Will Busting Dams Boost Salmon?

As dams fall on the Elwha River in Washington state and other rivers around the country, scientists are relishing rare opportunities to watch natural ecosystems restore themselves

ELWHA RIVER, WASHINGTON—"It's like an alien abduction," says George Pess, a fisheries biologist with the National Oceanic and Atmospheric Administration (NOAA) Fisheries in Seattle, Washington, as he walks past a pair of colleagues preparing to snatch their quarry. One of those colleagues, Martin Liermann, wades calf deep in a side channel of the Elwha River in Washington's Olympic Peninsula with a giant battery pack strapped to his back. Holding a 2-meter-long yellow pole connected to the pack, he dunks the business end of it in the water and pulls a red trigger. An electric jolt stuns a handful of steelhead fingerlings, a jolt that Liermann avoids thanks to the rubber chest waders and neoprene boots he's wearing.

Liermann's partner Holly Coe scoops up a few fingerlings and plunks them into a white 5-gallon bucket. When they've gathered a couple of dozen or so, they shuffle over to what looks like a makeshift surgical unit strewn amid the rocks on the river's edge. "Have you puked these guys over here?" Liermann asks Sarah Morley, a fisheries biologist with NOAA Fisheries. "Just one," Morley replies, as she plucks a fish out of the

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Glines Canyon Dam on Its Way Down Between September and November 2011

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No more. The Elwha Dam (*above*), built in 1913, is now largely gone (previous page). All that remains is the original power house and much of the sediment that was lodged behind the dam.

bucket, quickly measures and weighs it, and carefully wedges a syringe needle in the fish's mouth and pushes the plunger. Water shoots into the fish's stomach and forces the contents out onto a fine mesh sieve. "He had a full belly," she says as she spots a small slug, a few mayflies, a couple of leeches, and some green bits she can't identify. Morley carefully spoons the contents into a sample jar for later lab analysis and returns the fish to the bucket, after which it will be returned to the Elwha, hungry but otherwise unharmed.

There's good reason to be careful with the steelhead. They're one of three fish species in the Elwha listed as either threatened or endangered under the Endangered Species Act. (Chinook salmon and bull trout are the others.) Morley and Liermann's work on a bright day here in September is one of nearly a dozen related research projects designed to document the current state of the river. Just downstream, Pess and three colleagues sort through a small wedge of the streambed measuring and weighing rocks and other pieces of sediment. Upstream, John McMillan, a NOAA Fisheries contractor in a black dry suit, blue mask, and snorkel, sloshes his way down the river, occasionally plunging in to count the number of adult salmon he sees.

Morley's team also surveys aquatic invertebrates and algae to get a full sense of what types of food the salmon have available to them. Others collect tissue samples from the fish for genetic studies; track numbers of bears, otters, and other mammals in the area; sample isotopes of nitrogen and phosphorus nutrients in the water to determine the percentage that comes from the ocean, brought in by spawning salmon; and even cut out the ear bones of dead salmon that have already spawned to look for telltale signs of whether they came from hatcheries or were wild stock.

This intense interest came to a head as engineers were set to begin tearing out two massive dams that have blocked the free flow of water and salmon on the river for nearly 100 years. The dams—Glines Canyon and the Elwha—are some 64 and 33 meters high, respectively, the largest dams ever removed in the United States. It will take as long as 3 years to tear them out completely. But bulldozers and excavators have already made quick progress. Water now flows around the carved-out right side of the lower Elwha Dam and over the top of four notches hacked into the face of Glines Canyon Dam. Today, the river is close to flowing freely for the first time in 98 years.

Online
sciencemag.org
Podcast interview with author Robert F. Service.

The Elwha isn't alone. After a century of furious dam construction in the United States, the era of dam building has ebbed. Over the past 3 decades, increasing concerns about safety and the high cost of upkeep have pushed the number of removals up from an average of about 10 per year to six times that number today, with a total of nearly 1000 dams removed, according to numbers kept by American Rivers, a river advocacy group based in Washington, D.C. For much of this time, the focus has been on tearing out small, obsolete structures in the Midwest and East. But that pattern has begun to shift, says Martin Doyle, a river restoration expert at Duke University in Durham, North Carolina. "Bigger dams are starting to come out, out west," Doyle says, in part as an effort to rebuild endangered salmon and steelhead runs.

Even longtime proponents of dam building, such as officials at the U.S. Bureau of Reclamation, now support removals on a case-by-case basis. At a recent ceremony commemorating the demolition of the Elwha dams, Bureau Commissioner Michael Connor was enthusiastic. "This is not only an historic moment, but it's going to lead to historic moments elsewhere across the country," Connor was quoted in the *Los Angeles Times*.

All these dam removals have created a unique opportunity for scientists to study how quickly rivers revert to their old ways once obstructions come down. "We're stoked," says Mike McHenry, a habitat biologist with the Lower Elwha Klallam Tribe in Port Angeles, Washington, who has worked on river-restoration projects on the Elwha since 1989. "The hope here is we'll learn something we can apply in other places."

Tipping the scales

There are plenty of possibilities. According to the U.S. Army Corps of Engineers, the United States has more than 80,000 dams 3 meters tall or taller, most of them privately operated. River blockages of all sizes likely top 2 million, according to another survey. Many of these aging structures have fallen into disrepair, are too expensive to fix, or have been made obsolete as nearby mills have closed and large coal and natural-gas power plants have come online. "The need for these dams just doesn't exist anymore," Doyle says. "If you have a dam that's no longer generating revenue, you are basically sitting on a liability."

Privately held dams are licensed by the Federal Energy Regulatory Commission (FERC). As licenses run out, owners can apply for 35- to 50-year extensions. In most cases, however,

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Out of the Frying Pan?

Despite the continuing rise in dam removals, not all long-term trends are good news for salmon. Climate change and ocean acidification, according to recent studies, threaten to wipe out possible gains and could push many salmon runs to extinction by the end of this century.

A new climate-modeling effort called the Riverscape Analysis Project finds that climate change will affect rivers throughout the Pacific Rim. The effort, led by Jack Stanford and John Kimball at the University of Montana's Flathead Lake Biological Station in Polson, starts with a standard hydrologic model for how temperature and precipitation changes affect river temperatures and stream flows. The researchers incorporated information from satellite and space shuttle images on the physical characteristics of 1500 rivers, as well as the extent of existing salmon runs, and examined how expected air temperature changes given by scenarios from the Intergovernmental Panel on Climate Change would likely affect river temperatures, flows, and fish populations.

Stanford says that when he and his colleagues input past climate data, their models could explain 70% of the observed variation in river flows and temperatures. Not perfect, but by a modeler's standards, "that's pretty good," Stanford says. When they looked forward to the end of this century, they found that the model flagged dozens of rivers at serious risk of losing their salmon. The most vulnerable tend to be in California and the interior regions of the Columbia Basin in Oregon, Washington, and Idaho.

The results are preliminary, Stanford emphasizes, as he and his team continue to refine their models. But the general picture is clear, Stanford says: "Salmon will experience a warming [of water temperatures] across their entire range. In some places, it will get so warm that salmon will be eliminated."

David Purkey, a hydrologist at Stockholm Environment Institute (SEI) in Davis, California, calls the assessment "important" but notes that individual rivers will be affected not only by temperatures and stream flows but also by how humans manage water flows through dams and other diversions. Purkey, along with colleagues at SEI, the University of California, Davis, and the National Center for Atmospheric Research in Boulder, Colorado, recently ran a similar climate-change analysis on the Butte Creek Watershed in California. Their study took into account not only hydrology, CO_2 emissions scenarios, and six different climate models but also two different scenarios describing how dam operators managed water flows throughout the year. In a business-as-usual scenario in which operators didn't change water flows during summer temperature spikes, spring Chinook salmon runs became extinct by about 2070. But when water was allowed to flow through the dams in the hot summer months when the fish are most vulnerable, the additional cold water in the rivers allowed at least small runs to survive the century in some, although not all, scenarios.

One potential bit of good news for the salmon, Stanford says, is that rivers along the North Slope of Alaska and other arctic regions that typically freeze for much of the year are likely to become new free-flowing spawning habitats as temperatures warm. The North Pacific, however, would provide far smaller feeding ground for salmon than the current region between the northwestern United States and Japan in which the fish now spend the bulk of their lives.

Ocean acidity at high latitudes may pose an even bigger threat. Fossil fuel burning emits carbon dioxide into the atmosphere; the gas is absorbed by the oceans and quickly converted to carbonic acid. This reaction releases hydrogen ions into the water, reducing its pH—in other words, making the water acidic. Since preindustrial times, the overall pH of the oceans has declined by 0.1 pH unit. That may not sound like much, but the pH scale,

Good news, bad news. Dam removals are likely to increase salmon populations, but climate change and ocean acidification could do the opposite.

CREDIT: LEN KANNAPELL

the requirements for relicensing dams are now far more stringent than when the dams went in, meaning that complying with environmental and safety standards can cost more money than the dams generate. So it's often cheaper to tear out the dams than to bring them up to current standards. In recent years, Pennsylvania and Wisconsin have led the way in dam removals, each state tearing out hundreds.

Finding the proper balance between the usefulness of dams and their environmental costs has become particularly acute in the Northwest, where communities are struggling to safeguard salmon populations that have been declining for decades. In the Columbia River Basin, which at 673,000 square kilometers stretches across most of the Northwestern U.S. states and into British Columbia, dams have blocked an estimated 55% of historic salmon spawning habitat, says Michelle McClure of NOAA Fisheries. Those dams, together with loss of habitat from development, as well as competition from hatchery-bred salmon, have dropped wild salmon runs to roughly 10% of their historic numbers; 13 salmon and steelhead runs in the basin are now listed as either endangered or threatened.

To counter that decline, fisheries managers now mandate that most dams provide fish passage by building a parallel "ladder" or waterway. For dams that historically had no such passage, that is typically an expensive proposition; in many cases it has now tipped the scales in favor of dam removal. In 2008 and 2009, for example, that equation led Portland General Electric to rip out two power-producing dams on the Sandy River in suburban Portland. Dams have also come out along the Rogue River in southern Oregon, and the Wind and White Salmon rivers in southwest Washington.

Unique opportunity

Much the same calculation was at work on the Elwha. The Elwha Dam was installed in 1913, and Glines Canyon Dam 14 years later, to provide electricity for sawmills in nearby Port Angeles. By the 1990s, most of those mills had closed. The dams still provided power—but a total of only 19 megawatts, far below the 500 to 1000 megawatts of a typical gas- or coal-fired plant. When it came time for FERC relicensing, it was clear the costs of repairing the dams and adding fish passages didn't pencil out. Still, the company that owned the dams, James River Corp., didn't have the money to remove them.

In 1992, the U.S. Congress stepped in and authorized money to tear out the dams. But congressional opponents, including former Washington State Senator Slade Gordon, blocked dam-removal funding proposals for more than a decade. Among Gordon's concerns were that if dam removal succeeded in the Elwha, there would be a clamor to remove dams throughout the west—particularly those on the lower Snake River in Idaho, which have long drawn the ire of salmon advocates but have been a boon to farmers looking to barge their goods to coastal ports. "There was concern that when

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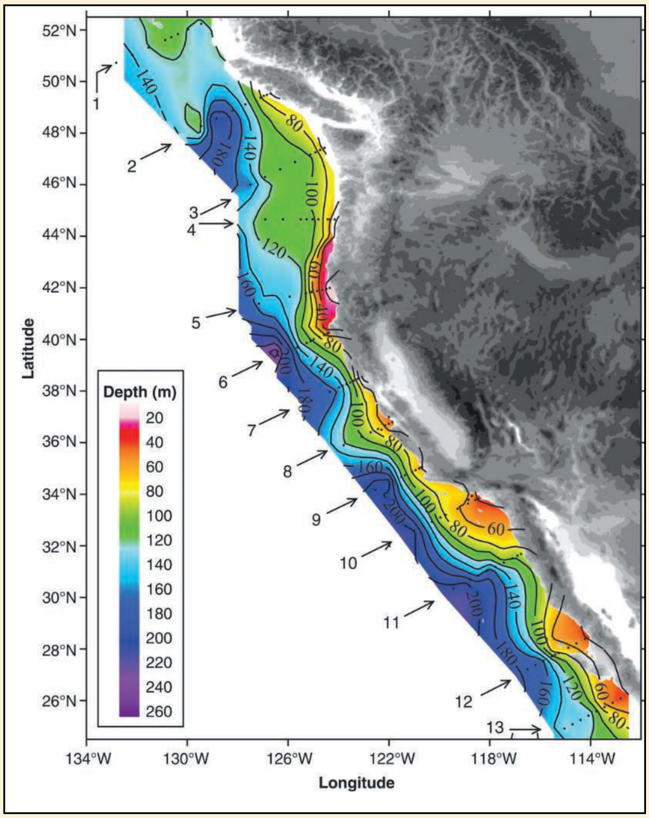
like the Richter scale for earthquakes, is logarithmic: Over this period, seawater acidity has increased by 30%.

According to emission scenarios from the Intergovernmental Panel on Climate Change, pH values will drop an additional 0.2 to 0.3 units by 2100, potentially doubling current acidity levels. Added hydrogen ions reduce seawater concentrations of carbonate ions, which oysters and other organisms use to build their shells. Lab and field studies suggest the drop in carbonate ions is already affecting oyster larvae and other organisms. The trend is particularly bad news for juvenile salmon: One of their primary food sources in the Pacific is pea-sized snails called pteropods.

Even without added CO_2 from human civilization, pteropods and other shelled critters in some coastal regions periodically experience high acidity levels. It happens when populations of algae, plankton, and other ocean organisms bloom and die, falling to the ocean floor. There they are gobbled up by bacteria that churn out carbon dioxide, making deep waters highly acidic. When surface winds push the top layer of water out to the open ocean, the deep corrosive waters from underneath surge upward, explains Richard Feely, a chemical oceanographer with the National Oceanic and Atmospheric Administration's Pacific Marine Environmental Laboratory in Seattle.

At the American Fisheries Society meeting in Seattle in September, Feely reported that he and colleagues had just completed a cruise throughout the North Pacific and down the West Coast of the United States. According to the team's latest surveys, ocean acidification from human causes already accounts for between 29% and 49% of the corrosive waters present along the West Coast of the United States through the North Pacific. The human contribution to this high acidity could rise to as much as 80% by 2050, Feely estimates. In a more-acidic ocean, pteropods and other organisms probably won't be able to build their shells. So the ability of salmon to thrive in the ocean could hinge on their ability to find food sources different from those they've relied on throughout the course of evolution. **–R.F.S.**



Caustic. Highly acidic ocean waters (red) periodically well up to shallow depths near the west coast of North America. As CO_2 concentrations in seawater increase, ocean acidification is expected to spread.

one dam falls, they are all going to fall," says Patrick Crain, a fisheries biologist with the National Park Service.

Ultimately, however, the Elwha was just too good a restoration opportunity to pass up. The Elwha dams sit close to the river's mouth where it flows out into the Strait of Juan de Fuca, near where Puget Sound meets the Pacific Ocean. Upstream, 83% of the 112-kilometer-long river lies within the protected wilderness of Olympic National Park. Before the dams were built, an estimated 390,000 salmon from 10 different species returned to the river to spawn each year—so many that early white settlers along the river complained that the slapping of fish was so loud during spawning periods that they couldn't sleep. Now that the dams are coming out, the Elwha has become not just the nation's second largest ecological restoration site after the Florida Everglades, but a rare opportunity to study how natural processes return to normal and how ecosystems respond. "It's really a unique opportunity, because the habitat is in such good shape," Pess says.

That opportunity sent Pess and colleagues from several federal, state, and

Near death. A female Chinook salmon is scarred and battered from her final journey up the Elwha.

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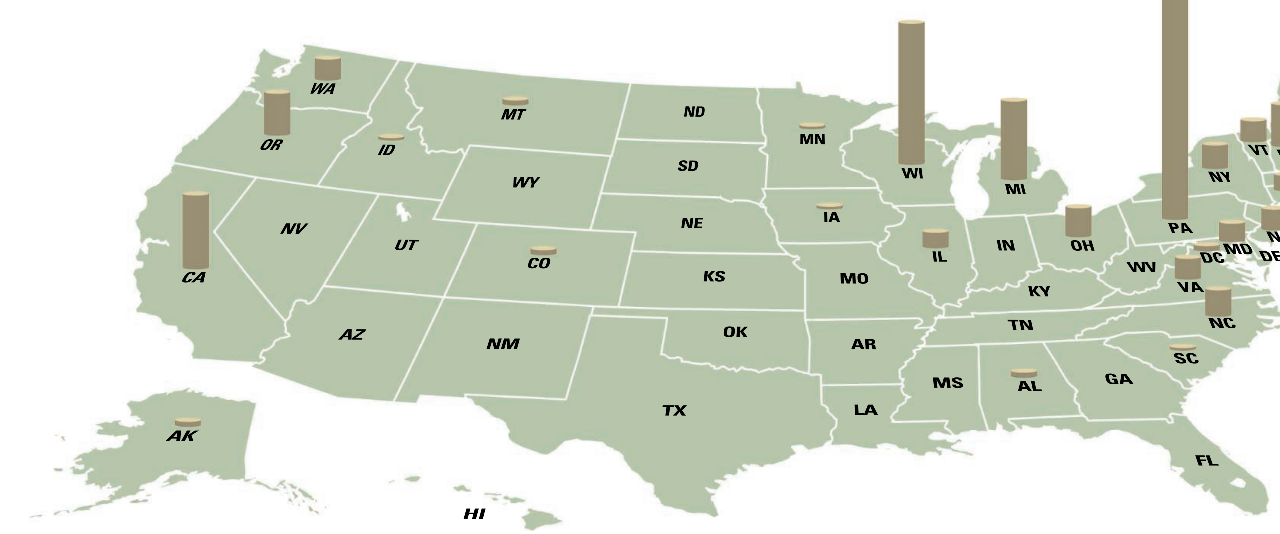
tribal organizations fishing for money to track the Elwha before and after the dams came down. Despite the removal project's $325 million price tag, little of it was dedicated to monitoring efforts. In the end, that was something of a benefit, Pess and others say, because it forced researchers from numerous organizations to build a broad network of collaborators to track the recovery. "We have very little information about how the ecosystem works. That's why so much effort is going into this project," says Peter Kiffney, a biologist with NOAA Fisheries in Seattle.

As they began to collect data on the Elwha a few years ago, it became clear that the river was dramatically altered from its free-flowing past. Not only are the fish counts drastically reduced, so too are the numbers of eagles, bears, and other animals that used to depend on the robust fish runs for survival. Over the decades, fine gravel in which salmon prefer to lay their eggs has largely washed out because it wasn't being replaced, leaving mostly rocks softball-sized and larger. The dams even blocked plant seeds from washing downstream, fragmenting some plant communities in the watershed.

So how long will it take for the river to recover? "It will be a great experiment," Pess says. Initially, the changes may not bode well for the salmon. The biggest concern, Pess says, is that 18 million cubic meters of silt and other sediment is trapped behind the dams, enough to fill 200,000 dump trucks; it will move downstream. Engineers are taking the dams down slowly to ensure that it doesn't

Dam Removals by State 2001–2010



all wash out at once. Some of the sediment will actually be trucked out. Botanists will then race to plant native species in the banks of remaining sediments, in an effort to stabilize them—a particular worry during spring high water flows.

High sediment levels can not only harm fish directly but can also suffocate eggs waiting to hatch. Such concerns prompted recovery officials to approve the construction of a new hatchery for steelhead and chum, coho, and pink salmon in the lower Elwha. But that hatchery itself has become highly controversial, as some researchers worry that hatchery-raised salmon will outcompete natives and further imperil wild fish runs. "I think the hatcheries [on the Elwha] are unneeded," says Jack Stanford, an ecosystem scientist with the University of Montana's Flathead Lake Biological Station in Polson. Stanford notes that every year, highly productive salmon streams such as the Copper River in Alaska carry sediment loads equivalent to what the Elwha will now face after the dams come out. Stanford has plenty of allies. On dedication day for the demolition of the Elwha and Glines Canyon dams, opponents filed a notice of intent to file a lawsuit to block the new hatchery.

Even with sediment problems and hatchery competition, giving fish access to new river territory can produce a quick reaction. "The response of fish can be pretty immediate," Pess says. "Salmon are very opportunistic creatures. If given the opportunity to utilize a habitat, they will use it."

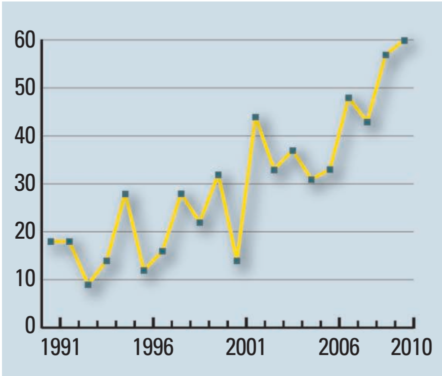
Pess points to one such example on the Fraser River in British Columbia, Canada. A landslide in 1913 triggered by railroad builders trying to blast a route for a track through Fraser Canyon cut off 80% of 1400 kilometers of prime salmon-rearing habitat. About 1 million fish a year still returned to the lower river. Some 30 years later, fish ladders were built to reopen access to the upper river. In the 40 years after they went in, salmon populations in the river doubled. At the American Fisheries Society meeting in September in Seattle, Rory Saunders of NOAA Fisheries reported that after two dams were recently removed from the Sedgeunkedunk Stream in Maine, Atlantic salmon, sea lamprey, and alewife all showed improved runs within 2 to 3 years. "This was much faster than any of us expected," Saunders says.

Still, Kiffney cautions that although salmon and other fish can return quickly, the recovery of the broader ecosystem can be far slower. For much of the past decade since fish ladders were installed in 2003, Kiffney has tracked the rise in salmon spawning up the Cedar River near Seattle. "After the fish ladders went in, whoosh, salmon numbers started climbing," Kiffney says. But the physical mass of all the salmon in the runs is still only 0.006 kilograms of fish per square meter of river—too low to make a broader impact. "In experiments we've done, we see ecosystem changes at 0.6 kg/m^2. So we need a 100-fold increase," Kiffney says.

Some estimates suggest such a return to historical salmon runs could be in store for the Elwha, says William Robert Irvin, president of American Rivers. But Pess and others are more cautious. Self-sustaining populations of different salmon species are likely to take 10 to 30 years to become established, Pess says. "There will be recovery. But it won't be the same as it was historically."

As the fish runs begin to improve, the first to spot the changes could well be Kent Mayer, a fish biologist with the Washington Depart-

U.S. Dam Removals by Year



Busted. Dam removals continue to rise (*above*), particularly in the East (*top*). But teardowns are increasing in the West in hopes of saving salmon runs.

ment of Fish and Wildlife. Last year, Mayer built a fish weir—essentially a temporary trap for large adult fish—2 kilometers below the Elwha Dam. The weir, which spans the full width of the river, is the largest such structure in the United States outside of Alaska. It enables Mayer and his colleagues to not only count fish moving upstream and downstream but also document their size and weight and take tiny tissue samples for genetic profiling before releasing them. Last month, on the day Pess, Morley, and their colleagues were weighing rocks and puking fingerlings, Mayer caught and released the first bright red sockeye salmon known to have spawned in the Elwha in modern memory—hopefully a harbinger that the long-extinct salmon run could soon return to the river. "There are days when I love my job," Mayer says standing waist deep in the fish trap. "This is one."

–ROBERT F. SERVICE

MAP AND GRAPH SOURCE: AMERICAN RIVERS