishing in the Delta, says that, "Nowadays when you do get a fish on, you're accomplishing something extremely more difficult than it was 30 or 40 years ago."

For many popular species, like striped bass, the data bear this out. Cox rattles off fishing factoids for the Bay and Delta the way sports buffs recall the stats about famous players and games. "The saltwater species have done pretty well," Cox adds. He has a deep, frank captain's voice that I can easily imagine carrying across the calm Delta waters. "But in the Delta itself, the fisheries have really declined."

Roger Mammon's preferred method of cooking fish is what he calls "Chinese style," with ginger, green onions, sesame oil, and soy sauce. But with more than 70 years of experience, the fisherman's favorite treatment for most fish he catches now is releasing them back to the ecosystem. Photo: Mike Hall

Changes to fisheries aren't always straightforward paths of decline. Take the story of the perennially popular striped bass. It's one of the most popular sportfish in the Delta, and, like many species, has suffered since the Delta's water began to flow across the state to irrigate orchards half a century ago. A further 50 years back would land us in the era of a commercial fishery for "stripers." But 50 years prior to that — in the 1870s — the species did not exist in California. It was introduced from Alabama in 1879 by men hoping the species would take to the ecosystem and provide sporting opportunities. What so many Delta residents now consider a beloved sportfish could be rightly viewed as an invasive species.

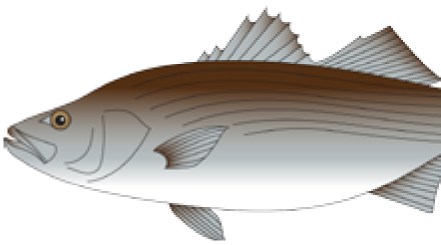
The rise and fall of striped bass is far from the only change to recreational fishing here in the last century and a half. Apps have replaced almanacs for checking the tides. The continuing drain of freshwater from the Delta to croplands, fruit trees, and cities hundreds of miles south is taking a toll on salmon and stripers alike. Legacy and emerging contaminants are accumulating in the flesh of various species in the Estuary, rendering some near-inedible. The specter of overfishing certain species lingers. These changes make it perhaps all the more impressive that sportfishing has remained as a regional pastime over the decades that have rendered everything from transportation to entertainment to communication unrecognizable.

At its core, fishing for pleasure seems almost unchanged, a pocket of life in the slow lane that has resisted the speeding-up of modern times. Cox offered an example of an acquaintance who hopes he doesn't catch anything when he goes fishing: "He just wants to be out there and left alone."

In a 1960 California Department of Fish and Game booklet called *Inshore Fishes of California*, one of the authors describes "one of the most contented persons [he] ever met" as an angler with a similar philosophy on fishing: 'It really doesn't matter if I catch anything. I enjoy the relaxation and peace of mind I get on my fishing trips.'"

Still, the enduring spirit of fishers in the Bay and Delta does not bely the seriousness of the declining populations of many sportfish species. As the few seasoned sportfishers who recall the Bay and Delta of the mid-1900s grey and fade away, the reality they remember will fade as well. There's data, of course, but it sometimes serves as a poor counterweight to lived experience and memory.

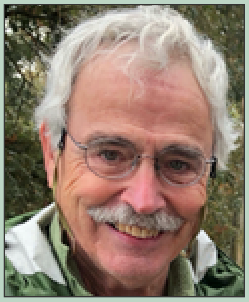
Roger Mammon has a hefty dose of both. A founding member of advocacy group Restore the Delta and president of the West Delta Chapter of the California Striped Bass Association, he has fished throughout the region for more than 70 years. "I get on social media and I see these people posting about catching fish and how great things are," says Mammon. "They just don't know what it used to be."



ENDNOTE

Let's Not Forget Suisun Marsh

PETER MOYLE



I started sampling the fishes of Suisun Marsh in 1979 because one of my UC Davis graduate students was looking for a place to study tule perch, a live-bearing native fish. We found not only a lot of tule perch in the marsh, but also an abundance of other native fishes. Clearly, this was a good place to study species for which we had little information at that time.

Two things helped with our new project. First, sampling boats could be launched less than an hour's drive from campus. Second, the California Department of Water Resources needed a study to examine effects of new tidal gates on fish. The gates are designed to retain fresher water in the marsh to benefit waterfowl, for hunting. They also keep marsh channels brackish, favoring estuarine fishes such as striped bass and splittail.

Now, 42 years later, Suisun Marsh is still the subject of a monthly sampling program. Over all this time, the team, now led by UC Davis' John Durand with sampling supervised by Teejay O'Rear, has come to a number of broad conclusions. After reviewing the list of stories that made it into this special issue, many of which I suggested, I couldn't let it go to print without sharing some of the team's findings about the importance of Suisun Marsh to fish in the San Francisco Estuary.

First, despite its small size relative to the Delta, Suisun Marsh is an extremely important rearing area for juvenile estuarine fishes. For native splittail, it is now the most important rearing area, as well as being a refuge for older fish. This benefits the entire estuary (see also p.5).

Second, fish habitat quality is closely tied to water management through operation of the tidal gates. In addition, managers of duck hunting clubs and wildlife areas regulate tidal flooding of marsh areas to benefit waterfowl. The fish also benefit from the abundant food produced by this exchange of water.

Third, the fishes of the marsh form a novel fish assemblage of native and non-native species that behaves remarkably like a natural fish assemblage. Composition, however, can change, reflecting changes in water quality and other factors, such as invasions of new species. The first collections of shimofuri goby and alligator weed in the Estuary came from the marsh, for example, and non-native invertebrates such as Black Sea jellyfish and Siberian prawns are now important players in the Suisun (and estuarine) ecosystem.

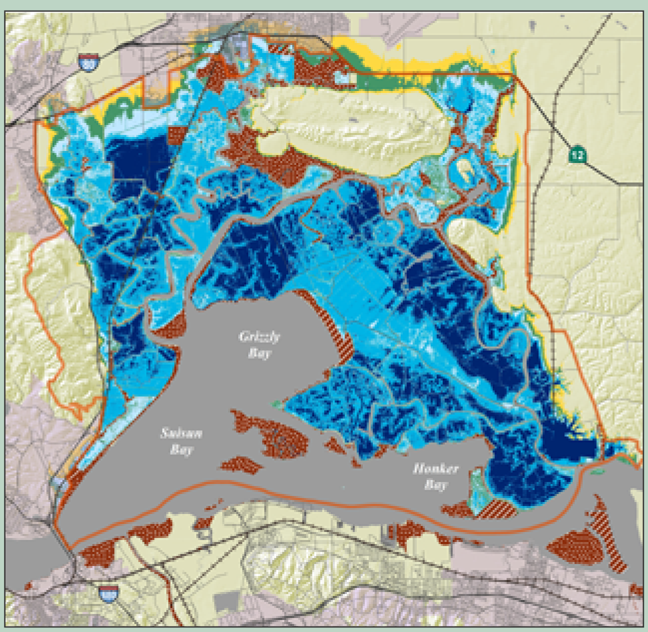
Fourth, much of the marsh is composed of small sloughs that don't mix very much with the large sloughs (Montezuma and Suisun), deterring invasive species (such as clams) while supporting native and pelagic fishes. Understanding this highly unusual feature could lead to improved management and control of invasive species.

Fifth, the sampling program is designed to accommodate volunteers, so over the decades, hundreds of students and others (including reporters) have been able to experience the fishes and marsh sampling. We like to think that better-informed citizens can play an important role in protecting Suisun Marsh and its fishes today.

Lastly, the disappearance of Delta smelt from marsh samples in the 1980s sparked an investigation to see if the population crash was widespread. It was. The smelt was listed as threatened in 1993 (see also p.3).

Years of studying Suisun Marsh have demonstrated its importance to the San Francisco Estuary as a whole. Its importance goes way beyond fish, as discussed in our 2014 book *Suisun Marsh: Ecological History and Possible Futures*. The book uses maps to show how the marsh will change under various management scenarios and sea-level rise. It also shows how local communities such as Suisun City, on the marsh's edge, face flooding. Indeed, the marsh may serve as a landscape-scale levee to some extent, offering protection to adjacent urban areas. Communities that benefit from protection of their neighboring marshes, however, must also remember to protect the marsh as an ecosystem that supports a diversity of life, including native fishes.

In short, Suisun Marsh is a novel ecosystem that can serve as a laboratory to help us better understand the Delta and Estuary. For me personally, it has always been a great place to "hang out" and to be amazed that such a wild, open place exists in an urbanized region.



Projected flooding due to sea level rise in Suisun Marsh as of 2100. If duck club levees collapse, they could absorb lots of tidal water, providing some protection for Suisun City, initially. Eventually, the Marsh would become shallow water open-water habitat — quite productive for pelagic fish but easier for harmful clams and aquatic weeds to invade. Image Source: Moyle et al, UC Press.

San Francisco Estuary Partnership
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San Francisco Bay and the Sacramento-San Joaquin River Delta comprise one of 28 "estuaries of national significance" recognized in the federal Clean Water Act. The San Francisco Estuary Partnership, a National Estuary Program, is partially funded by annual appropriations from Congress. The Partnership's mandate is to protect, restore, and enhance water quality and habitat in the Estuary. To accomplish this, the Partnership brings together resource agencies, non-profits, citizens, and scientists committed to the long-term health and preservation of this invaluable public resource. Our staff manages or oversees more than 50 projects ranging from supporting research into key water quality concerns to managing initiatives that prevent pollution, restore wetlands, or protect against the changes anticipated from climate change in our region. We have published *Estuary News* since 1993.

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FISH ILLUSTRATIONS	Adi Khen

BOULDERS, *cont'd from page 16*

researchers suspect, keeps non-native fish species at bay. Yet these intermittent waterways, she says, "are very underappreciated in terms of their importance for supporting regional biodiversity."

In California, intermittent streams make up more than half of the state's river miles. Along those, Leidy has found summer pools in waterways such as Alameda Creek, as well as streams in the Diablo Range, northern intercoastal range, and Central Valley foothills. But he suspects there are far more.

"It might be a really good strategy to go out and identify areas where these persistent pools are located," he says. "Then you can target those areas as refuges to climate change in the future."

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Beneath the surface of this "Middle Pool" swim five native fish species: Southern coastal roach, Sacramento sucker, Sacramento pikeminnow, Ohlone sculpin (formally riffle sculpin), and brook lamprey, as well as frogs and turtles. Photo: Rob Leidy.

UC Berkeley graduate student Hana Moidu now leads monitoring and data analysis of the species harbored by Coyote Creek's pools.