The Gift of Salmon

In Alaska, biologists are learning that when wild salmon are free to swim upstream to spawn, dozens of other species flourish too

by Kathleen Dean Moore and Jonathan W. Moore, Photograph by Art Wolfe

From the May 2003 issue; published online May 1, 2003

My son and I splash upstream in hip boots, searching for signs of the sockeye salmon that return each summer to spawn and die in this wild Alaskan creek. I've come here to see for myself what he wrote home about last year:

The creek is so full of sockeye, it's a challenge just to walk upstream. I stumble and skid on dead salmon washed up on the gravel bars. It's like stepping on human legs. When I accidentally trip over a carcass, it moans, releasing trapped gas. In shallow water, fish slam into my boots. Spawned-out salmon, moldy and dying, drift down the current and nudge against my ankles. Glaucous-winged gulls swarm and scream upstream, a sign the grizzlies are fishing. The creek stinks of death.

Today the whole streamside world is clean and sparkling. We slosh along gravel bars, startling golden-crowned sparrows, until Jon bends down and picks up a single salmon vertebra, bleached white. Other than this, all evidence of salmon has disappeared.

Where did the piles of dead salmon he witnessed go? What difference does their living and dying make to the health of the entire ecosystem?

Jon, a graduate student in aquatic ecology, works summers with the Alaska Salmon Program of the University of Washington, a research project begun in 1946. The program's scientists and their colleagues in other institutions are finding that salmon, as they fatten in the ocean and then swim back into freshwater creeks and lakes, return energy and nutrients upriver in a vast recycling system that nourishes plant and animal life throughout the watershed. The nutrients leave a chemical record in lake bottoms that charts the rise and fall of salmon populations and may offer clues to patterns of climate change.

Most of the coastal rivers in North America once teemed with great runs of anadromous fishes—organisms that hatch in inland freshwater streams, migrate to the salty sea, then return to the streams to spawn. For more than 10,000 years, migrating fishes—Atlantic, chinook, and coho salmon, American shad, blueback herring, and striped bass, to name a few—have returned in astonishing abundance to the great rivers up and down the Atlantic and Pacific coasts. But many of the runs are gone now, eliminated in only a century. Studies of the relatively undamaged rivers in Alaska may help explain how an ecosystem suffers when it loses upstream movements of fish.

These sockeye salmon are swimming upstream to spawn. In Alaska, salmon still abound, but in the lower 48 many runs have been decimated by dams, habitat degradation, and overfishing. The Columbia River in the Pacific Northwest was once teeming —2,112,500 salmon were caught in 1941; by 1998, the catch had dwindled to only 67,200 fish.

Jon works out of a gray, weathered cabin behind the beach on a mountain lake connected by rivers to the sea. Yellow rain slickers, wet socks, and bright orange jackets hang from pegs on the front of the cabin, and a bear-gnawed canoe rests upside down by the window. Peeling off hip boots, Jon sits on a bench by the front door and explains what scientists are learning.

People are used to thinking that rivers flow only downstream, he says. A leaf or an insect falls into the water, soil washes off a bank, a minnow dies, and the river carries many of those nutrients toward the ocean. What the salmon do when they swim upstream is to reverse that flow of nutrients.

"Salmon put on more than 95 percent of their mass in the ocean, then swim upstream and die," says Daniel Schindler, when I connect with him by crackling radiophone. Schindler is an aquatic ecologist at the University of Washington and a scientist with the Alaska Salmon Program. "The fish move energy and nutrients against the current, making the river of nutrients flow upstream from the ocean to the headwaters, compensating for nutrients gravity takes away." Nutrients are the raw materials of life that are necessary for every one of life's functions, from the growth of a neuron to the greening of a leaf.

When there are large populations of salmon, the return of nutrients can be huge. Ted Gresh, an environmental consultant in Portland, Oregon, estimates that during the historical runs in the Pacific Northwest, 500 million pounds of salmon returned to spawn and die each year. Researchers estimate that in the Columbia River alone, salmon contributed hundreds of thousands of pounds of nitrogen and phosphorus to the watershed each year.

Now trucks and barges carry manufactured fertilizers up the Columbia. Overfishing, dams, habitat destruction, and competition from hatchery fish have damaged the Columbia's wild salmon runs. Throughout the Northwest, rivers receive on average only 6 percent of the nutrients that they received a century ago, a dramatic starvation.

At least 66 species in the Pacific Northwest seek salmon for sustenance, feeding on the eggs, carcasses, and every life stage in between.

American crow
American dipper
American white pelican
Arctic tern
Bald eagle
Barrow's goldeneye
Belted kingfisher
Black bear
Black-billed magpie
Black-crowned night heron
Bobcat
Bonaparte's gull
Brandt's cormorant
California condor
California gull
California sea lion
Caspian tern
Clark's grebe
Common goldeneye
Common loon
Common merganser
Common murre
Common raven
Common tern
Cope's giant salamander
Coyote
Double-crested cormorant
Elegant tern
Forster's tern
Glaucous gull

The team Jon works with is trying to understand how, in a healthy stream, vectors spread nutrients from salmon throughout the ecosystem. A vector is anything that moves nutrients from one place to another, including a flood that washes a carcass into the forest, a bear that fills up on salmon and then defecates in the tundra, or any salmon scavenger that eats in one place and urinates, defecates, or dies in another. Even maggots are vectors, to judge from Jon's notes:

When I lift a salmon that has been dead for two days, it's just a salmon-skin bag filled with maggots. I hear the maggots scrabbling under the skin, making it writhe and pulse. Maggots fall out of the eye sockets. As soon as a salmon dies, carrion flies swarm into its mouth and gills and lay eggs. The eggs hatch quickly into maggots, which devour the salmon at a frightening pace. In only four days, a dead salmon will melt into about 10,000 maggots. They wriggle out of the salmon into the ground, where they eventually pupate into adult flies that zoom around the streams, buzzing in our faces. Spiders and birds eat the airborne flies. Some maggots wriggle into the stream, where they are eaten by arctic grayling and rainbow trout.

At the peak of salmon spawning, creatures converge on the river and go to work. Mink near healthy salmon streams time their reproductive cycles to the seasonal surge of salmon, according to Merav Ben-David, a behavioral ecologist at the University of Alaska at Fairbanks. She found that female mink undergo lactation, an energetically taxing change, when salmon carcasses are most available. A report by the Washington Department of Natural Resources identifies 66 vertebrates that feed on salmon. Young salmon also eat dead salmon. Research by Robert Bilby, an aquatic ecologist at the Weyerhaeuser Company, shows that up to 78 percent of the stomach contents of young coho salmon and steelhead are salmon carcasses and eggs.

Jon's notes describe the feeding frenzy when the salmon are spawning:

On the banks of the salmon stream, we come across bear kitchens, trampled ferns and grasses and decomposing salmon parts, where the bears dragged salmon to eat. Gulls have a hard time breaking open salmon skin by themselves, so flocks of gulls follow the bears, waiting to swoop in and swallow up leftovers. Gulls nest on exposed islands that quickly become littered with salmon bones. As the chicks grow fat, the island is whitewashed with digested salmon. Rain washes guano into the lake.

Bald eagles rip into salmon and carry the food to their chicks. Caddis flies feed on salmon carcasses underwater, then hatch into adults that take to the air. Rainbow trout feed on salmon flesh that slowly breaks free from decomposing carcasses. Mink gorge on spawned-out fish. Trees grow rapidly with all this fertilizer. Tourists buzz in on floatplanes to fish, throwing the guts to gulls and freezing fillets in waxed cardboard cartons to be flown back to Tacoma or St. Louis.

Three days ago, when we came up here to the spring-fed ponds that feed the creek, we counted 216 salmon, their backs sticking out of shallow water. Female salmon were digging their nests, and the males were fighting for the females. They lined up side by side, hooked jaws thrust out of the water, sizing each other up. Then all hell broke loose. One salmon grabbed another in its toothy jaws and shook it like a bulldog, thrashing the weaker fish through the water.

Today, in the same pond, there are only three salmon alive, the rest killed by bears. The three remaining salmon swim slowly through the carnage.

It feels like there are bears everywhere. Around a tight corner, I find fresh grizzly tracks in the sand, slowly filling with water

and blood.

To analyze the historical importance of salmon in the diets of grizzly bears, Grant Hilderbrand, a research biologist working for the Alaska Department of Fish and Game, used nitrogen-sampling techniques. To determine how much of the nitrogen in an ecosystem comes from salmon, scientists measure stable isotopes. Nitrogen in the terrestrial and freshwater environment is composed primarily of the lighter nitrogen isotope N-14, with little of the heavier isotope N-15. However, salmon have a relatively high ratio of N-15 to N-14 compared with nitrogen-fixing sources such as alder trees. So scientists can estimate how much nitrogen comes from salmon by measuring the ratios of N-15 to N-14 in any tissue they collect, from moose hair to willow leaves.

Hilderbrand and his colleagues snipped hair and cut bone from western grizzlies long dead and displayed in places like the American Museum of Natural History in New York City. They found that between 1856 and 1931, 33 percent to 90 percent of nitrogen in grizzlies came from salmon—even as far inland as Idaho. Now salmon runs in the lower 48 are seriously depleted, and so are the grizzlies.

In Alaska, there seem to be plenty of bears. Jon and I have seen them every day patrolling beaches, minding their own business, waiting—as we are—for the salmon to return. One morning, Jon and I end up perched like swallows on the peak of the research station roof. I'm holding a giant can of bear spray in each hand. Jon has binoculars, scanning the brush.

We had just pulled the boat onto the beach at camp when a grizzly charged out of the alders toward the boat. Jon was in the doorway of the cabin. I was fiddling with my camera on the beach. I heard Jon say, in a voice sons don't often use with their mothers, "Get in the cabin." I did. We climbed a ladder to the roof to look for the bear, but it had gone. à

So here we sit. There is no movement in the brush.

Looking out over the gravel beach, the blue inlet, the whitewashed rocky islands, the floating loons and soaring gulls, I am beginning to understand that the stream the scientists are studying is not just a little creek. It's a river of energy that moves across regions in great geographic cycles. Here, life and death are only different points on a continuum. The stream flows in a circle through time and space, turning death into life across coastal ecosystems, as it has for more than a million years. But such streams no longer flow in the places where most of us live.

It's raining the next day. We pull on hip boots, shrug into slickers, and pile into the boat, heading to another creek to look for salmon. Walking upstream is tough—every rock is slick with algae. In the quiet pools, we muck through ankle-deep mud, stirring up dense, swirling silt.

After the salmon spawn, this streambed will be as clean as a gravel driveway. As a female salmon digs redds, the nests where she will lay her eggs, she helps create the conditions in which her eggs will thrive—a clean gravel bed under moving water. Turning on her side and beating her tail violently against the streambed, she washes away clouds of silt. Then she lays her eggs. She moves a short way upstream and does it all over again, scouring algae off rock, washing silt out of the eddies, aerating gravel. In a few days, the entire stream will be bank-to-bank redds and as clean as if the fish had set about with brooms and scouring pads.

Even as salmon shape the stream, the stream shapes the salmon. Thomas Quinn, a fish biologist at the University of Washington, says the shapes of fish have evolved to reflect the streams the salmon are in—whether it is three inches deep or three feet. Big is risky: A fish with its back sticking out of the water is more likely to have its hump ripped off by a bear. But big is an advantage, too, because a female sockeye is more likely to mate with a big male. So the shallow streams select for smaller fish, and in the deeper rivers or lakes, male salmon grow so humped they look as though they've swallowed dinner plates.

To draw any conclusions about the growth of salmon in the streams, scientists need to know how old they are. They age salmon much as they age trees, by counting rings on their ear bones, or otoliths. Jon describes the research:

Holding the salmon by their empty eye sockets, we root around in the soupy brain and pluck out the otoliths. They are the consistency of old seashells and the size of a baby's fingernail. Scientists count the rings under a microscope in order to learn how many years a salmon spent in freshwater and how many years in salt water. After chopping the heads off a hundred rotting salmon, our hands and sleeves are slippery with slime. Blackflies and mosquitoes bite our faces and necks, but we don't want to slap them with our fishy hands. We rub away mosquitoes with the backs of our wrists.

The nutrients salmon leave behind provide important measures of change in the ocean. When they leave freshwater, sockeye salmon spread out all over the Pacific, from California to Japan. They stay in the ocean for several years, and then they deliver themselves upstream to the pools that scientists are studying. "Salmon amplify the climate signal," Schindler says. Very subtle changes in the ocean can have a substantial effect on populations. A temperature shift of only one or two degrees can affect nutrients enough to make a two- or threefold difference in the number of salmon that return to rivers. So if researchers can chart the changes in the number of salmon that swim upstream, they can get an accurate history of alterations in the ocean—which gives evidence of how climate has changed over time.

Schindler and his colleagues are looking for that evidence in the sediments under lakes. They take core samples from lake bottoms where nutrients have slowly accumulated, layer by layer, over millennia. By measuring the relative amounts of N-15 at each level, Schindler can read off the history of a salmon population's rise and fall.

He has learned that salmon populations increased and decreased through the centuries, in complex but predictable cycles. In the lakes Schindler studies, sediments record a 50-to-70-year oscillation in salmon populations. But the picture is complicated. On top of the large waves of population change, there are regular, small ripples that reach a peak every 15 to 20 years. Bruce Finney, an aquatic ecologist from the University of Alaska at Fairbanks, used the same technique to show that there has been an even larger, slower variation in salmon populations. Two thousand years ago, salmon populations abruptly dropped in the North Pacific. Numbers stayed low for 800 years, then increased gradually, peaking between the years 1200 and 1900. Finney believes that changes in climate cause the cycles in salmon populations, and as scientists struggle to understand the rate and effects of global warming, salmon may help them distinguish normal climate variations from the early warnings of a system gone dangerously wrong.

Schindler found that the cycles of the salmon are mirrored by the growth of plankton, the foundation of the food chain that nourishes life in a lake. The more salmon, the more zooplankton, and the more algae flourish in the lake. His cores show the precipitous drop in plankton levels and lake productivity that mark the start of large-scale fishing in the late 1800s. Over the last 100 years, fishing has diverted up to two-thirds of the annual upstream movement of salmon-derived nutrients from the local ecosystem to human beings.

On my last day, Jon takes me by boat across the lake to the mouth of a small creek. Low clouds hang over the lake, and the water looks as solid and shiny as silver plate. We climb up onto the seats of the boat to get a better view into the water. Jon hands me his polarized sunglasses.

He points toward the deep water at the mouth of the stream. Suddenly, there are the sockeye salmon, hundreds of them, neon red orange, like goldfish big as cats. All pointing in the same direction, they glide in a huge circle—a slow, wide stream of sockeye, waiting for the exact moment they will pulse into the creek. I have never seen so many salmon, and I had no idea they were so beautiful. Their heads are almost invisible, as iridescently green as the water itself. But their backs are vividly, incandescently red. The fish come and come, slowly disappearing under the boat. I look over at Jon, who is watching intently.

Alaskan salmon populations are among the most pristine in the world. In the lakes where Jon works, each year about 1 million salmon make it past the gill nets and fishing boats, although another 1 million to 2 million are harvested. So the stream-filling densities we see are a fraction of what the run would be if left to nature. Some streams would average more than three salmon per square yard over their entire length. Scientists study this ecosystem as if it were intact, but no one knows what a river would look like if it were untouched by humans.

Nonetheless, by studying the cycles of renewal in Alaska, scientists are showing how profoundly the system is broken elsewhere, and they are beginning to understand how quickly we must act.

If we can find a way to preserve and restore salmon habitat, reduce competition from hatchery fish, remove obstacles to free-running streams, and manage fish harvests to leave enough salmon-derived nutrients upstream, then perhaps the salmon will find a way to return.

I have seen sockeye salmon swimming upstream to spawn even with their eyes pecked out. Even as they are dying, as their flesh is falling away from their spines, I have seen salmon fighting to protect their nests. I have seen them push up creeks so small that they rammed themselves across the gravel. I have seem them swim upstream with huge chunks bitten out of their bodies by bears. Salmon are incredibly driven to spawn. They will not give up. This gives me hope.

A Salmon Homecoming

"Back in the early 1990s, when I looked down in this stream by my apartment, I could see dozens of Atlantic salmon sitting in a pool filled with shopping carts and tires," says Douglas Watts, president of the Friends of Kennebec Salmon in Maine. "These fish swam all the way from Greenland to come home to the Kennebec River, and they couldn't go upriver to spawn because the Edwards Dam blocked the way. They couldn't stay in the river below the dam because the water was too warm. So they sat in this dead-end stream by the mouth of the river, trying to stay alive."

For millennia, the Kennebec River and its tidal estuary had been thriving nurseries for Atlantic salmon. Then in 1837, a new dam barred salmon from most of their spawning beds and buried the river under a reservoir. By the end of the 20th century, native runs of Atlantic salmon on the Kennebec had slipped toward extinction.

Dams alter the habitat of a river. Without periodic floods to scour the river bottom, silt below a dam buries the gravel beds where salmon spawn. If a salmon makes it past a dam, it finds a river transmogrified into a lake, burying the oxygen-rich riffles where salmon lay their eggs.

In 1997 the Federal Energy Regulatory Commission decided that the small amount of power the Edwards Dam generated did not justify the environmental costs. Deconstruction began on July 1, 1999, and Edwards became the first functioning hydroelectric dam in the nation to be removed to restore fish passage. Migratory fish regained access to a 20-mile stretch that rapidly restored itself to a wide, gravel-bottomed, fast-flowing, cold-water river. Biologists watched.

Alewives swam back 2 million strong in the first year, along with striped bass, American eels, and eight other species of fish once native to the Kennebec. The next year, Paul

Glaucous-winged gull
Golden eagle
Gray wolf
Great blue heron
Grizzly bear
Harbor seal
Harlequin duck
Heermann's gull
Herring gull
Killer whale
Marbled murrelet
Mink
Northern fur seal
Northern (Steller's) sea lion
Northern river otter
Northwestern crow
Osprey
Pacific Coast aquatic garter snake
Pacific giant salamander
Pacific loon
Pacific white-sided dolphin
Pelagic cormorant
Pied-billed grebe
Raccoon
Red-breasted merganser
Red-throated loon
Rhinoceros auklet
Ring-billed gull
Steller's jay
Thayer's gull
Tufted puffin
Turkey vulture
Virginia opossum
Water shrew
Western grebe
Western gull

Christman, a fisheries biologist with the Maine Atlantic Salmon Commission, found proof that Atlantic salmon were spawning: He located six new gravel nests sheltering the bright red eggs of the Atlantic salmon as far as 18 miles upstream.

Last summer, standing on the bank of the resurrected river, Watts saw something he had feared no one would ever see again. "All of a sudden—*whoosh*—a huge salmon jumped three feet out of the water."

— *K.D.M.*

Web Resources:

The Salmon Planning Act is a bipartisan bill that would fund studies to look at dam removal on the lower Snake River. For more about the politics behind salmon restoration, see the Sierra Club's Web site: www.sierraclub.org/wildlands/species/salmon.asp.