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ESTUARY

Green Deal for Watersheds — Five Stories of Restoration, Retrofit, and Renewal

Listening for the Ping of Sacramento River Salmon

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EDITOR'S DESK

Green Deal for Watersheds

ARIEL RUBISSOW OKAMOTO

In all my years of covering California water, the term "watershed" pops up again and again as an organizing principle. Yet managing water, land use, wildlife on a watershed scale, from the snow-dusted tippy-tops of the Sierra to the saltwater deeps under the Golden Gate, has always been a mindbender. We've all worked on "watershed management" or restoration plans, and some have even attempted "integrated" water management or "one water" plans. But really corralling all the jurisdictions, property owners, water rights holders, and management agencies in any given watershed into doing something for the whole — in which some give up for others — remains the stuff of wishful thinking and endless meetings.

In this issue of ESTUARY, we celebrate the ambition of working on the watershed scale. In five stories, we explore everything from dam removal to cold water releases for steelhead to the restoration of creek mouths and former flood control channels. We listen in on where the salmon are moving as they migrate from the Sacramento River's headwaters to the Pacific, and through the maze of the Delta. We count the number of drops of wastewater recycled in the Pajaro River watershed to irrigate the strawberry fields and recharge aquifers. We describe how various visionary planners, engineers, and scientists are going about undoing all we've done to block, constrain, and harness watersheds over centuries. Undone, these vast drainages can go back to distributing floods, moving sediment, feeding fish, hosting willows and wetlands.

In two other stories, we explore how selenium and microplastics travel through watersheds and food webs. As these contaminants break down, runoff, and end up in fish tissues, they remind us that watersheds carry our carelessness downstream.

As climate change rattles California, watersheds remain the most powerful scales for adaptation. If we work with them, not against them, they will absorb our atmospheric river events, buffer us from fire, conserve our water supply, shade our fish habitats, offer corridors for migration and transition, and help us retreat from rising seas. We've been restoring and greening our watersheds for years but it's time to up our game. They're the most resilient infrastructure we have.

Below: Okamoto on Steamboat Slough with salmon researchers. Photo: Kathleen M. Wong

STREAMLINE

Regulatory Teams Attempt to Coordinate

CARIAD HAYES THRONSON, REPORTER

As the Bay Area races to restore 100,000 acres of wetlands ahead of rising tides, two initiatives to accelerate and improve restoration projects are moving into higher gear.

In March the San Francisco Estuary Partnership released its Wetlands Regional Monitoring Program Plan, which lays out the science framework for a long-term program to monitor tidal wetlands around the Bay. "The focus of the plan is how we're going to answer five guiding questions about the status and trends of our tidal wetlands," says the Partnership's Heidi Nutters. The questions explore where wetlands and restoration projects are located and how they are changing; how sea level rise, development pressure and other external drivers are affecting them; the impacts of policies, programs and projects on wetland species; what new information is needed to understand the lessons of various programs and policies; and how wetland projects influence human health and safety.

The framework is only the first phase of what will ultimately be a four-year planning process. "We still have really important components that need to be developed," says Luisa Valiela of the U.S. Environmental Protection Agency, Region 9, which is funding the effort. "These include the data management system, and a model for governance and funding." Valiela notes that although the monitoring plan is focused exclusively on tidal wetlands, "we hope to build on success and eventually make it a regional program that encompasses wetlands throughout the Estuary's watershed and the Delta."

Nutters says the team planning for wetlands monitoring is also working closely with the Bay Restoration Regulatory and Integration Team (BRRIT), which comprises representatives from each of agencies that permit projects. The integration team is charged with streamlining permitting for large-scale, multi-benefit restoration projects. "We are working with the BRRIT's Policy and Management Committee, which is tasked with rooting out permitting obstacles, to identify opportunities for the WRMP to add value," she says.

Meanwhile, since its launch last August, the BRRIT has met with the proponents of every project on the Restoration Authority's priority

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E N D A N G E R E D

Network Listens for Passing Salmon

KATHLEEN M. WONG, REPORTER

It's a cold morning in early February, and Chris Vallee of the U.S. Geological Survey is motoring upriver along Steamboat Slough. His two-man crew is hunched in the bow with backs to the wind, wrapped to the ears in water-resistant jackets above warm layers. Vallee pilots the vessel in relative comfort behind the shelter of the windscreen.

The boat passes the usual Delta sights: greenish-brown water drifting past road-crowned levees, the occasional dock and house, a greater egret the color of alabaster lifting off from a eucalyptus branch. After glancing periodically at the open laptop perched on his console, which displays a GPS map of our destination waypoints, Vallee turns the bow toward shore.

The bank is armored with riprap and sheltered by a few trees. As we nose up to dry land, hydrologic technicians Norbert "Nubs" VandenBranden and Ryan Johnson scramble ashore, feeling with bare hands for the steel cable they know is tucked beneath the rocks. After detaching the cable from a nearby tree with leg-length bolt cutters, both hop back into the boat.

Vallee and his team are here to maintain an array of hydrophones used to track migrating native fish. The work is part of a multi-agency effort to provide more timely and detailed information about the movements of salmon, steelhead, and sturgeon in the Central Valley. Deploying hundreds of listening stations across the watershed, the program lets scientists follow thousands of tagged fish as they navigate from hatcheries and headwater streams toward the Pacific Ocean.

The goal of the program is to keep migrating fish safer while continuing to supply water to San Joaquin farmers and Southern California cities. Whether this relatively new technology ultimately helps conserve native fish populations remains to be seen.

As Vallee maneuvers the boat back toward the center of the channel, VandenBranden and Johnson hook the cable to a winch. Soon, a triangular metal frame rises from the depths. They ease the dripping hulk into the bow, and set to work swapping out

USGS crew servicing hydrophones. VandenBranden and Johnson (top), Vallee (bottom). Photos: Kathleen M. Wong

the white plastic cylinder bolted to its center: a hydrophone.

Vallee types the ID number of the receiver, now stowed carefully on deck, into the computer, and a fresh instrument gets lowered into the water. A few checks to make sure the hydrophone is located and oriented correctly, and they move on to the second receiver at this site. The four receivers here form two acoustic "gates" able to hear the high-frequency sound emitted by a tagged fish no matter where it's located along this cross section of the channel.

The team moves with the smooth efficiency of long practice, communicating with few glances and fewer words. It's no wonder: they revisit these autonomous receivers every three months to install units with fresh batteries and download their fish detection data.

The USGS is responsible for 80 to 100 receivers positioned at key junctions along Delta waterways. But the agency was visiting this site and others long before the fish telemetry program existed. The USGS has mounted its receivers adjacent to equipment that tracks water quality characteristics such as water level, flow, salinity, temperature, and turbidity. That's because layering velocity, discharge, and water quality data atop tagging information adds tremendous scientific value.

"It gives us a lot better information to pass on to water managers for what conditions are ideal for fish, and on the flip side what conditions are lethal," says UC Santa Cruz fisheries biologist Cyril Michel, part of the large team collaborating on salmon tracking. For example, several studies have shown that higher flows in the river and Delta seem to be the strongest predictor as to whether fish survive that first migration to sea.

That's good news for fish, according to Michel. "We have the ability to increase survival of fish if the right decisions are made. We have the levers to control the water that comes down the river."

"Everyone wants more water, but fish are the regulatory constraint on the water flows we have," Vallee says.

From fin snips to fish blips

The ability to follow fish on their watery travels is the realization of a long-held dream for biologists. The paths fish hatchlings take to reach the Golden Gate, the length of their journey to the ocean, and even the likelihood of a new fry surviving the journey have all long been a mystery.

Over the decades, methods of marking fish for tracking have undergone a sea change. Fin snips were the first method used to distinguish hatchery-born from wild fish. Then, in the 1960s, scientists came up with the idea of also injecting smolts with a sliver of wire etched with a code revealing where and when the fish was born. Traps and trawls were set up at spots downstream to recapture tagged fish. Any fish with snipped fins had its head chopped off and taken back to the lab, where scientists could prise out and read the tag.

But coded wire tags gave limited information. "The recapture rate was only a tenth of a percent. At this rate it took about 20 years to start to get meaningful results," says Russ Perry, a USGS research fish biologist.

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Nor did wire tags reveal the routes fish took to get to a capture site. "We might see high mortality between the Red Bluff Diversion Dam and the Chipps Island trawl [opposite Pittsburg], but we didn't necessarily know where that occurred," says Michel.

In the mid-2000s, technology that made WiFi and cell phones possible began to transform fish tracking. Tags got small enough to fit inside the belly of a juvenile salmon. When a tagged fish swims past a listening station, the receiver automatically logs its tag number.

Over the past 15 years, the practice of acoustic telemetry has changed from small-scale use for basic science research to large-scale use by professional agency scientists to guide management decisions. On the order of 20,000 fish have been released since the technology first became available.

Real-time receivers are the latest improvement in the world of fish tracking. Connected to a modem, these devices upload detections as they are received to an online database. The data is instantly available and free for anyone to download from the online portal Cal Fish Track.

"The fish swims by, and through the beauty of cell technology you can see on the website the fish survived to be detected there," says Rachel Johnson, a research fish biologist with NOAA.

Real-time data promises to enable water managers to adapt their operations based on the season's fish detections. "This is one of the most exciting parts of the program — the ability for us to collect information in real time and translate the information [into something that helps us] understand if there's an effect from management choices," says Josh Israel, a fish biologist with the U.S. Bureau of Reclamation.

Many scientists view real-time as a major advance over autonomous receivers, which must be hauled out of the water to have their data downloaded every few weeks. "A lot of that information is generated on timelines not necessarily reflecting agency needs," Israel says.

Fish listening stations along the Sacramento River. Map: Amber Manfree

The era of cooperation

Scientists from all the major fish tracking and water agencies are now working together to build an acoustic telemetry network offering broader and more detailed coverage of the Central Valley watershed. The Interagency Telemetry Advisory Group, or ITAG, met for the first time in August of 2018. The member list reads like a who's who of fish research and water management in the region: California Department of Fish and Wildlife, National Oceanic and Atmospheric Administration, California Department of Water Resources, UC Santa Cruz, UC Davis, U.S. Army Corps of Engineers, U.S. Bureau of Reclamation, U.S. Fish and Wildlife Service, U.S. Geological Survey.

"It's been easy for agencies to support this because ITAG is focused on creating the kind of information that can be used for fisheries and water management," says Israel, who co-chairs the group. "ITAG is a big backbone that can support both basic research and investigations into a variety of questions."

Much of the funding for ITAG coordination has come through Israel's employer, the U.S. Bureau of Reclamation. The bureau plays a major role in dam operations and water deliveries in California. Other state and regional investors include the Delta Stewardship Council, whose managers want to see continued advances in science coordination, synthesis and communication.

"We have repurposed the telemetry data to describe broad patterns in outmigration and life history diversity for salmon," says Pascale Goertler, a Delta Stewardship Council scientist who has synthesized 10 years of telemetry data. Her project helped illuminate ITAG's data integration needs. "We want to understand how juvenile salmon navigate the risks and rewards of freshwater residency under changing conditions."

ITAG has made major progress in its year and a half of existence. Participants are now using compatible equipment. Duplicate tag numbers, where two different fish had the same number because different agencies were tracking them, are a thing of the past. All receivers in the network recognize all participants' tags, producing more detections across the watershed. Care and maintenance of the receivers is divvied up among the participants. All agencies are now using the same river mile designations, making it easier to find and service receivers.

"It's a great idea, and it's working very well. I can see it in the way people help each other," says Flora Cordoleani, a fish biologist for NOAA as well as an ITAG facilitator. For example, she says, participants are now willing to lend gear or replacement parts.

ITAG also organizes workshops to teach protocols for inserting tags as well as estimating survival and movement rates from the detection data. Unified by ITAG, scientists are now implanting acoustic tags by the thousands in fish runs of interest in the Central Valley, more specifically 7,200 green sturgeon, Chinook, and steelhead in 2020.

Advancing the science

There's no denying that native fish, particularly salmon, need all the help they can get. A juvenile salmon born in a headwaters stream has just a 3 percent chance of making it through the Central Valley and out to the Golden Gate. In many years, a larger proportion die within the weeks they spend outmigrating than during the whole one to three years they spend in the ocean. "Survival for Central Valley salmon is terrible," Michel says.

Acoustic telemetry data has the potential to improve conditions for fish by giving scientists new insights into their habits. Tagged fish are released in groups of hundreds of animals apiece to answer specific questions. The routes fish take can reveal everything from the progress of a run of interest to how fish react to infrastructure like gates, screens, and pumps, or certain water conditions.

These insights could be used to nudge fish away from danger zones and toward better habitat. For example, researchers have found salmon grow larger and faster in the Yolo Bypass. Learning how salmon ply the waters near the bypass' Fremont Weir entrance will help engineers design a gate to pull fish into this fishy Eden.

Simulated salmon runs

Right now, scientists' best guess about how a given fish group's migration will play out comes from the Delta STARS model. This computer simulation predicts where fish will go, and how fast, under given water operation conditions. The model lets scientists and managers release virtual fish at the top of the Delta. River flow and channel information helps the model fill in the details through eight segments of the watershed.

USGS biologist Russ Perry based the model on five years of acoustic tag data from late-fall-run Chinook. "That predictive model basically would be impossible if it weren't for this amazing network of telemetry receivers and acoustic tag releases over a number of years," he says.

The model lets managers break down how components such as a given route or water conditions affect chances of survival. "You can look at the differences between scenarios and understand whether one is better or worse," Perry says.

NOAA Fisheries has already used Delta STARS to evaluate the effects of the California WaterFix plan on fish, while the USBR and DWR used it to study potential fish impacts from proposed operations changes to the Central Valley Project and State Water Project.

Perry is now using telemetry information from winter and spring runs to build more flavors of the model for those imperiled stocks.

The costs of tracking

New knowledge from acoustic tagging comes at high cost. Each autonomous acoustic receiver currently costs up to $6,500. Real-time receivers cost even more due to the need for solar panels for power and communications links. The fish tags can run a few hundred dollars apiece. Multiply this by dozens of receivers and thousands of tags, and the bill for the equipment runs into the millions of dollars.

Then there's the need to refresh the equipment as improvements come along, the same way businesses must keep their computers and other equipment current. Right now, most of the network's receivers are two or three years old. Plans are to upgrade the system every five years or so.

As advanced as it seems, the technology severely limits which fish can be tracked. Current tag designs are too large for many juvenile fish. Smolts must be at least 80 millimeters long to accommodate a tag.

"We're looking via telemetry at only the largest size class of juvenile salmon emigrating through the Delta," Perry says. "The information is amazing, but we have to keep in mind the other populations and life stages out there when these different environmental conditions and water operations are occurring."

Questionable stand-ins

To simulate these other types of runs, hatchery smolts could be tagged and released when the wild fish begin their migrations. "But then the question is whether these fish are true surrogates for the population of interest," says Michel.

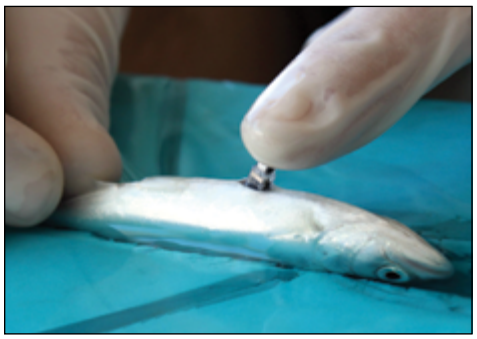

Photo: Myfanwy Johnston

The lion's share of tagged fish have always been from hatcheries. Managers want to know how well these stalwarts of the commercial and recreational salmon fisheries fare. In the case of the winter run, they want to see whether wild fish are protected (the winter run is the most endangered of the salmon runs). Tagged animals are released together with the larger group of fish, and all mingle on their journey to the ocean. Yet many scientists question how well hatchery-raised animals surgically altered to carry a tag truly represent the behavior of untouched, wild-born salmon.

Hatchery fish are believed to have lower migration survival rates than their wild brethren. After all, they've grown up in an environment without predators, and no natural culling has occurred before release.

However, both hatchery and wild fish should respond similarly to environmental conditions like flows, temperatures, or routes. So using hatchery fish to make inferences about relative changes in survival due to environmental conditions tends to be more sound than using them to infer absolute values of survival, says Perry.

It could also be argued that tagging a fish as small as a salmon smolt is so invasive that it may alter the animal's responses. Fish are poured into water laced with sedative, have their belly cut open with a scalpel, and get a tag nearly as large as their head poked into their abdominal cavity before the wound is sutured back together.

If a major reason for the telemetry effort is to help guide water-delivery decisions, data from tagged hatchery fish might carry more weight than it can scientifically bear.

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Seeing is believing

Around USGS they have a name for the instant eye candy that can be seen so quickly onscreen when the telemetry yields detections: "one fish, two fish, red fish, blue fish."

Perry says managers must remain alive to the shortcomings of the data, however. "It's tempting to use the raw detections coming out of the telemetry system," he says. "But it has to be statistically analyzed first." These manipulations involve quality filtering of the data, as well as calculations that can add in measures such as of the number of tagged survivors that evaded detection.

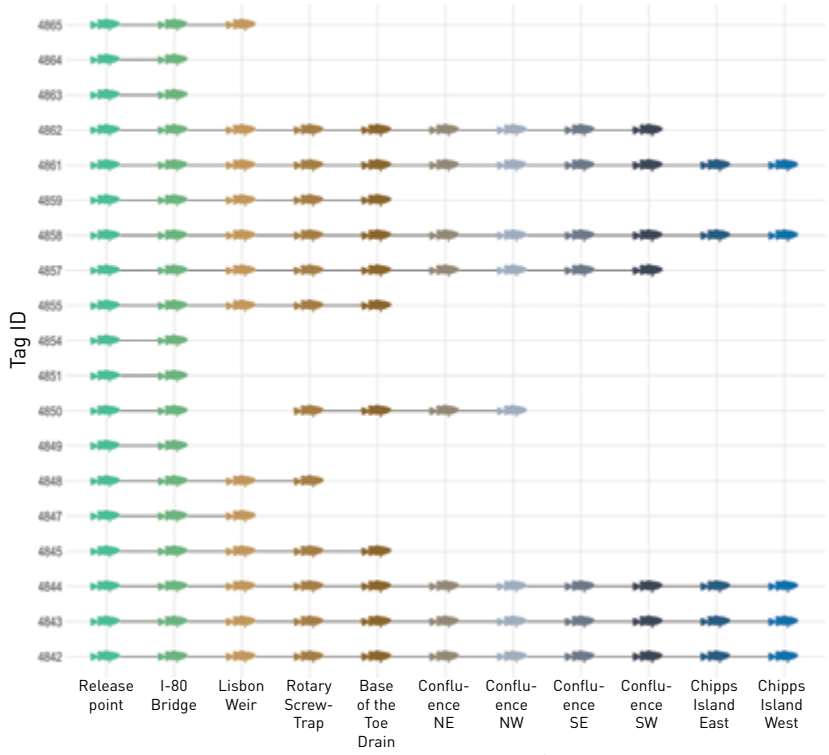
In fact, scientists say acoustic tagging should be considered just one of many sources of information used to inform water management, along with trawl and screw trap data, fish surveys, and historical trends.

"There's a worry that when people see pretty dots on a screen, they interpret that as understanding, but it's only raw material," says Steve Culberson, lead scientist for the Interagency Ecological Program. "What I'm more concerned about is that we will collect all this data but not invest in the intellect — the seats we need to fill — to ingest, analyze, understand and communicate what it all means."

Nor do pretty dots always have statistical significance in terms of the number of detections obtained from each release group within certain regions of the Delta. Only a tiny percentage of any fish cohort gets tagged due to costs. Vanishingly few of those are detected as far as the Delta or pumps. Vallee worries that a lack of detection data will be used by water managers to approve exports. "It's the fox guarding the henhouse," he says.

In times of crisis, like extreme droughts, any insights into where endangered salmon are located can be valuable. Consider what happened during the 2015 drought. Declining water quality in the interior Delta threatened the water supply pumped to the San Joaquin Valley. Water managers knew they could boost freshwater levels by opening the Delta Cross Channel gates in Walnut Grove to allow Sacramento River water to improve conditions. Yet opening the channel can pull endangered outmigrating winter-run salmon on an often fatal detour through the interior Delta.

Encounter Histories of Tagged Chinook Salmon Smolts
Released upstream of I-5 bridge in the Yolo Bypass



Source: Myfanwy Johnston

Throughout that drought year, administrators kept asking about the location of the troubled runs. Data from tagged fish and real-time receivers kept them informed. "Having the data and models to see what's going on now is helpful when decision makers are confronted with balancing fish and water," Johnson says.

This scenario would only happen in an emergency. "Acoustic tagging data isn't used regularly to operate the Cross Channel because tagged fish are released after we've closed the channel to protect passing salmon," Israel says. "The only time we may deviate is when the state and federal water projects are at risk of not meeting Bay-Delta water quality standards."

Vallee feels several additional technologies could help inform water and fisheries management in the Delta. These include split-beam sonar, which detects the air in fish bladders to count animals but doesn't identify species, and acoustic cameras, which are towed behind a boat and automatically image any fish that pass through their sound beams. A video version of the latter, dubbed SmeltCam, is already being used to study the fragile Delta smelt.

Real-time data: an emerging experiment

Current wildlife and water policies explicitly embrace the use of real-time telemetry data, even as many scientists retain a healthy skepticism about outcomes.

"The policy landscape is allowing more flexibility in decision-making based on current conditions versus calendar-based ones," Perry says. "People see value in trying to manage for the complexity around water reliability and fish based on what is happening."

"Having the fish movement data integrated with other information about the environment, and maintaining this array over years and years, gives scientists the chance to get a full picture, over time, of how fish use the system," says Louise Conrad, Deputy for Science for the Delta Stewardship Council.

"Sociologically, it improves our ability to communicate among our different tribes, and that's a good thing," says IEP's Culberson. "It has moved the needle on what we know and given a sense of pride to the people doing the work, because they are solving problems."

"We're Californians. We're Delta folk. We're fishermen. We're water users," says Vallee. "We want decisions to be made with the most accurate data, as precisely and truthfully as possible."

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www.sfestuary.org/estuary-news-real-time-telemetry-reveals-salmon-journeys/

WATERSHED

Dam Tweaks Yield Results

ALASTAIR BLAND, REPORTER

For the first time ever, cold water is flowing steadily through Calaveras Dam in southern Alameda County, and into the creek canyon below. It's been just 15 months, but already, fish are responding.

"After one year of flows, we're seeing lots of rainbow trout," says Brian Sak, the supervising biologist with the San Francisco Public Utilities Commission (SFPUC), owner and operator of the dam.

Sak says he and other biologists who routinely survey the creek using snorkeling gear never saw this freshwater native fish — the same species as ocean-going steelhead — occupying Calaveras Creek before.

The return of rainbow trout to Calaveras Creek marks a milestone in an ongoing, multi-agency restoration of Alameda Creek, which drains more than 600 square miles of the East Bay. Much of the watershed is heavily developed and modified, especially the northern reaches in and around Pleasanton and Livermore.

Other parts remain relatively wild, but the area gets scorching hot in the summer, and flows diminished by dams and diversions have made Alameda Creek and its tributaries like Calaveras Creek an even less hospitable environment for trout, steelhead, and salmon, which evolved in a watershed with seasonally intermittent flows in many reaches.

But starting in the 1990s, state and federal agencies, as well as environmental groups, pressured the SFPUC to comply with environmental laws and restore flows in Calaveras Creek, which for decades was nothing more than as a series of warm, stagnant pools. The idea was to revive native fish populations in the Alameda Creek watershed.

The SFPUC owns Calaveras Dam, which impounds the water that it sends to its 2.7 million customers. Since the dam's construction in 1925 by the Spring Valley Water Company, no measurable flows have been allowed through the barrier. The fact that there was water in the creek channel at all was incidental: the result of planned drainage from a leaking dam. But facing legal action, the SFPUC agreed to overhaul its operations in the interests of steelhead recovery as part of its dam rebuild, which wrapped up in 2018.

Finally, in January of 2019, water began to stream out of Calaveras Dam. The flow since then has ranged between 7 and 12 cubic feet per second. Though not much more than a lively trickle, this water has had significant effects on the watershed.

"Calaveras Creek has become a cold-water refugia," says Tim Ramirez, the SFPUC's natural resources and lands management division manager.

As trout have moved into the newly revived creek, nonnative species — primarily largemouth bass and bluegill, which prefer warm water (and prey on baby salmonids) — have evacuated the system, presumably moving into the lower reaches of Alameda Creek.

"What's happened to the stream is exactly what everyone expected to happen," Ramirez says.

Prior to the release of cold reservoir water, Calaveras Creek's water tended to range in temperature from 70 to 75 degrees Fahrenheit: a very inhospitable range for any type of trout or salmon. But after the releases began, temperatures plunged. Now, summertime flows run a cool 52 to 57 degrees. While this has been good for trout, it may be less so for other native species. California roach, Sacramento sucker, Sacramento pikeminnow, and prickly sculpin, among a few other species, all inhabit the watershed and prefer relatively warm water. "We anticipate these species will also move downstream where water temperatures are suitable," Ramirez says.

But the restored cold flows are mandated by the National Marine Fisheries Service, which tends to keep out of inland water issues unless anadromous salmonids are involved. The agency has a recovery plan for endangered Central California Coast steelhead, and this plan is guiding the Alameda Creek restoration efforts. The agency has set an optimistic target of 2,000 spawning adult steelhead for the entire watershed.

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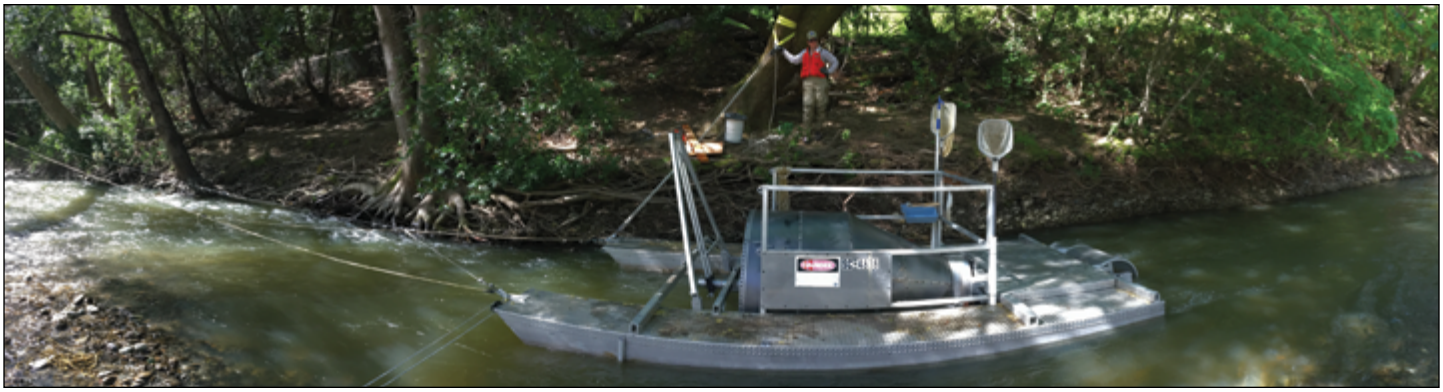

Rotary screw trap in Alameda Creek for trapping fish. Photo: SFPUC

Fish water releases from new Calaveras Dam. Photo: SFPUC

Jeff Miller, director of the Alameda Creek Alliance, one of the groups that challenged the SFPUC's past abuse of Calaveras Creek, says he's happy with the progress being made as different public entities collaborate on reviving the watershed. "The cold water is pushing the invasive predators out and overall we're looking at potentially having 20 miles of spawning and rearing habitat restored," he says.

Miller is optimistic and says even Chinook salmon are liable to return to the system if cold flows are maintained and migration obstacles removed. Like other waterway advocates watching the restoration, he anticipates the installation of fish ladders by county agencies at a few key pinch points that currently block the upstream migration of adult spawning fish.

Already, juvenile steelhead — the offspring of resident rainbow trout — can and do make the exit migration to saltwater, something SFPUC biologists have been tracking since 2015. Using traps designed to catch small fish swimming downstream, the researchers have caught as few as just a handful of outmigrating smolts in a year to as many as several dozen. Sak says there isn't enough data to explain this variation and says it could be the result of "highly variable" monitoring efforts.

Newborn rainbow trout in Alameda Creek. Photo: SFPUC

"It will take a number of years for creek conditions, as well as the creek's geomorphology and biology, to stabilize to some new post-water-release norm," he says. "Likewise, it will likely take many years for us to even begin to decipher what is going on under the new flow regime."

Farther into the watershed, officials are expecting the eventual arrival of steelhead. Carol Mahoney, a water resources manager with the Zone 7 Water Agency, which oversees the northern and eastern reaches of the Alameda Creek watershed, says the local tributaries are not a particularly steelhead-friendly place. The waters are heavily impaired by urban pollution, invasive predators like bass, diminished flows and high temperatures, and concrete-lined banks that offer little in the way of shelter for juvenile steelhead.

Nonetheless, Zone 7 is operating some of its facilities as though the federally endangered species will return. She says her district "undertook a project that removed fish passage barriers and impediments on a reach of Arroyo Mocho, and we have attempted to establish a riparian canopy in this area to see if shading is sufficient to reduce temperature enough to support healthy salmonids."

There are clear limits to how completely the Alameda Creek system can be restored. Research from the San Francisco Estuary Institute has shown that the health of the steelhead runs in the system depended heavily on a healthy estuary, where wetland habitat historically provided shelter and abundant food for young fish.

That component of the watershed that has been totally eliminated by urban lowland development.

"In the lower basin, Alameda Creek is now just an armored flood control channel that dumps into the Bay," Sak says. Without this critical piece, the ecosystem is unlikely to rebound to historic abundance no matter how much water flows through the watershed.

But Miller is as optimistic as ocean-going salmonids are resilient. "We stand a good chance of seeing recovery of steelhead and even the chance of Chinook salmon reestablishing themselves," he says.

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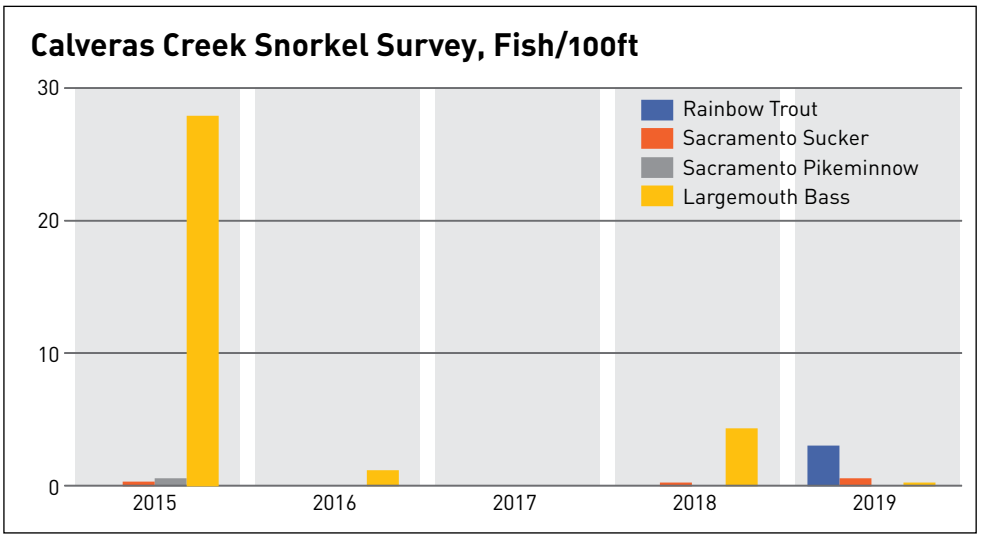


SEDIMENT

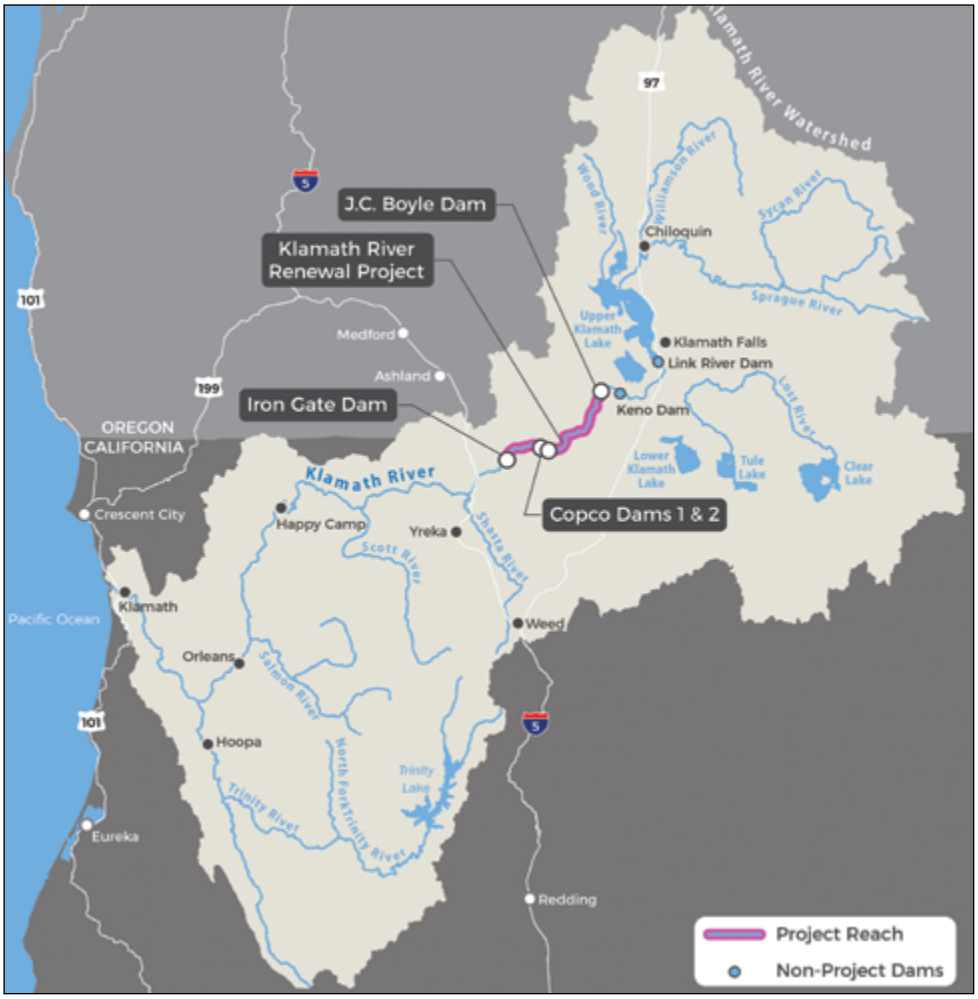
Rebooting the Klamath

LISA OWENS VIANI, REPORTER

In 2002, more than 70,000 adult salmon died on the Klamath River when U.S. Bureau of Reclamation diversions caused water temperatures to spike, which led to the spread of diseases that wiped out the fish. "That was a wakeup call for everyone who relies on the basin," says Amy Cordalis, general counsel for the Yurok Tribe, which recently declared that the river has the rights of a person and standing to bring a tribal court case against entities that harm it.

"There are bounds on this system and if you mismanage it, you can kill off what was once the third-largest salmon run on the entire West Coast," says Cordalis. She says the massive fish kill led the tribe and other stakeholders to ask what the river needed in order to recover. Their conclusion? "Dam removal is critical to healing and restoring it," she says. In February, the Klamath River Renewal Corporation (KRRC), a nonprofit group of river stakeholders including the Yurok and Karuk Tribes, filed supplemental information with the Federal Energy Commission (FERC) to support their application to take over management of four hydroelectric dams in the upper watershed. If all goes according to plan, those dams will then be removed and their footprints — and unimpeded river flows — restored by 2023.

While the KRRC has been watching and learning from other dam removal projects on the Elwha, Carmel, and Penobscot, this one is unique. "There's never been a project that has considered removing four dams at the same time on the same river and restoring this much land," says KRRC chief executive officer Mark Bransom. More than 100 miles of river and tributary streams, and approximately 2,200 acres of formerly inundated land will be reconnected and restored to a more natural state. The project is also unique because the ultimate sink for the sediment currently captured behind the dams is 190 miles downstream at the river's mouth.



Klamath River Watershed in Northern California. Map: KRCC

That sediment — and potential impacts to fish in the river — is one of the main reasons the dams will all come down at the same time, with concurrent and coordinated drawdown of the reservoirs in January, February, and March of 2022. In those winter months, salmon are most sparse in the mainstem Klamath River, present primarily in tributaries and the ocean. "The paramount reason [for the near simultaneous removal] is the need to limit impacts to multiple salmonid species to one cohort," explains Jorgen Blomberg, design team director with Environmental Science Associates (ESA), which is one of several engineering and design firms working on the dam removal and restoration plans. Other reasons include satisfying the conditions of the FERC permit, which includes all four dams, as well as the restoration team's goal of relying on the river's own power to evacuate the sediment left behind the dams.

Blomberg says that's a large slug of sediment to move in one season. The team has evaluated multiple scenarios for sediment evacuation once the dams are down and the river

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Photo: Mid-Klamath Watershed Council

has flowed through the footprints of the reservoir. The restoration team's goal is to reestablish fish passage through the dam footprints as well as connections with some of the major tributaries to the main stem. "We're focused on helping the river move as much sediment out during that one season as possible," says Blomberg. "Having the river do a lot of the work is more cost-effective than bringing in equipment."

Even so, ESA and other team members have also come up with plans to help mobilize sediment as needed, possibly using airboats with nozzles and networks of pumps and hoses to help recirculate standing water over the sediments. "Some of this sediment is like 'duck poop,' very fine clay-based sediment," explains Blomberg. "It's hard to have equipment out on it while it's still saturated." To tackle this tricky situation, the team is considering using a combination of amphibious and land-based equipment.

Copco No. 1 dam on the Klamath, one of four to be removed. Photo: Michael Wier

The restoration team has conducted high-resolution bathymetric surveys of current conditions in the reservoirs and compared them to pre-dam topography to get a better understanding of how much sediment is in each reservoir, where the sediment is thickest, and where the deposits are most extreme. ESA has also examined historical photos and descriptions of the habitat types in the river corridor prior to the dams.

"We're using all of that information to build a picture of what we think the post-drawdown condition will look like," says Blomberg. "We don't expect to be able to re-set the landscape to what it was pre-dam just because of the volume of material that settled out in the reservoirs: millions of cubic yards of fine sediment behind the dams."

Team partner AECOM conducted test plots using sediment samples taken from different locations in the reservoirs and found that the sediment can become very hard and fractured, which repels water. "It can be hard to percolate through it and for plants to establish," says Blomberg. "That then is tied to our team's approach for revegetation." As the drawdown occurs and the sediment dries out, the restoration team will do a heavy seeding of native workhorse species, he explains. "As the water recedes during the drawdown, there'll be a massive deployment for seeding the reservoir footprints to give the desired natives a foothold."

Blomberg says the best workhorse species in the riparian zones will be the typical pioneers —alder, willow, cottonwood — that come in on their own. Those species will also be planted at select locations. "Those are the ones that really seem to make the difference and reestablish structure," he adds. In the meantime, the Yurok Tribe is mapping and eradicating invasive species and working to improve salmon spawning habitat in the tributaries.

After the river has had two seasons to run through the reservoir footprints, contractors may return to reshape and refine floodplain features and to conduct additional planting, says Blomberg. But the project's main thrust is letting the river do most of the work itself to reestablish physical processes and hydrological connections with its floodplain, tributaries, and riparian zone. "It's really about re-setting the physical processes that allow for the positive trajectory of the ecosystem to recover on its own," he explains. "Because the footprint is so massive and the budget is limited, we can't baby this landscape, we need to help it launch itself."

Cordalis says the Yurok Tribe realizes that restoring the river completely back to health will take time. "We've been here forever and we're in it for the long haul," she says. "My grandmother was born in 1904 before all of these dams and development altered the river so dramatically. She had a healthy, clean, abundant river, with fish runs in the river year-round. I want her river back."

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TEAMS , cont'd from page 2

list, and has started the permitting process for several projects, including San Francisco's 900 Innes, or India Basin, project and Contra Costa County's Lower Walnut Creek (see p. 11). Because both of those project plans were well along before the BRRIT began operating, the proponents were not able to take advantage of the pre-application consultation that is key to the BRRIT's work, says the Regional Board's Keith Lichten. "The project proponents have been very understanding, in their willingness to illustrate some of the challenges associated with Bay-margin wetland permitting," he says. Although these projects are benefitting from the ease of communication the BRRIT allows, Lichten admits that solutions and lessons learned are "really going to be most of use to future projects."

RESTORATION

Opening the Mouth of Walnut Creek

ROBIN MEADOWS, REPORTER

Paul Detjens is driving us from his Martinez office to a restoration site near the mouth of Walnut Creek on Suisun Bay, a project he spearheads as an engineer for the Contra Costa County Flood Control District. These lower reaches of the creek — straightened, widened, and leveed by the U.S. Army Corps of Engineers — have been a sluggish, silt-filled problem for more than half a century. Detjens has worked to find a solution for the last 17 years.

Now that the district has taken the unusual approach of parting ways with the Corps in favor of local control, a fix is finally in sight. Goals include sustaining flood protection, restoring habitats, reconnecting the creek with its historical floodplains, and offering public access so people can enjoy the wonders of newly restored marshes. "We want to work with natural processes, not against them," Detjens says.

The closer we get to our destination, however, the more industrial the landscape becomes, and the more improbable it seems that we're in the right place to realize this vision. We're heading east from I-680, just before the bridge to Benicia, on Waterfront Road. That sounds picturesque. But first we pass Copart's vast parking lot, crammed with thousands of junker cars, and next comes the immense bulge of the Acme Landfill. Though the road parallels Suisun Bay, you can't see that far. Instead drivers have a close-up view of the Union Pacific Railroad tracks and an array of elevated petroleum pipelines. The massive tanks and towers of the Marathon Martinez Refinery lie straight ahead.

Then Detjens takes a right on a narrow levee road and it all begins to make sense. Here, Walnut Creek makes its way down a slender strip of land — squeezed between the landfill and the refinery — as it traverses the final few miles to the bay. The project Detjens heads will restore this lowest stretch. Confined by levees and hemmed in by industry, the creek still holds the tremendous power of water and thus the potential to reshape land according to the laws of nature.

This winter, the last parcel needed for the restoration fell into place. "I've been here since the start in 2003 and have pretty much worked on it since then," Detjens says. "This is an emotional, exciting time to finally be so close to implementation."

Bounded by the 1,400-foot Briones Hills to the west and 3,800-foot Mount Diablo to the east, Walnut Creek drains Contra Costa County's largest watershed at nearly 150 square miles. The creek's woes began in the early 1800s, when Spanish ranchers grazed cattle in the watershed's plentiful grasslands. They also introduced shallow-rooted non-native grasses. "The land became unstable and erosive," Detjens explains. The post-World War II development boom made matters even worse. The watershed's population jumped 15-fold from 1940 to the mid-1960s, and each new house, business, and road added to the creek's troubles.

"When you pave over a watershed, you disrupt the natural function where water soaks into the ground," Detjens says. With nowhere else to go, stormwater rushed into the creek. "The banks were eroding and falling in, and there were lots of floods," he adds. The town of Walnut Creek was

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Restoration and Public Access Plan for Project's North Reach

Source: Placeworks/ESA


(L-R) Paul Detjens describes plans for restoring creek connection to Bay; vision rendering of future views from the site; kayaking at the creek mouth; black rail. Images courtesy CCWFCD, Placeworks, Laurie Hall & Black Rail Project.

inundated repeatedly, suffering four major floods in the 1950s alone.

Back then, people were at the mercy of floods. "Nothing was regulated the way it is now," Detjens says. Citizens demanded action, resulting in the formation of the flood control district where he works. The district then sought outside help for taming the waters of Walnut Creek. "We couldn't handle it on our own, it was too expensive," he says. "Like many others, we turned to the federal government." That ended up causing yet another problem for the creek.

In the early 1960s, the district teamed up with the U.S. Army Corps of Engineers, which designed, built, and largely paid for a flood-control project extending 22 miles upstream from the creek's mouth on Suisun Bay. The district's responsibilities were to provide the land, and to own and to maintain the project. The latter proved to be impossible for the lowest four miles of Walnut Creek, near the mouth.

Here the land flattens, water slows, and silt settles. And it turned out that there was a lot more sediment coming off the watershed than the Corps had calculated. "They were off by a factor of five and the project immediately filled up," Detjens says. "It never worked right, it was completely flawed —it just turned into a big sediment trap."

That put the district in a no-win situation. Bulrushes, cattails, and other water-loving plants soon sprouted in the trapped sediment, creating habitat for protected species like the salt marsh harvest mouse, Ridgway's rail, and the California black rail. The district then faced conflicting directives. "One branch of the Corps was saying, 'You must dredge out the sediment,' and the other branch was saying, 'No way will we give you a permit for that,'" Detjens says. "It was untenable — it was like the two-headed monster Muppet in Sesame Street that couldn't agree with itself." Wildlife and water-quality permitting agencies concurred that dredging was not an option.

Being out of compliance with the maintenance agreement had major repercussions for the district. To be eligible for disaster relief from the Corps, flood-control projects must pass annual inspections and the impasse over the lower four miles put the entire 22-mile Walnut Creek system in danger of failing.

At first, Detjens worked with the Corps to find a solution. In 2004 the district and the Corps embarked on a joint study to reengineer lower Walnut Creek. "Everyone was like, 'We're going to fix this,'" he says. But a decade and $3.6 million later, the study was only on step three of the Corps' ten-step planning process. In addition, the Corps had run out of planning money so the district would have to shoulder that entire cost. "We had already put in our half — $1.8 million — for the study," Detjens says. "We really didn't have an appetite for more Corps bureaucracy."

So the district took matters into its own hands. "We ended up doing something pretty unknown," Detjens says. The solution hinged on the fact that lower Walnut Creek is fundamentally distinct from the rest of the project. "The lower four miles are tidal, so they have different habitat and operate differently from the upper 18 miles," he says. Importantly, sediment accumulation in the lowest part of the creek does not cause floods in the upper part, where the cities are. The district decided to take back local control of the lower reaches of Walnut Creek while retaining its partnership with the Corps for the upper reaches.

Called selective deauthorization, the process requires an Act of Congress. Representative Mike Thompson sponsored the legislation and in 2014 President Obama signed the deauthorization of lower Walnut Creek into law. The upper 18 miles comply with the maintenance agreement and so remain eligible for disaster relief, while the lower four are under local control. "It keeps the Corps' management intact where it works and gets them out of the way where it doesn't," Detjens says.

By the time selective deauthorization of lower Walnut Creek went through, Detjens had already laid the groundwork for moving forward independently. "We had gone through a community visioning process and had come up with a more compelling vision of what we wanted," he says, stressing that the plan reflects local expertise and values. His outreach is ongoing and includes tours of the restoration site, community meetings, and a stakeholder advisory group. The local plan offers far more than the Corps' proposal — including habitat restoration and public access in addition to flood control — and will cost far less at about $19 million instead of $50 million.

Detjens stands on the levee the Corps built along lower Walnut Creek, just off Waterfront Road. A constant low rumble from the Marathon refinery fills the air, but there are also high notes from birds and that fresh, clean smell after a rain. In the distance, the peaks of Mount Diablo disappear into low, gray clouds. Detjens points out the creek side of the levee, which is crowded with tall marsh plants rippling in wind. You can't even see the water. On the other side of the levee lies a remnant of the creek's former floodplain. Starved of sediment, the peaty soil has subsided and is vis-

ibly lower than the marsh that thrives between the creek levees.

The land around lower Walnut Creek is so altered that it offers few clues of what was once here. To find out, historical ecologist Sean Baumgarten and colleagues at the San Francisco Estuary Institute sifted through archival records like maps, photos, and written documents. "Drawing on multiple, independent sources paints a relatively complete picture of the pre-European landscape," Baumgarten says.

Baumgarten found that lower Walnut Creek originally meandered through extensive wetlands, including a broad swath of tidal marsh between present-day Highway 4 and Suisun Bay. Much of that is now gone. Also missing is the connection between the creek and the lands around it. "Understanding what's been lost helps identify key ecological functions that you want to restore," he says.

Next came setting priorities for restoration. A multiagency team called Flood Control 2.0 brainstormed where and how to bring back ecological function given the limitations of today. "Flood Control 2.0 is more than a report on a shelf," Detjens says. "Their work was foundational to our project planning."

The Corps' levees disconnected the creek from the marsh, diminishing the tides that scour sediment out of the channel. Moreover, disconnecting the creek from its floodplains concentrates stormwater in the channel, resulting in flooding. To undo this harm, the team recommended setting levees back as well as breaching them in strategic spots. Reconnecting lower Walnut Creek with its remaining floodplains will redirect stormwater to places where it can spread out and percolate into the land. Reconnecting the creek with tidal wetlands will let sediment feed new marshes and enhance their resilience to sea-level rise.

A surprising amount of tidal marsh can be brought back. Even the narrow stretch along the landfill offers room to work with. The creek channel is more than 450 feet across here, and the floodplain remnants outside it are wide enough to set the levee back another 350 feet. Altogether, freeing this part of Walnut Creek to meander and overflow will restore about 55 acres of tidal marsh.

Source: ESA

Far more tidal marsh will be restored just before the creek's mouth on Suisun Bay. Here the land opens up, so while the creek is still channelized, its future is not as tightly constrained by industry. In 2004, the Contra Costa County Flood Control District bought a 122-acre parcel adjacent to this part of the creek, in partnership with the East Bay Regional Park District and the John Muir Land Trust. They got it for a song. "The property was in default, and we purchased it for about $700,000 in back taxes," Detjens says.

Called Pacheco Marsh in a nod to the historical landscape, today the parcel looks nothing like its name. The land is high and dry, dominated by short non-native grass. "It was drained and filled," Detjens says, as he leads the way towards the bay. Yet this heavily degraded land still offers the promise of renewal. Frogs call nearby, and salt marsh harvest mice and nesting black rails live here. In addition, protected tidal marsh lies on both sides: the 275-acre Peyton Hill Marsh to the west and the 760-acre Point Edith Marsh to east. Ultimately, restoring Pacheco Marsh and the creek's upstream floodplains will give wildlife an uninterrupted corridor of high-quality habitat.

The 122-acre parcel purchased in 2004 stops just short of Suisun Bay. In between sits a 19-acre parcel, dubbed the donut hole because it is completely surrounded by protected lands. Late last year, the donut hole finally joined the lower Walnut Creek restoration project. The Marathon Martinez Refinery bought this last piece of the project for $4 million in December and will donate it to the John Muir Land Trust. The transaction was shepherded by Tim Fitzpatrick, an engineer at the refinery and longtime member of the restoration project's stakeholder advisory group. "The term 'win-win' is often overused," Fitzpatrick says. "In this case, however, it is not."

Detjens couldn't agree more. "It's absolutely strategically placed — right between our parcel and Suisun Bay," he says. "It will allow full tidal marsh restoration." The Marathon parcel sits high above the bay, overlooking a fringe of tidal marsh lush with cattails and tules. The restoration project will add a new tidal channel that ties into an existing one with a mouth on the Bay (see cover). The

continued on next page

restoration will also take advantage of Pacheco Marsh's unnatural height, creating a gradient from wetlands to uplands. The latter will provide high-tide refuges for wildlife, and give tidal marsh room to migrate inland as sea level rises.

Michelle Orr of Environmental Science Associates, which developed the restoration plan, calls the project groundbreaking. "It remakes an old flood-control channel into something that's more in line with our current thinking," she says. "It's a new way of doing flood protection and a new approach to baylands restoration that builds in a lot of climate resilience."

The project will also offer public access. The John Muir Land Trust plans to build 2.5 miles of trails, boardwalks, and bridges in Pacheco Marsh. "You're a world away once you're out there," says Linus Eukel, who directs the land trust. "It's an opportunity to allow people to really connect with shoreline habitat. It will be a sanctuary for birds, habitat, and people."

In 2019, the project was awarded $7.9 million for construction from Measure AA, the $12 annual parcel tax that supports restoration projects in the San Francisco Bay. Rosalie Howarth, a Walnut Creek homeowner and avid birder, can hardly wait. "For a dollar a month — one less biscotti with your latte — we'll forever protect this land for everybody, people, wildlife, and plants alike."

The funding is in place, the permit applications have been filed, and Detjens is more than ready to begin restoring lower Walnut Creek. "Local control isn't the answer to everything but in this case, it was definitely the answer," he says. "It worked so much better to be nimble, flexible, and inclusive instead of being confined to the rigid federal process — we have the local expertise to know how the creek actually works and to develop plans that are sustainable for natural processes and the environment."

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DEREGULATE

Taking a Break from the Corps

ROBIN MEADOWS, REPORTER

Corte Madera Creek, which drains the small watershed between Mount Tamalpais and San Pablo Bay, is barely four and a half miles long. But this little creek is an outsized problem for people in Ross and other towns built right up to its banks. Nearby streets can flood to depths of three feet during the rainy season, running like streams and leaving a shocking amount of mud in their wake.

Engineers test concrete in channel. Photo: MCDPW

"Our peaceful creek turns into a rushing torrent in winter," says Chris Martin, who grew up in Ross. One of his neighbors kept a canoe outside of his house for rescuing those stranded by floods, only to be stranded himself at age 100 years. "He called 911 and they said to handle it himself," says Martin, a former Ross mayor who ran for office to work towards a better solution.

Finding a fix has been contentious since 1971, when the U.S. Army Corps of Engineers put a mile-long concrete flood control channel through Ross. "It never worked," says Sandra Guldman, board president of Friends of Corte Madera Creek. "It disconnected the creek from the floodplains, wrecked the coho salmon fishery, and didn't accomplish its purpose — it's a failure any way you look at it."

The local community has repeatedly rebuffed the Corps' attempts at redoing the project. The most recent effort, developed under a 2014 agreement between Marin County and the Corps, was shot down in 2018. The plan received so many public comments that responding to them would have taken more staff time than the County was legally able to provide under its agreement with the Corps. "We were working under a strict 50/50 cost share that did not allow us to exceed the funding currently allocated to the project," explains Liz Lewis, who oversees the project as water resources manager for the Marin County Department of Public Works.

So the County and the Corps terminated the 2014 agreement. "I think everyone heaved a huge sigh of relief," says Guldman. This short-term shift to local control keeps the project under Corps authorization, leaving open the possibility of partnering with the Corps on future flood control efforts further up Corte Madera Creek.

Local control will speed reworking the flood control channel in Ross. "The Corps has a lot on its plate — projects can take a long time," says Martin, a longtime member of the region's flood control advisory board. Another benefit of local control is that it will facilitate aligning the project with community priorities. "It will be a comprehensive flood control program," he continues. "It will be as natural as possible and will provide public access where possible."

Key elements of the local plan include removing one or both sides of the concrete channel where feasible, and then restoring floodplains and riparian corridors. "Widening the creek will increase its capacity to accommodate flood flow," Guldman says. Ultimately, the project could also help steelhead trout and coho. "We're working to improve passage for salmon through the concrete channel until they reach a natural stream bed in Ross," says Lewis.

The project, estimated at $13.5 million, is on track to be constructed by 2023. For the thousands of people who live, work and go to school along this part of Corte Madera Creek, finally getting a respite from flooding will be the biggest relief of all.

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R E C Y C L I N G

Sustaining Pajaro Valley's Water

DANIEL MCGLYNN, REPORTER

The Pajaro Valley enjoys a temperate microclimate, in part because it is situated at the hip of Monterey Bay. It lays like an east-west-oriented horseshoe, with the open end settling around the coastal plains of Elkhorn Slough and its various tributaries and side sloughs. Rimmed by the Santa Cruz Mountains to the north, the Gabilan Range to the south, and the San Andreas Fault at its head, the Pajaro Valley is a unique place in California.

Marks from the state's past — traces of the indigenous creekside camps to the Mission landmarks and Gold Rush-era place-names — tell part of the valley's story. Unlike in neighboring areas that have embraced the commuting car culture, the endless lines of perfectly aligned row crops reveal that this valley is still very much a working landscape.

But the Pajaro Valley is different from the rest of the big ag regions in California. The loamy soil isn't irrigated with massive surface water infrastructure like in the Central Valley. "There are no federal or state water projects here," says Marcus Mendiola, a water conservation and outreach specialist with the Pajaro Valley Water Management Agency. Nevertheless, the 28,500 acres of well-tended crops in the lower Pajaro watershed are planted in what is considered among the most valuable agricultural land on the planet.

The farms that create the economic engine of Pajaro Valley operate at different scales. Some growers are small, while others have labels you might recognize from the grocery store: Martinellis, Driscolls, California Giant, to name a few. Regardless of the amount of acreage under management, one thing that the farmers (and all residents, for that matter) share is that most of their water comes from the ground.

How to best handle the area's diminishing supply of groundwater has occupied local water managers for decades. "People have been documenting groundwater concerns here since the 1950s," says Mendiola. But improvements to conservation and infrastructure — funded in part by California's 18-year old Integrated Regional Water Management program — have bolstered the valley's chances of thriving in the face of future stresses like climate change and seawater intrusion.

Strawberry fields forever

Like cairns that show the way on a faint trail, the coastal distribution pipeline operated by the Pajaro Valley Water Management Agency and serving 5,000 acres of prime farmland is marked every so often by turnouts. The turnouts pop above ground as six-to-eight-inch-diameter pipe and then bend at 90 degrees. They are affixed with a series of valves (and usage meters, which are in the process of being converted from hand-read manual meters to digital meters). The turnouts allow irrigators to connect to a vast system of water infrastructure managed by the agency, known locally as PV Water.

PV Water was created in 1984 by state charter to deal with the valley's diminishing water supply. The agency is solely focused on the conservation and management of groundwater for irrigation, which accounts for 85 percent of the water demand in the valley.

"The entire geology of this area is like a layer cake," says Mendiola. Historically, the recharge rate of the layer-cake-like aquifer used to keep pace with the withdrawal rate. So much so that valley old-timers remember when wells near the coast would run artesian, which means that the aquifer was so full that when tapped, water would come to the surface without pumping, Mendiola says. But in more recent decades in the Pajaro Valley, like in much of California, the demand for water has exceeded the supply, meaning the level of available water in the aquifer was continually receding.

The color of PV Water's turnouts and wellheads along the 21 miles of the coastal distribution pipeline system is significant. Blue paint means that the valves connect to a well underneath the ground. The health of these wells — both quality and quantity (salinity is a major concern) — is managed through recharge efforts. For the past two decades, PV Water has been experimenting with new ways of increasing natural recharge (or allowing water to percolate through the ground, which filters the water and raises the level of the underlying aquifer) across its jurisdiction.

In 2002, one of PV Water's first major infrastructure projects came online. They retrofitted equipment that Santa Cruz County once used to dewater cropland and now use it to pump water — permitted up to 2,000 acre-feet a year and only when the water quality and quantity meet certain thresholds — into a recharge basin a mile-and-a-half away. This time of year, ducks love the recharge pond, which is in the middle of what feels like endless fields of just-ripening strawberries. Underground it's

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Above photo: Early strawberries growing near PV Water's Harkins Slough recharge basin. Photo: Daniel McGlynn

A blue recovery well that pumps water adjacent to the Harkins Slough recharge basin.

refilling local aquifers. "After all, the best and most efficient place to store water," Mendiola says, "is underground."

Here and there on the horizon, purple turnouts are visible. Purple means the water is coming from a recycling facility. Opened in 2009, and continually improved since, the Watsonville Area Water Recycling Facility helps PV Water manage for both agricultural output and a healthy aquifer. By using water recycled from Watsonville's municipal wastewater plant, the agency is able to offset some of the demand for groundwater. "The groundwater creates a hydrostatic barrier, which prevents further seawater intrusion," Mendiola says. As an added benefit, further treating water coming from the wastewater facility and sending it back to the fields as high-quality, non-potable water reduces the need to send the nutrient-rich water through a discharge pipe into Monterey Bay. For the last 14 years, PV Water has been monitoring nutrient loading of soil and groundwater in their recycled water delivery area. "We have not observed a negative impact to the soils from recycled water deliveries," Mendiola says.

The water diverted into the recycling facility averages about 57 percent (or about 6,000 acre feet) of Watsonville's wastewater over the course of a year. During peak dry times as much as 100 percent of Watsonville's discharge is recycled according to Mendiola. In three concrete structures, the recycled water goes through additional processing steps including more solid separation, filtration, and disinfection, and blended with other water sources before entering PV Water's coastal distribution system and made available to irrigators. The system has worked so well that it was expanded in 2014 to include an additional 1.5-million-gallon storage tank to keep up with demand. The new tank, as well as the recycling facility itself (which today is under construction to add additional filtration), was funded in part because recurring droughts led California to make a priority of promoting more integrated regional water management in the early 2000s.

When reach exceeds grasp

First launched in 2002, Integrated Regional Water Management (IRWM) alleviates some of the burden of managing California's complicated water situation. A collaborative effort led by the Department of Water Resources, IRWM is an organizational structure designed to get water-related funding earmarked via bond measures prioritized and delivered to water-related projects around the state. So far, the department has awarded $1.5 billion in IRWM grants for infrastructure, education, conservation, and access.

The Watsonville Area Water Recycling Facility, which is operated by PV water can recycle as many as 1.1 billion gallons of water a year. Photo: PV Water

The goal is to better coordinate water-related expertise, data, and funding across jurisdictional, watershed, and political boundaries to concurrently achieve social, environmental, and economic benefits, explains James Muller, principal environmental planner with the San Francisco Estuary Partnership and the grant manager for 39 projects under three IRWM grants in the Bay Area.

IRWM divides the state into 12 funding regions that are allocated a discrete share of the total IRWM funding made available by bond propositions. The Department of Water Resources solicits proposals from these funding regions that must meet an arduous set of eligibility criteria.

The Watsonville Area Recycling Center received several rounds of funding under Proposition 84 including $4.7 million to build the coastal distribution pipeline, $6.8 million to build the recycled water facility, and $900,000 to build the 1.5-million-gallon storage tank. While the money did help get those projects built, IRWM funds represent only a portion of the total construction and maintenance costs for most large-scale projects. "You also see projects that would never happen unless they were funded by a program like IRWM," says Muller.

"It's been good," says Brian Lockwood, general manager of PV Water, about the IRWM process. "It's definitely developed increased collaboration. It makes you think and work together at a more regional scale, instead of only working in your own box."

And the work continues. While Lockwood is concerned that the tap of IRWM funds might not be flowing as steadily as in previous years, the agency is still using IRWM money to expand the availability of recycled water for irrigation.

In Pajaro Valley, PV Water will break ground soon on an addition to the coastal delivery system, bringing more recycled water to more farms to the north. The project is funded by $3 million in IRWM funds. "We'll be able to add two miles to our 21 miles of the existing coastal distribution pipeline," Lockwood says.

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A purple turnout delivering recycled water to some of Pajaro Valley's valuable farmland Photo: PV Water.

MIGRATIONS

Tracking Curlews Cross-Country

JOE EATON, REPORTER

Long-billed curlews are a familiar winter sight on San Francisco Bay's mudflats and beaches and in the Central Valley's pastures and alfalfa fields. North America's largest shorebird (the world's second-largest, after the endangered Far Eastern curlew), the longbill is hard to miss, with a three-foot wingspan and, in adult females, a six-inch scythe of a beak. Until recently, the species' migratory behavior was little known, with only sparse band returns. Telemetry has filled major gaps, enabling researchers to track curlews from nesting grounds in Idaho's Snake River watershed — where a once-thriving population faces local extinction due to poaching — to the Sacramento and San Joaquin valleys, but so far with only one data point for the Estuary.

This winter, Jay Carlisle, director of the Intermountain Bird Observatory, teaming with Nils Warnock of Audubon Canyon Ranch and netting expert David Newstead of Coastal Bend Bays and Estuaries Program, caught two curlews at Limantour Beach in Point Reyes National Seashore and outfitted them with transmitters. Those birds may reveal where the wintering curlews on the California coast and Bayshore are coming from.

Curlew telemetry was pioneered in 2007-2010 by a team headed by Gary Page of Point Blue and including Warnock, with 29 birds from Oregon, Nevada, and Montana. Nine Oregon curlews and a few from Nevada were tracked to Central Valley farmlands. The Montana birds wintered from the Texas Panhandle to the Mexican Plateau.

Carlisle, who is also on Boise State University's faculty, began his curlew project in 2009 at the Bureau of Land Management's Long-billed Curlew Habitat Area of Critical Environmental Concern, which once had the highest breeding population of curlews in the interior mountain West. Four years later, a grant enabled him to buy transmitters. "Other people became interested, and it grew organically," Carlisle recalls. He partners with researchers in eastern Idaho, western Wyoming, and southwestern Montana.

Patterns emerged: 80 percent of his southwest Idaho subjects migrated to the Central Valley and 20 percent to the Imperial Valley. Most eastern Idaho and western Wyoming curlews headed for Mexico. Last year the telemetry project expanded to British Columbia and New Mexico, the northern and southern extremes of the curlew's breeding range.

Technological advances have made tracking easier, at least. Carlisle uses lighter-weight devices than Page's group, 9.5-gram solar-powered transmitters. High return rates indicate birds with transmitters are adapting well. The data isn't GPS-quality yet, and there's down time for recharging. A pilot project with cellphone data, used with snowy owls and other species, is in the works.

Still, data gaps remain. Page's group had one data point near Arcata. Carlisle says a bird from Montana wearing a wonky device transmitted once from the northeastern end of San Francisco Bay in 2014 and was never heard from again. "Thousands winter from Arcata to San Diego, but nobody has tracked birds from these areas," he adds. Although he wanted more California subjects, most of the curlews at Limantour eluded Newstead's cannon nets. Hopes now ride on the two wearing transmitters provided by the Smithsonian's Migratory Connectivity Project.

Meanwhile, Carlisle's original subjects are in trouble: "We saw the population in southwest Idaho not functioning at an optimal level, with low nesting success. They were looking like a sink population. There had

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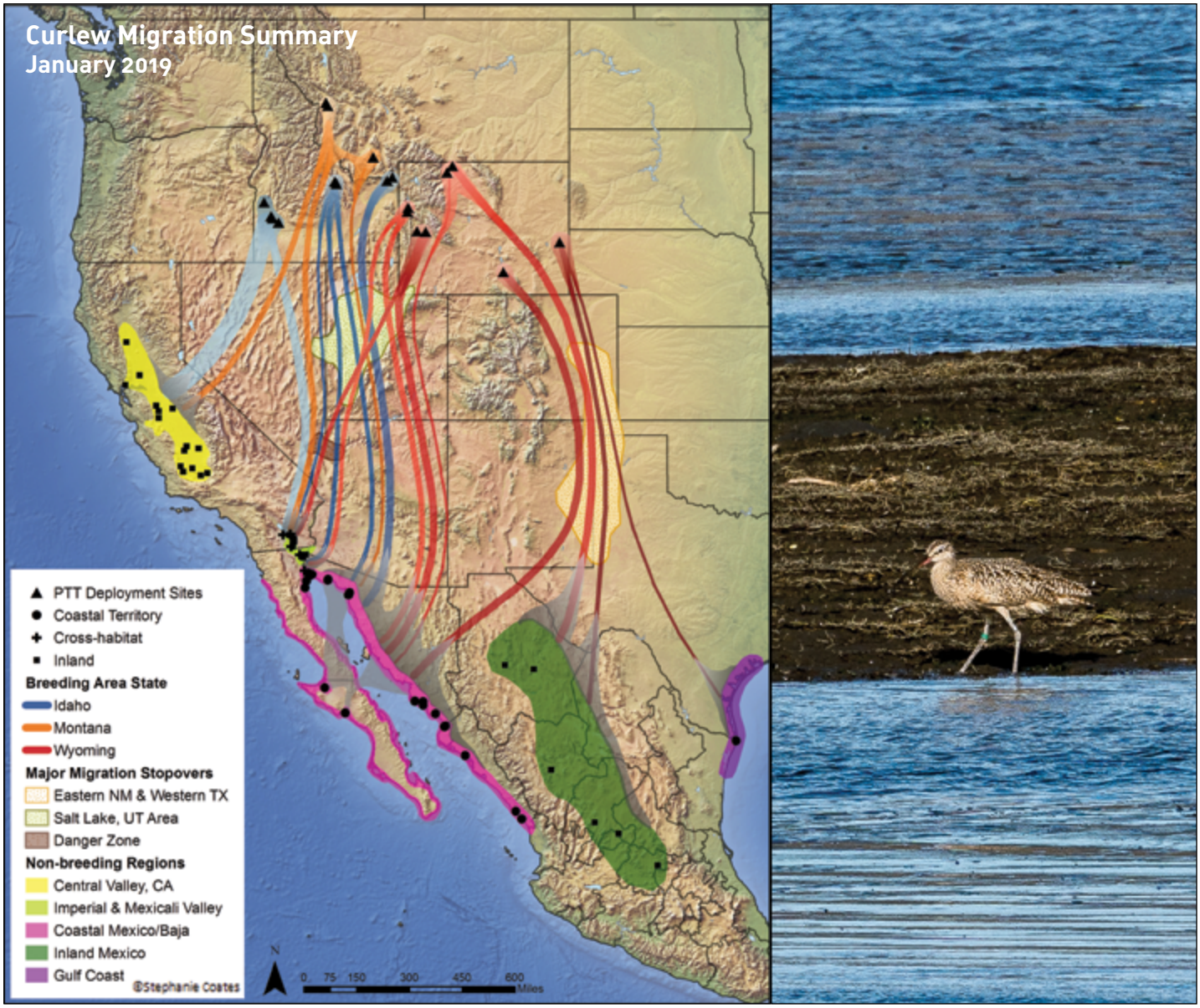
Curlews at Drakes Bay near Point Reyes; curlew being fitted with transmitter pack. Photos: Nils Warnock



Boise State University: Intermountain Bird Observatory

Photo: Scott Jennings

been a 90 to 95 percent decline in Idaho over the last 40 years while other populations in the region appear stable. We considered possible factors like changes in climate and habitat, but poaching hit me over the head with a sledgehammer. It was the big issue."

Over six years, seven of 16 transmitter-equipped curlews were found fatally shot on BLM land. In 2016 Carlisle's team shifted their research efforts to the Morley Nelson Snake River Birds of Prey National Conservation Area, BLM-administered and used by the Idaho National Guard, finding gunshot curlews there as well.

Although longbills were once hunted for the table (market hunting, in fact, pushed the related Eskimo curlew toward extinction), Carlisle says the Idaho curlews are being shot and left to die. Both BLM sites are accessible to target shooters and "varmint hunters" legally going after coyotes, badgers, and ground squirrels, and the large, vocal curlews are collateral damage. "Adults point to teenagers as the culprits, and vice versa," he says. The rapid growth of Idaho's human population is a contributing factor. Killing curlews violates the federal Migratory Bird Treaty Act, but resource agency law enforcement personnel lack the resources to address it. Carlisle and his colleagues have launched an educational campaign in local schools, stressing the curlews' ecosystem services as consumers of insect pests.

While many grassland birds are experiencing catastrophic declines, long-billed curlews had appeared to be an exception. "It's such a habitat generalist that adapts well to humans," Carlisle notes. "Some birds spend a hundred percent of their lives in agriculture-dominated land," migrating from Idaho pastures to California alfalfa. But all crops aren't equal from a curlew's perspective. California's burgeoning almond, walnut, and pistachio orchards are useless to them. Coastal-wintering birds may fare better, but are still vulnerable to chemical exposure, coastal development, and sea level rise. The troubles of these charismatic shorebirds could extend beyond the killing fields of Idaho.

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F I S H E R I E S

Where Have All the Herring Gone?

ALASTAIR BLAND, REPORTER

Pete has fished San Francisco Bay for nearly all of his 60 years. A lifelong San Francisco resident who keeps his last name to himself, he recalls herring runs in the 1970s the likes of which rarely, if ever, occur anymore.

"I remember herring spawns that went from Oyster Point all the way to the Golden Gate Bridge," says Pete, a former commercial fisherman, referring to the point near Brisbane. He also remembers massive spawns that stretched contiguously from the Tiburon peninsula out the Golden Gate to Point Bonita.

Today, the fish still return. Each year between December and March, schools of Pacific herring, *Clupea pallasii*, lay and fertilize their eggs in the Bay's shallow waters. When the fish gather at sites like Point Richmond, China Basin, and the Sausalito waterfront, so do frenzied birds and pinnipeds, all feasting on the sardine-sized fish. As the female herring lay their eggs on rocks, pier pilings, and eel grass, the males release clouds of sperm that color the water a chalky gray.

Fishermen also attend large herring spawns. Recreational anglers fill buckets and coolers using hand-thrown nets, while commercial gillnetters, who sell the bulk of their catch for various industrial purposes, fill boats.

But these spawns are a pale shadow of the massive events of the past. Veteran fishermen say they've watched northern California's herring, which also spawn in Tomales and Humboldt bays, dwindle away.

"You used to see herring breezing the surface on the open ocean," says Tom Baty, a naturalist and lifelong resident of Inverness who has fished the Point Reyes area since the 1960s. "But we don't anymore, and we don't find them in salmon bellies anymore, either."

Today, a San Francisco Bay herring spawn tends to be a comparatively isolated event — often limited to a single cove or a mile of shoreline.

Population figures from the California Department of Fish and Wildlife illustrate a long downward trend, accented by periodic spikes in abundance. Average returns through the 1980s, reported in estimated spawning biomass, hovered in the 50,000-ton range. By the 1990s, biologists' estimates — which they base on density and extent of egg deposition during spawn events — had dipped into the 30,000-ton range.

The fish staged a comeback of sorts early this century, with a record-smashing spawn in 2005-2006 and another surge beginning in 2010, when estimated abundance spiked to circa-1980s levels for four years.

But then the numbers plunged to new depths, and since 2015 the herring have trickled into the Bay. Returns have not exceeded 18,000 tons for six winters in a row, and last year saw just 8,030

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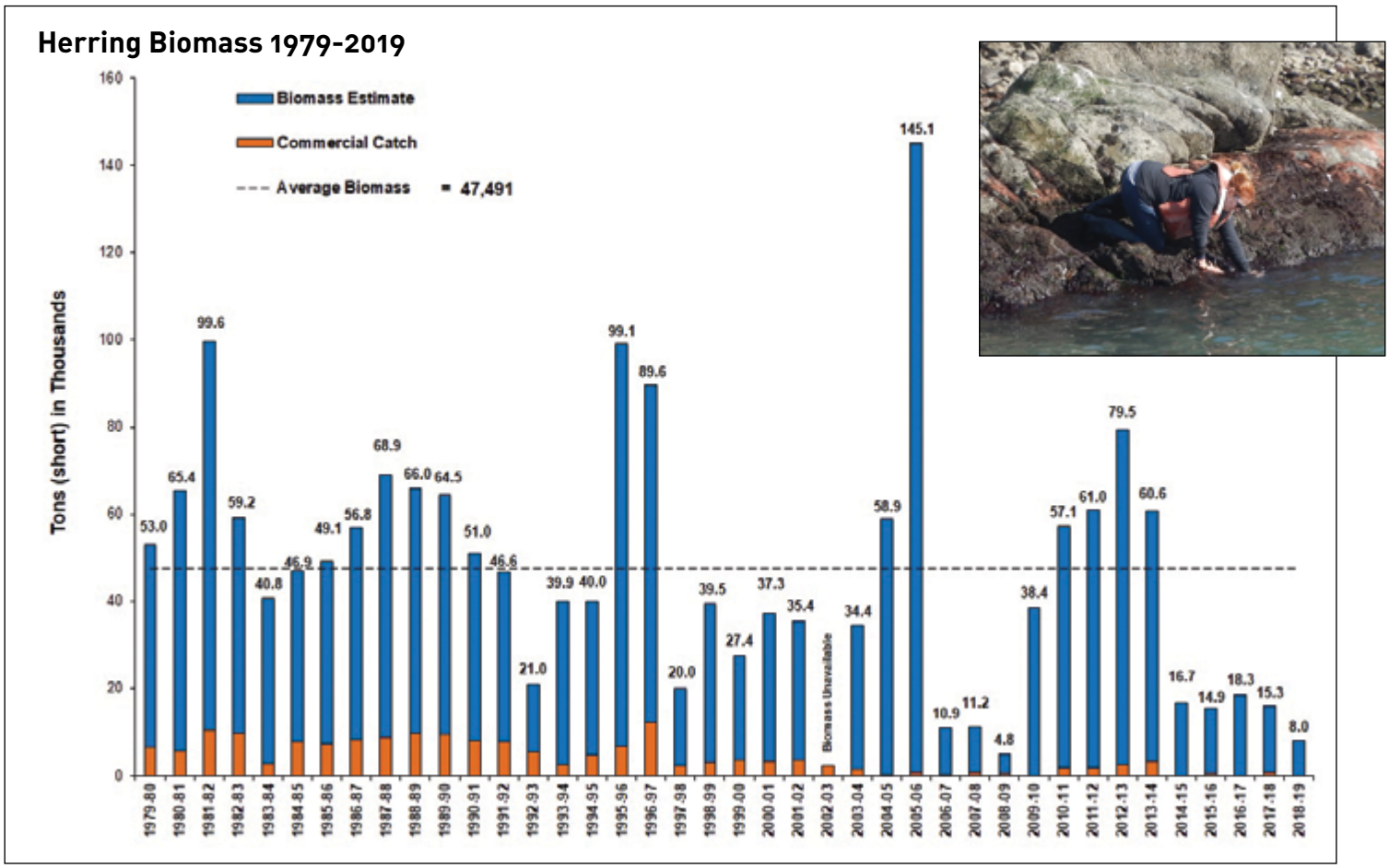

Chart & Photo (this year's biomass survey in action): CDFW

tons — the second lowest biomass on record. (The lowest, 4,800 tons, came in 2008-2009 and is generally believed to have been the result of the 2007 *Cosco Busan* oil spill.)

This season, based on visible spawning events and accounts from recreational fishermen trying fruitlessly to catch the herring, seems to have been one of the worst years on the books.

No one is sure what's ailing these oily, nutritious pillars of the food web, but different sources have different theories. Some blame overfishing, while the California Department of Fish and Wildlife contends that the harvest rate is sustainable. The department sets commercial catch quotas at less than 10 percent of the previous year's estimated biomass. It's a squishy management system, but the department's herring team believe it works. Commercial fishing, they say, likely dented herring stocks several decades ago. Using nets, the Bay's herring fleet used to catch thousands of tons of herring every year. Landings peaked in the late '90s at 12,000 tons.

But the department, whose biologists declined to be interviewed by phone, says the more recent decline has probably been due to unfavorable ocean conditions.

"Since the early 1990s, environmental conditions off the coast of California have been more variable than in previous decades, with more rapid shifts between warm and cool conditions," Fish and Wildlife's herring team wrote in an emailed statement. "This oceanographic variability has been reflected in the increasing variance of the spawning biomass of the San Francisco Bay Herring stock."

Today, the fleet generally catches a few hundred tons of herring each winter. The females' roe is sold to Japan as a delicacy while the rest of the catch, including the male herring, is treated as little better than trash. Industry sources say it's mostly used as livestock and aquaculture feed.

"Zoo food," Baty recalls, was the euphemism that fishermen and Fish and Game staff used for such herring.

Kirk Lombard, a sustainable fishing advocate who has gained some local fame as a seafood foraging guide, believes the commercial fishery should have been closed years ago, when the herring population showed signs of stress.

"If the fishery has gotten so bad that they're putting limits on the recreational catch," Lombard says, referring to a decision to do so last year, "then why is there even a commercial fishery at all?"

This is not the first time that an apparent decline in herring population has prompted concerns. In 2003, the Department of Fish and Game itself (now Fish and Wildlife) sounded the alarm. By the department's estimates, the Bay's herring population had crashed, and at a public meeting in Los Angeles in August of that year, department biologist Becky Ota recommended that the California Fish and Game Commission close the fishery. Fishermen lashed back. They contended a closure was unnecessary and that Fish and Game was using flawed methods for counting fish and eggs and was underestimating the biomass. The commission sided with the industry and voted to maintain a generous quota.

A few years later, estimated biomass spiked to its record high of 145,000 tons. Fishermen who had argued just three years before that the department's methods for estimating population were flawed now stood by the sky-high figure as evidence that the population was healthy. Commercial fishing continued, even as herring numbers subsequently waned.

Some scientists, like William Sydeman of the Farallones Institute, stand by the department's diagnosis of the ailing herring population — that the dip in herring numbers is the result of depressed ocean productivity. In recent years, warmer surface waters have weakened upwelling cycles, depriving the food web of the cold, nutrient-packed bottom water that drives the growth of plankton, on which herring and anchovies feed.

But Sydeman says he isn't sure what's causing the reduced ocean productivity.

"Is it part of an ocean-warming cycle that will reverse naturally, or is it related to human-caused warming?" he says.

Herring are struggling elsewhere, too. Up the coast, all the way to Alaska, populations have shriveled. A once-productive fishery in southern Alaska collapsed in the 1990s. It has failed to rebound, prompting a grim theory that the ecosystem, perhaps more plastic than elastic, has simply re-stabilized as one without herring.

In British Columbia, activists have called for a ban on industrial herring fishing, which they blame for the decline in several distinct populations. Pacific Wild, a group based in Victoria, has argued that fishery managers, by using the year 1950 as the baseline for abundance, are misevaluating the health and stability of herring populations. The group contends that historical abundance of the fish was far greater than presumed and that 1950s numbers represent a depleted fishery.

In fact, shifting baselines is a problem that affects fisheries everywhere. The phenomenon occurs when successive generations of people lose sight of past abundance levels and end up misinterpreting a depleted population of animals for a thriving one. It's a dangerous process that can cause misguided management and further depletion.

In the case of California's herring, accounts from experienced fishermen remind us of what once was.

"You could see these massive, massive spawns, where it seemed like they'd go on for miles," says Baty, recalling winter herring runs in Tomales Bay in the 1960s, when he was a boy.

There has been essentially no fishing pressure on the Tomales Bay population for many years, but Baty thinks heavy commercial harvest in the past pushed Tomales Bay's herring into what ecologists call a "predator pit." Facing growing numbers of pinnipeds and cormorants, the fish just can't recover, he believes.

Jon Warrenchuk, a Juneau-based scientist with the advocacy group Oceana, suspects a range of factors are responsible for ailing herring runs.

"It's the cumulative impacts of climate change, ocean acidification, habitat loss, predation, and the lingering effects of past and present industrial fishing," he says.

To Lombard, the ambiguity surrounding the herring collapse is exactly why fishery overseers need to act cautiously and, at least temporarily, close the commercial fishery.

"Given the state of the environment, global warming, and the deplorable state of fisheries," Lombard says, "do we have the leisure anymore to assume that natural cycles are causing this and that the herring will just come back?"

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CONTAMINANTS

Kinky Fish Spines Linked to Selenium

JOE EATON, REPORTER

It's been more than 30 years since Kesterson National Wildlife Refuge joined Three Mile Island, Hunters Point, Love Canal, and the Cuyahoga River in the geography of contamination. You may have seen the horrific images of deformed shorebird chicks, poisoned by selenium in runoff from San Joaquin Valley farm fields. Kesterson is no longer on the map (it's now part of the San Luis refuge), but selenium is still very much with us, entering the Estuary through the San Joaquin River and from refineries and other sources around San Francisco Bay, working its way through aquatic food webs from clams to sturgeons and diving ducks.

Scientists with the U.S. Geological Survey (USGS) and the National Oceanic and Atmospheric Administration (NOAA) are using new tools to track selenium, with the Sacramento splittail, a California-endemic fish with its own checkered past, as an indicator species. In a macabre echo of Kesterson, deformed juvenile splittail have provided clues to the patterns and processes of selenium contamination.

Named for its forked caudal fin, the Sacramento splittail is the only surviving member of its genus. (The closely related Clear Lake splittail went extinct in the 1970s.) With a maximum length of 18 inches, it's a midsize minnow that is tolerant of high-salinity conditions. Adults move into freshwater in winter and spring to spawn in flooded areas, producing over 250,000 eggs per individual female; surviving hatchlings follow slough channels into the Estuary. It's a boom-or-bust life cycle, with better reproduction in wet years. Habitat loss exacerbated by the drought of 1987-93 led to its listing as a threatened species by the U.S. Fish and Wildlife Service in 1999. Following litigation by water agencies, the listing was remanded in 2004. Today the fish has no federal protected status, although it's still a California Species of Special Concern.

Historically, adult splittail fed mainly on opossum shrimp and other crustaceans. After the invasion of the exotic clam *Potamocorbula amurensis* in the 1980s reshaped Estuarine food webs, clams replaced crustaceans in their diet. Apart from filtering plankton from the water column, one thing the M&M-size *Potamocorbula* excels at is accumulating selenium. The splittail's clam-heavy diet also makes it a handy species for monitoring selenium. In 2011, the discovery of juvenile splittail with spinal deformities characteristic of selenium toxicity suggested other pathways of exposure, since the younger fish don't eat clams.

Robin Stewart, lead author of new paper on splittail and selenium, is one of the region's most seasoned current experts on bioaccumulation of metals in estuarine species. Growing up in Manitoba, she wanted to study orcas. Seasickness rerouted her career trajectory, and she wound up working on clams with USGS. A specialist in chemical contamination, Stewart has looked at mercury and selenium. Her USGS mentor Samuel Luoma was an early advocate of monitoring bioaccumulated selenium in animal tissues in addition to dissolved selenium in water, influencing new US Environmental Protection Agency water quality criteria proposed in 2016. The agency proposed adding selenium criteria for fish (muscle, egg and ovary, and whole body) and clam tissue.

In an article that recently appeared in *Science of the Total Environment*, Stewart and Fred Feyrer of USGS and Rachel Johnson of NOAA analyzed selenium in adult splittail collected in 2010 and 2011. Their data held some surprises. In some sampled splittail, selenium levels exceeded the proposed EPA protective criteria for fish ovaries. Liver levels, not included in the EPA criteria, were also high. Unexpectedly, muscle concentrations were below the EPA criteria.

"Muscle is often used as a convenient proxy for liver and ovary, but for this species there's a disconnect," says Stewart.

Also of note, the muscle tissue selenium concentrations didn't vary between the wet year and dry year in the splittail sampling period, although such variation has been documented in *Potamocorbula* clams that splittail feed on. Indeed historically, the amount of rain, runoff, and flow has influenced many measures of estuarine contamination.

One clue to the relative importance of various sources of selenium in the system was that selenium levels in the fish were higher at the mouth of Pacheco Creek, near three oil refineries, than in other locations. That's suggestive but doesn't settle the question of whether the selenium in adult splittail is coming from the Sacramento River, San Joaquin Valley runoff, within-Estuary point sources, or even the Pacific Ocean.

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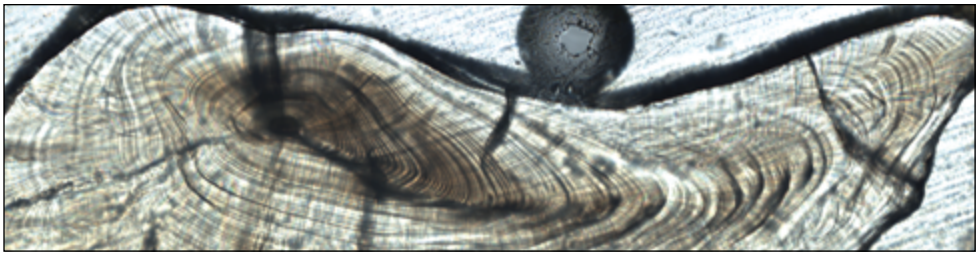
Above: Spinal deformity in splittail. Photo: Fred Feyrer, USGS



Lapilli otolith in splittail. Photo: George Whitman, UC Davis.

"We need more sophisticated tools, and our team is building them," Stewart adds. "USGS scientists and collaborators are implementing three-dimensional computer models of flows and selenium tracers that may help us understand how selenium from different sources is transported and mixed in the Estuary under changing flow conditions, thus affecting fish exposure."

Colleague Rachel Johnson has focused on juvenile splittail, in a collaboration with Stewart, Feyrer, and other scientists whose results have just been published in *Environmental Science and Toxicology*. A splittail's otoliths — tiny bones in the fish's head that help it keep its balance — contain a diary of its movements and a timeline for selenium exposure. "Otoliths are a powerful tool for tracking organisms that are too small to tag," she explains. They have bands, like the growth rings of a tree, that form daily. Stable isotopes of elements like strontium in the growth bands provide a geographic marker of where the fish was when a particular layer was formed: what Johnson calls "a spatial map — a library of signatures."

The Sacramento and San Joaquin rivers and the Pacific Ocean each have distinctive ratios of strontium isotopes. It's down to watershed geology: younger volcanic rocks in the South Cascades and the Lassen region for the Sacramento, older southern Sierra granite for the San Joaquin.

When Johnson analyzed the otoliths of deformed juvenile splittail collected in the Delta at a pumping station, she found that they had acquired an initial dose of selenium from their mothers through the yolk they used for nourishment after hatching. But the highest concentrations were in a portion of the otoliths formed when they were feeding on fly larvae and other benthic invertebrates in the San Joaquin floodplain, where habitats accessible for spawning in wet years harbor elevated selenium levels. "The otolith tool allows us to see a complete picture of selenium exposure," Johnson says. "Using otoliths to look at contaminants is a novel use of the diet history the otoliths provide."

Both adult and juvenile splittail are prey for striped and largemouth bass, and some Californians catch them for food and bait, with a two-fish bag limit. Human health risks from bioaccumulation of selenium via splittail seems to be less of a concern than the potential effect of this potent reproductive toxin on fish populations. Feyrer says that available survey data suggests splittail numbers are relatively stable for now.

Stewart approaches selenium levels in splittail as a signal of broader changes in patterns and processes influencing the Estuary. "Selenium concentrations in the Sacramento River are lower than in the San Joaquin," she says. "If more Sacramento River water were diverted before reaching the Delta, that could result in changes to the concentrations, spatial patterns, and source mixtures of selenium in the Estuary. We need to understand how Delta plumbing changes could change selenium exposure."

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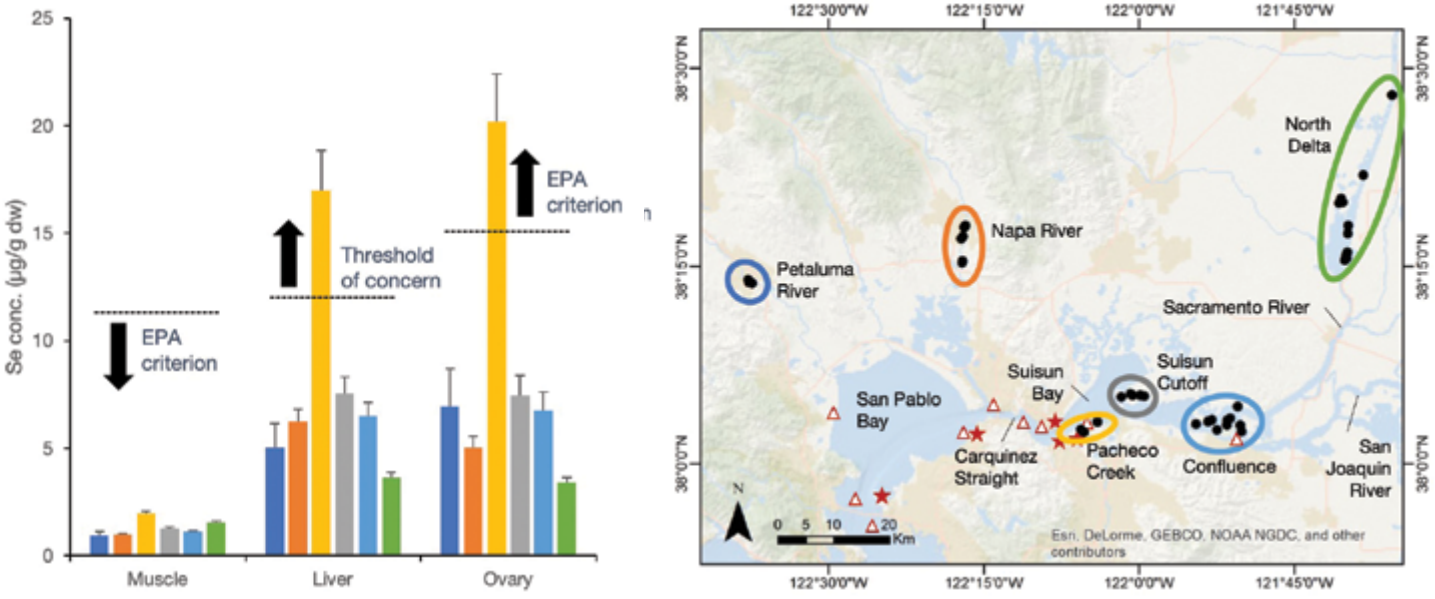
Splittail Tissue Collection Stations & Selenium Concentration Results



Areas of San Francisco Estuary where Sacramento splittail were sampled in 2010, 2011 and 2017 (North Delta only). Black filled circles – sites of fish collections. Red arrow – agricultural irrigation sources from the San Joaquin Valley. Red stars – oil refineries. Red triangles – wastewater treatment plants. Colors on the bar chart reflect Splittail collection areas on map of same color. Source: Stewart et al 2020. Reprinted from Science of the Total Environment*, Volume 707, with permission from Elsevier.*

MONITORING

Microtrash Tiresome for Watersheds

JACOBA CHARLES, REPORTER

Stormwater sluices microparticles of plastic, rubber, Styrofoam, balloon string, and other trash through the region's watersheds. On a rainy day, this microtrash might be invisible in the mulch of garbage tugging against the bars of a stormdrain. But as many as 30 particles smaller than five millimeters in diameter occur per liter, according to a report published by the San Francisco Estuary Institute and 5Gyres last October titled "Understanding Microplastics Levels, Pathways, and Transport in the San Francisco Bay Region."

"This is a groundbreaking study," says Chris Sommers of the environmental consulting firm EOA, Inc., where he is an expert on stormwater monitoring and management. "It shines a light on the magnitude of the amount of microplastics that are out there, and where they end up."

While a 2015 amendment to California's Water Quality Control Plan requires zero trash in stormwater by 2030, this policy applies only to items that are greater than five millimeters in size. Until now, there has been no study of the smaller microtrash following the same pathway, either in the Bay Area or beyond.

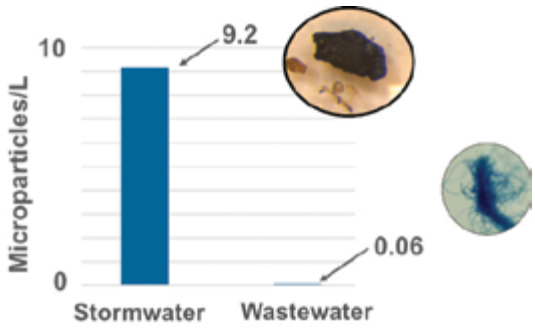
"I am really encouraged by the level of interest this issue is getting," says Sommers, a reviewer of the study for the Regional Monitoring Program. "Historically, trash has not really been seen as a 'sexy' pollutant; sometimes it's hard to get the public engaged in stormwater quality issues."

The SFEI/5Gyres report estimated that stormwater carries an overall load of 7.2 trillion pieces of microplastic from small tributaries into the Bay each year. This is more than 300 times greater than the estimated microplastic load from municipal wastewater, which has more often been studied as a source of this pollution in the environment.

The research team was also surprised by the types of microtrash found in stormwater.

"A big proportion of what we saw in the stormwater were black rubbery fragments," says Diana Lin of the San Francisco Estuary Institute, a lead author of the report. "But a lot of the larger plastic litter items are polyethylene or polystyrene — that's what we were expecting to see."

The average microparticle abundance is greater in stormwater



All microtrash that visually looks like plastic is dubbed "microparticles" by researchers. The subset that they are able to conclusively identify as plastic is microplastics, which include rubber and Styrofoam.All are considered potentially harmful because they are slow to break down and accumulate in the environment, and can be ingested by wildlife.

After the black fragments, which made up nearly half of the particles and which researchers suspect are cast off by vehicle tires, fibers made up the other main type of microplastics found. These hairlike threads comprised 39 percent of the particles, and could come from a variety of sources including abandoned clothing and cigarette butts. Foam and spheres — such as degraded Styrofoam, or deconstructed Beanie Babies — made up less than 1 percent of what was found in stormwater.

There are reasons that this is the first time researchers have studied microparticles in stormwater in the Bay. "This is a particularly hard matrix to sample," says Lin. "You have to be ready to go out in the middle of the storm when water flows are at their highest, often very late at night."

The team had to be ready to mobilize their vans, go to sample sites, and extract samples of the churning water in drains, along creek banks, and off street bridges. The trash was then filtered out using a series of sieves that categorized it according to size.

Back in a lab, the microtrash then had to be identified, separated, and grouped into different types.

The study sampled stormwater from 12 tributaries that feed into the Bay, and found that microparticles were discharged at a rate of between 1.3 and 30 particles per liter, depending in large part on whether or not they were located in urban or rural watersheds.

The study also sampled microparticles in municipal wastewater, prey fish, and Bay sediments and surface waters. Different distributions of microparticles were found in each type of sample. Other than in stormwater, fibers were the most common in all sampling categories. The black, rubbery fragments were also common in sediments.

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Over all, researchers found high levels of microplastic contamination in the Bay. Levels measured were also higher than in other locations worldwide to date, and far higher than the more rural reference samples from Tomales Bay used in the 2019 study.

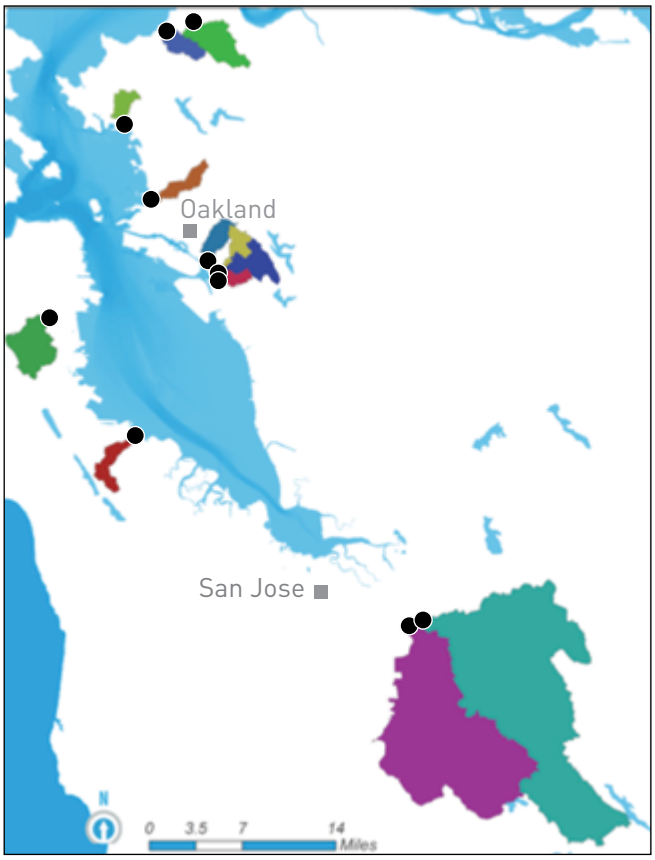
Researchers are following up on this study with further investigations into the biological and ecological effects of microplastics.

"Now that we have the data on occurrence, it will take a lot more work to understand the impacts," Lin says. Microplastics research is a relatively new scientific field.

"The question is, are microplastics impacting anything adversely? We don't know that yet," says Sommers. "For now, this research just brings up a yellow flag — that there is a lot of this stuff coming into the Bay from this one pathway."

Potential impacts could range from the physical, such as fish not getting enough nutrition because they are mistaking microplastics for food, to the chemical, due to the different materials microparticles are made of, says Lin. "The plastics can have different additives, like chemical plasticizers and dyes, that could be causing extra toxicity," she says. Confirming whether the black fragments are in fact from tires is also important, Lin says. Tire rubber contains a variety of chemical additives that can be toxic to wildlife.

Watersheds sampled for microparticles and microplastics in stormwater



Black dots: sampling sites. Source: SFEI

In addition to understanding impacts, more research needs to be done on how to reduce microtrash pollution in the first place, Sommers noted.

While society is unlikely to replace the widespread use of plastic products and rubber tires, researchers have identified a possible treatment. A second 2019 study, also co-authored by Lin, found that a bioretention rain garden was able to capture more than 90 percent of microparticles in stormwater.

"From a management standpoint, the more we reduce "macro" trash, the less microtrash is going to be caused downstream," says Sommers. "At the end of the day, the solution really is trying to get people to change their behavior and reduce trash, regardless of its size, at its source."

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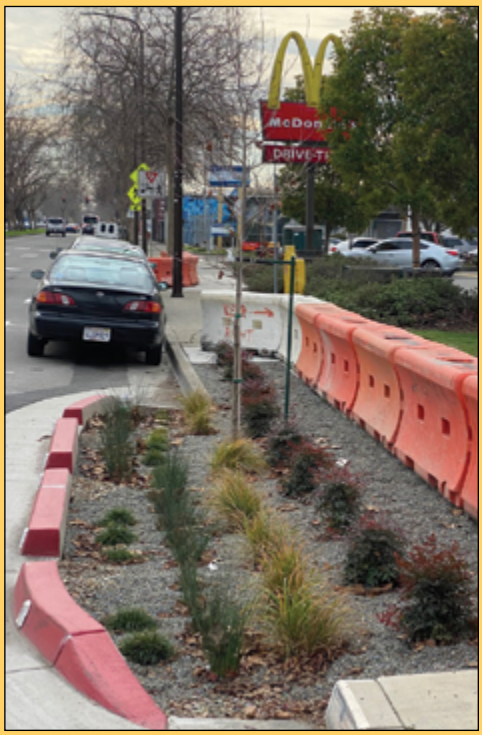
GREENDEAL

East Bay Spine Stretches

CARIAD HAYES THRONSON, REPORTER

The first section of a long-planned stormwater "spine" opened in Berkeley in February, with a second site in Oakland expected to be complete by the end of March. The two curbside treatment sites are part of the San Pablo Avenue Green Stormwater Spine Project, which will ultimately drain runoff from approximately six acres of impervious surface. Two more sites, in Emeryville and El Cerrito, are expected to be operational by the end of the summer. "Green infrastructure is going to play an increasingly important part of watershed management," says project manager Josh Bradt of the S.F. Estuary Partnership, noting that the S.F. Bay Regional Water Quality Control Board's stormwater permit requires all Bay Area cities to develop watershed-based green infrastructure master plans.



Curbside stormwater treatment protects receiving water bodies both by intercepting pollutants and by reducing the water volume entering them, which says Bradt, "can be really disruptive to some habitat." Bradt notes that by making sidewalks more pleasant, surface level improvements like the spine projects can help build public awareness for stormwater management. "The plans that the cities have developed are going to take a lot of money to implement, and they're going to need public support," he says.

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TECHNOLOGY

Toxics Flock to Beads in a Scientific Tea Bag

ASHLEIGH PAPP, REPORTER

A UC Santa Cruz team is upgrading long-established methods of testing water for algal blooms and toxicity. Their new technique deploys a cloth envelope of custom-designed plastic beads that paint a more complete picture of toxins floating in marine and fresh water.

The traditional way to test for algal toxicity in a water body, according to Raphael Kudela, a professor of ocean sciences at UC Santa Cruz, involved either taking a single water sample or harvesting shellfish and then grinding up and analyzing the tissues.

SPATT hoop sampler alongside mussels, the traditional testing method.
Photo: Keith Bouma-Gregson

SPATT types used by Kudela's lab.
Photo: Raphael Kudela

Both of these methods posed problems for different reasons: the former offered only a one-time glimpse into water quality at the moment of sampling, and the latter involved killing a living creature whose body could process and alter the targeted toxins. So the results generated from either method don't give a totally accurate representation of what's in the water.

When a New Zealand scientist shared a novel method to test water quality in the early 2000s that didn't involve harvesting shellfish, Kudela and his team of researchers quickly adopted the idea. After some fine-tuning, they named their new technique Solid Phase Adsorption Toxin Testing (SPATT, for short).

The technique takes advantage of custom-built plastic, or resin, beads that are designed to adsorb specific things. Adsorption works by attracting molecules like a magnet. The molecules, such as toxins in the water, latch onto the sides of the plastic bead's surface but are not absorbed into them. In the case of Kudela's water toxin testing, he primarily uses a type of bead called "HP20," equipped with tiny holes of a specific size and a charge that attracts about a dozen different known water toxins including freshwater microcystins and domoic acid. (The shellfish method, by comparison, often only shows one toxin in its analysis.)

Kudela and his team assemble the testing apparatus themselves. They place about three grams of the plastic beads in a mesh material, fold and sew the bag on two sides, and then heat seal it along the top. "It looks a lot like a tea bag," Kudela says.

More recently, he found that cinching two pieces of loose material in a plastic embroidery hoop, like the kind earlier generations use to stitch floral motifs, not only was easier to assemble but could better withstand water currents and waves. The team suspends these SPATT bags or hoops in the water 2-7 meters deep for a week to a month, either from a rope in saltwater or zip-tied to rebar in freshwater, where they can passively adsorb toxins in the water.

Once removed from the water, the SPATT is taken to the lab for analysis. Researchers remove and rinse the beads in a solution of methylene and water. The methylene acts as another magnet, extracting the toxins stuck to the resin beads. The researchers then collect a small vial of the liquid, with the toxins included, and analyze a single drop of it in a mass spectrometer. This machine applies speed and force to determine the mass of a particle, which can then be used to analyze its composition.

Locations where SPATT is routinely used by Kudela and his team, with the Romberg Tiburon Center, a long-term testing site, circled in red.

So far, SPATT has been used to measure water quality from the Santa Cruz Wharf to the Berkeley Marina and at the mouths of the San Joaquin and Sacramento rivers. Researchers in multiple locations in California, a few other states, and some international communities have also begun to implement this new method.

Kudela is currently working with multiple organizations and agencies monitoring water quality to develop a rubric of sorts, for comparison of results generated from the new approach to those from the older, more traditional methods. "Working with management organizations is a challenge," he says, because their way of gauging water toxicity has been based on traditional methods.

Aside from saving the lives of shellfish, SPATT also produces, says Kudela, "an unequivocal result about what's in the water."

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RECREATION

Time Travel on the Bay

ALETA GEORGE, REPORTER

Few boats on the San Francisco Bay can claim to be time machines, but that's just how Liam O'Donoghue, tour guide of the Oakland and Richmond historical waterfronts, views the *Pacific Pearl*. "In day-to-day life we look at the world in a three-dimensional view," he says, "but when you know history, you can look at it through four dimensions because you can see into the past using your imagination."

O'Donoghue is the host and producer of the award-winning podcast *East Bay Yesterday*. With him as a guide, fishing fleet operator Fish Emeryville has been taking people out on the water for sold-out tours of East Bay waterfronts since last year, after owner and captain Andy Guiliano asked O'Donoghue to lead historical tours during the off-season. "There's a beautiful collision of wonderful things out there," says the captain, who has cruised under the Golden Gate Bridge thousands of times but only been on it three times.

O'Donoghue leads two historical waterfront tours aboard the Pacific Pearl, a 50-foot Delta Marine boat that accommodates 35 passengers. Last fall I boarded the *Pacific Pearl* for the Oakland tour, and cast off again in February for the first Richmond tour of 2020. I also sat down with O'Donoghue for an interview between tours.

"It's pretty mind-blowing that the first people in the Bay Area were here before the Bay existed," he says. "Most humans live for less than a century, and our view of the world is limited by that timeframe. By looking at things in terms of what's unfolding over millennia instead of decades, maybe it will make us reconsider the incredibly harmful impact that humans have had on the planet in a relatively short time."

As Captain Andy steered the boat out of the Emeryville Marina for the Oakland tour, O'Donoghue began with the geologic history of the Bay. Heading west out of the marina, the boat slowed alongside the defunct Berkeley Pier constructed in 1926, and from the cockpit O'Donoghue talked about the sea life now dependent on the wood pilings.

With the boat turning south, he related the histories of Treasure and Yerba Buena islands. In the Oakland Estuary he shared tales about fights for the waterfront and workers' victories. His diverse storytelling reflects the wide range of ages and backgrounds of those onboard, illustrated when he pointed out a houseboat where Tom Hanks once lived. Later, people craned their necks to take in the scale of the towering cranes and shipping containers in the Port of Oakland, where the docking and evacuation of the *Grand Princess* cruise ship would soon become part of history.

"The shipping containers almost look like toys when you see them from the Bay Bridge, but when you're riding alongside them in a fishing boat looking up, it's like being next to a ten-story building," O'Donoghue says. "You get a sense of how much commerce is coming and going out of the Port of Oakland, and what a nexus of global capital it is."

For the Richmond tour, we launched in the morning on an ebb tide under a hazy blue sky. Captain Andy threaded the *Pacific Pearl* through the Berkeley pier as if it were a time portal. We stopped for the history of the Albany Bulb, the origin of the City of Albany, and the transformation of Point Isabelle from battery dumping ground to popular dog park. A pause near Brooks Island led to an explanation of its layered history that includes an Ohlone fishing ground, a quarry, a gun club, and finally, a bird sanctuary owned by East Bay Regional Parks District.

The next destination was the old Richmond shipyard where we learned about the Ford assembly plant (now the Craneway Pavilion) and the Rosie the Riveter Museum. Four young women, who never left the bow of our boat, waved at sailboats and tugs and cheered when the captains honked in reply. "History makes me feel more emotionally connected to myself and where I live," said Jozefina Logu, one of the women at the bow.

"I gravitate towards natural history stories on the Richmond tours because there's been such an amazing transformation," says O'Donoghue. "In the World War II era, this shoreline was completely industrialized, and thanks to the efforts of Lucretia Edwards and other

East Brother Island lighthouse; container ships at Port of Oakland; guide Liam O'Donoghue; osprey nest; Richmond shore.
Photos: Gene Anderson (lighthouse, osprey, blue gloves); Aleta George (all others)

activists, there are now 32 miles of public shoreline. I think it's important to remind people that there have been victories, and that individuals who are organized and motivated can make a difference."

At one point the tour paused to observe an active osprey nest on a decrepit pier, where one of three ospreys screamed in complaint above us. We also stopped at the Brothers Islands to view the lighthouse-turned-bed-and-breakfast and a group of seals sunning themselves on the shoreline of West Brother. Unfortunately, all 14 seals slipped into the water; we were either too close or too loud, but it's a simple fix in the future. With wildlife around, O'Donoghue should consider putting his stories on hold so passengers could listen to the slosh of the waves and enjoy observing the animals.

After nearly three hours of good storytelling and incomparable beauty, we slipped back through the time portal of the Berkeley Pier, wiser for having experienced another dimension of the Bay.

O'Donoghue's tours fill up fast. Go to Fish Emeryville, or subscribe to his newsletter www.tinyletter.com/eastbay_yesterday, to receive announcements of the new dates.

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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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Lower Walnut Creek, Contra Costa County (see p. 11)

PACIFICOCEAN

Urchinomics

ALASTAIR BLAND, REPORTER

Desperate times, as the adage goes, call for desperate measures.

Other times, they just prompt creative solutions — like Norway company Urchinomics' proposed remedy for the purple urchin seafloor takeover that has wiped out the North Coast's bull kelp, turning once lush forests into bleak urchin barrens.

The animals rapidly proliferated about five years ago after a disease nearly wiped out their chief predator, the sunflower sea star. As the algae eaters multiplied, kelp forests, already stressed by unusually warm water, collapsed. Abalone — seaweed grazers, as well — have died by the millions, and even fish have reportedly grown scarcer in the ruined ecosystem. The urchins themselves, lacking vegetation to eat, are starving. Their insides — and notably their gonads, termed uni at sushi tables — have withered away to almost nothing, making them commercially worthless.

But Urchinomics proposes to capture the overpopulated urchins, fatten them up in circulating seawater

tanks, and sell them to restaurants — hopefully in volumes sufficient to dent the urchin armies and allow a kelp comeback. The idea is to create a sustainable micro-economy and an urchin market that pays divers to keep collecting more. The financial incentive to operate would be a contrast to alternative removal efforts that rely on volunteer labor — like smashing them underwater and mass harvest for compost reduction.

Urchinomics is now exploring the possibility of launching an urchin ranching facility at Bodega Bay later this year, which has raised eyebrows. At a February meeting of the Greater Farallones National Marine Sanctuary Advisory Council, some members voiced concerns about the potential environmental impacts of such an aquaculture facility.

But the advisory council is largely optimistic. Press liaison MaryJane Schramm says combatting the urchin takeover "goes directly to our mandate to maintain or restore ecosystem balance." Citizen science, she adds, may be an important part of implementing any action plan, "since eradication or control efforts are likely to be ongoing and work-intensive."

"The ocean waters continue to warm, a condition which may stress remaining kelp concentrations which tend to thrive in cooler waters," she says.

As for Urchinomics, it's not clear yet if market demand will float their proposal. Historically, purple urchins have had little value — even healthy ones with fat gonads. Instead, their larger cousin species, the red urchin, has been the traditional keystone of the California uni market. When healthy, a red urchin uni slab is almost the size of a banana slug.

So the onus is on Urchinomics to convince diners that dainty purple urchin gonads are worth paying for. Given the current bleak state of northern California's coastal seafloor, hopefully they'll want seconds.

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