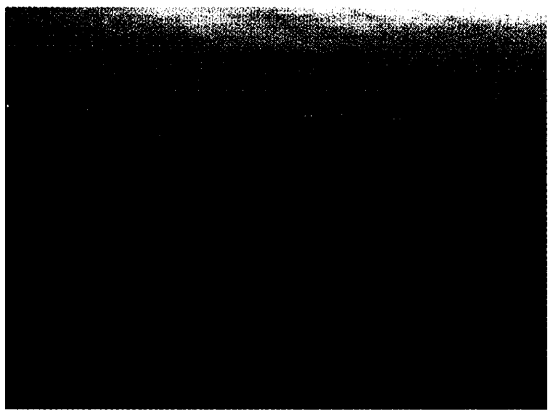


Only dormant? Olympus Mons, the largest volcano in the solar system, may erupt once more.

face. At least a few such cycles are evident in Viking images, say Baker and his colleagues, cycles that could presumably repeat again. Other scientists, however, find the available imagery unconvincing or doubt that all that water could get back into the southern highlands fast enough for the next episodic outburst.

In an upcoming *Icarus* paper, Clifford and planetary geologist Timothy Parker of the Jet Propulsion Laboratory in Pasadena, California, reject such episodic rejuvenation. Instead, they propose, Mars has more or less steadily wound down geologically but not to a dead stop. They start with an "inevitable" ocean on early Mars, albeit an ice-covered one; the young planet's inner heat would have been too great to allow the water to be locked up beneath the planet's surface, they say. Water cycling slowly from lowlands to highlands by sublimation from the ice would feed into the subsurface highlands, from which it might occasionally burst to cut the outflow channels. But eventually, as internal heat waned, such a thick barrier of frozen ground would form that only the isolated and increasingly infrequent intrusion of magma could allow water to break out.

Sorting out what Mars actually did "is an incredible challenge," says McEwen. "It's probably a complicated story, and we've barely begun to figure it out." Doing geology from orbit is never easy, he notes, but on Mars today it's proving particularly difficult. The Mars Orbital Camera onboard MGS is providing unprecedented detail of the surface. Still, its high-resolution images come in strips just 3 kilometers wide that will cover perhaps only 1% of the planet. Given the fuzzy Viking views of terrain surrounding the strips and the alien nature of the landscape, at times "you don't know what you're looking at," says McEwen. Diametrically opposed interpretations are common. Add in the uncertain dating, and "we're asking questions we can't answer without sending people and collecting the samples," says planetary geologist Kenneth Edgett of Malin Space Science Systems in San Diego. A wetter Mars would certainly help sustain any such visitors. **–RICHARD A. KERR**

ECOLOGY

Can Science Rescue Salmon?

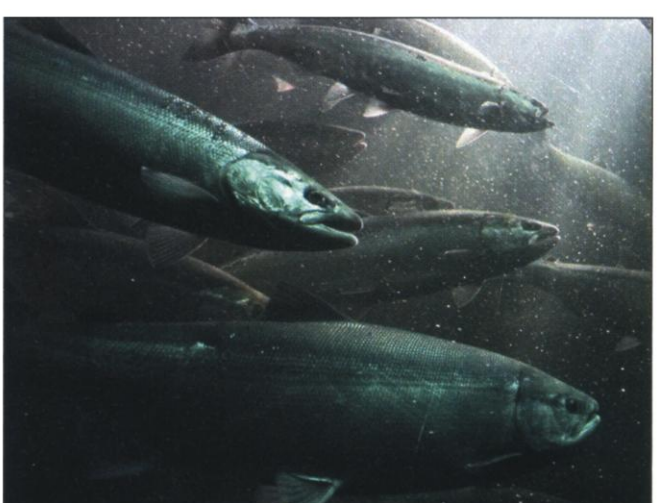
As scientists wrangle over whether breaching dams will save endangered Snake River salmon, the Clinton Administration has decided to bypass the controversial decision

PORTLAND, OREGON—For now, at least, the dams will stay, as the controversy swirling around them escalates. At a press conference on 27 July, the National Marine Fisheries Service (NMFS) released a long-awaited plan to save the Columbia River's endangered salmon by restoring fish habitat, overhauling hatcheries, limiting harvest, and improving river flow. What the plan did not do, however, was call for immediate breaching of four dams on the Snake River, the Columbia's major tributary—an option that has been the subject of a nationwide environmental crusade. The NMFS will hold that option in abeyance while it sees whether the less drastic measures will do the trick. Responses from both sides were immediate and outraged. "This plan keeps the fuse burning on the extinction time bomb," charged Tim Stearns of the National Wildlife Federation, while presidential candidate George W. Bush and Senator Slade Gorton (R–WA) had already slammed NMFS for not ruling out breaching absolutely.

Without question, the stakes are huge: Wild salmon are cultural symbols of the Pacific Northwest. Yet breaching the Snake River dams—bypassing them with newly constructed channels—would cost almost $1 billion and affect thousands of jobs. No one disputes that these dams, and the 14 other major and hundreds of minor dams in the Columbia Basin, have drastically reduced Northwest salmon populations, some of which are headed for extinction. The disagreement concerns whether breaching the dams is indeed the silver bullet or whether the salmon can be rescued by other means.

In theory, at least, the warring parties all agree that salmon conservation should be driven by science. Indeed, Vice President Al Gore has promised to convene a post-election "salmon summit" to save the fish with an "objective, science-based process." But science is unlikely to provide the answer to an intrinsically political debate—especially because the scientists themselves disagree, often vocally, providing ample ammunition for both camps. At the heart of the dispute is the maddeningly incomplete body of data on Columbia Basin salmon —and especially the role the multiple threats play in driving the fish to extinction.

In the past 18 months, two scientific teams have issued their conclusions about the relative contribution of the chief threats to Snake River salmon: hydropower, habitat degradation, hatchery misuse, and overharvesting—collectively called the "four H's" (see sidebar, p. 718). One team, composed of state, academic, and tribal scientists, fingered dams as the major culprit and called for bypassing them. The other team, scientists from NMFS, countered that other factors were equally to blame and that fixing them would have more certain benefits. The new NMFS plan signaled a clear winner in the debate: The fisheries agency listened to its own scientists. But because the plan is expected to be challenged



Uphill battle. With their natural path obstructed, sockeye salmon travel up a fish ladder to return to their spawning grounds.

CREDITS: (TOP TO BOTTOM) MALIN SPACE SCIENCE SYSTEMS AND JPL; PROCESSED BY GIL ESQUERDO, PSI; B. SWEET/AP

in court, the scientific fight will likely continue for years. "I can't imagine anything cooling down these debates," admits Phil Levin, an ecologist at the NMFS Northwest Fisheries Science Center in Seattle.

On the brink

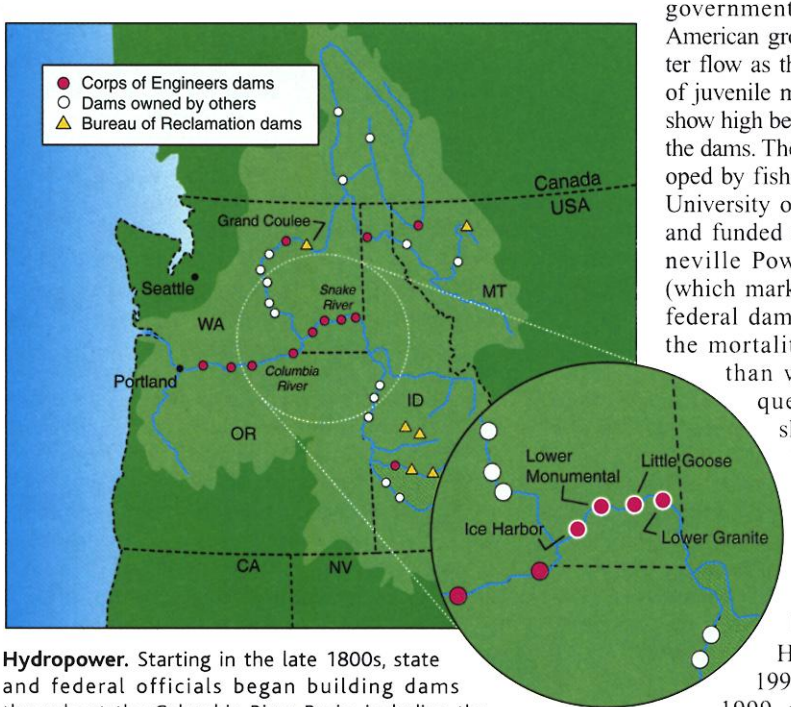
The Pacific Northwest is home to five species of salmon, each of which is known by several names (Chinook or king, chum or dog, coho or silver, pink or humpback, and sockeye or blueback), and a related species of sea-going rainbow trout called steelhead. Because salmon and steelhead that spawn in one part of a river rarely interbreed with those that spawn in other parts, the six species are divisible into hundreds of individual stocks, each with its own distinct genetic, behavioral, and morphological imprint.

Under the Endangered Species Act, NMFS is charged with protecting many endangered species of fish and marine mammals. Legally, "species" can refer to full species, subspecies, or "distinct population segments" of species. For salmon, NMFS protects what it calls "evolutionarily significant units" (ESUs): groups of related stocks that form a distinct population. ESUs are "the building blocks of salmon species," says Robin Waples, head of the conservation biology division of NMFS's science center. "The individuals have a lot more similarity among themselves than with other ESUs, and a largely independent evolutionary trajectory."

According to NMFS, the Snake River has four ESUs—sockeye, spring/summer and fall Chinook (the season indicates when these distinct ESUs spawn), and steelhead—all of which are endangered. In the rest of the Columbia Basin, eight of the other 14 ESUs are listed. NMFS estimates that most of these ESUs have a greater than 50% chance of extinction by the next century, and some much sooner.

Salmon runs in the Northwest have been shrinking since the late 19th century, reduced by cannery operations, mining, and logging. But the most severe impact has come from dams, some of which entirely closed rivers, eliminating upstream habitat. (Grand Coulee Dam by itself blocked fish from more than 1500 kilometers of the Columbia.) Beginning in 1877, federal and state agencies tried to counter the fall in salmon and steelhead populations by setting up fish hatcheries. "Hatcheries provided a very popular answer to all these problems," says Joseph Taylor III, an environmental historian at Iowa State University in Ames. "The promise of fish culture tells everyone, 'You can continue what you're doing.' " But the hatcheries were not a cure-all, and the populations continued to dwindle.

The decline accelerated in the late 1970s, particularly for Snake River fish. The blame quickly focused on the lower four dams on the river, built between 1961 and 1975. Initially, the lower Snake dams had few turbines, so most of the water—and the juvenile salmon—went over the spillways, a less harmful route than through the turbines. In the late 1970s, the Army Corps of Engineers, which operates most of the Columbia Basin dams, added more turbines to boost the dams' power-generating capacity. Fish mortality soared. Alarmed, activists pushed the agency to let more water spill over the dams.



Hydropower. Starting in the late 1800s, state and federal officials began building dams throughout the Columbia River Basin, including the four in contention on the lower Snake River *(inset)*.

Because spilled water amounts to lost electricity, the corps tried other ways to reduce the losses. It built improved fish ladders and other structures for bypassing the dams, modified the turbines to reduce their effects, and transported young fish down the river in barges and trucks. These efforts cut juvenile mortality by as much as half, according to an NMFS study.

But the damage was already done. Snake River ESUs were so depleted that listings under the Endangered Species Act were inevitable. The first, for sockeye salmon, occurred in 1991, followed quickly by the two Chinook populations. Snake River steelhead were listed in 1997. Because the act blocks federal actions that jeopardize listed species, agencies such as the corps and NMFS were vulnerable to litigation. A series of lawsuits forced them to consider a wider range of strategies for salmon recovery, including the most radical: "permanent natural river operation," or breaching the dams.

Multiple models

To determine whether less drastic methods could rescue the fish, state, federal, and tribal agencies joined forces in 1993 to examine research on the salmon life cycle, particularly the effects of downstream migration through dams. At the time, two models dominated the field. One, developed by biologists from state governments and local Native American groups, focused on water flow as the major determinant of juvenile mortality; it tended to show high benefits from bypassing the dams. The other model, developed by fisheries scientists at the University of Washington (UW) and funded mostly by the Bonneville Power Administration (which markets power from the federal dams), blamed most of the mortality on factors other than water flow; consequently, it tended to show fewer benefits from breaching.

To resolve differences between the models, the two teams formed the Plan for Analyzing and Testing Hypotheses (PATH) in 1994 (*Science*, 23 April 1999, p. 574). Funded by the Bonneville Power Administration, PATH had a core group of 25 scientists, including a half-dozen NMFS researchers. Through workshops and papers, PATH intended to create a unified body of salmon science. The corps and the Bureau of Reclamation (the other agency responsible for Columbia River dams) could use the results to reform the hydropower system; NMFS could use them to make its legally mandated judgment—a "biological opinion," in the jargon—about the impact on Snake River salmon of the four Snake River dams, as well as other dams downstream.

PATH looked first at the historical record. Although it was tempting to blame the population decline on the dams, especially because it accelerated after the last was built in 1975, it turned out that the productivity of the North Pacific had changed at about the same time, reducing all Columbia River salmon populations. To isolate the dams' effect, PATH compared the Snake River stocks with those farther down the Columbia, which was less heavily dammed. Lower Columbia salmon also declined after 1975, but not as much as the Snake River stocks.

CREDIT: FEDERAL CAUCUS, COLUMBIA RIVER FISH AND WILDLIFE RECOVERY, *CITIZEN UPDATE 3A*

Because all the other factors affected both stocks equally, PATH scientists argued, the difference had to be due to the dams. "We painstakingly went through and looked at all the H's," says Paul Wilson, who worked on PATH for the Columbia Basin Fish and Wildlife Foundation. "In the end, we concluded that hydro was still the most important" source of mortality.

But there was a puzzle. By this time, the corps and the Bureau of Reclamation were barging and trucking most juveniles around the dams. Yet the percentage of salmon that later returned to spawn was lower than the percentage that had returned before the dams were built. Some unknown factor seemed to be killing the fish after they passed the dams. State and tribal scientists within PATH argued that dams and barges were having delayed impacts on salmon survival. Their UW colleagues countered that the hydropower system alone could not produce such a large impact and concluded that the change in ocean productivity had to be at fault.

Hoping to settle this and other internal disputes, PATH created a supermodel that predicted the future population levels for Snake River spring/summer Chinook; models for the other Snake ESUs, they hoped, would soon follow. The model contained every assumption everyone on the team thought important. Rather than try to agree on one set of the most likely assumptions, PATH kept them all, running the supermodel for each possible permutation, more than 5000 times in all. In a series of voluminous reports completed in April (www.efw.bpa.gov/Environment/PATH), the group said that in almost every scenario, breaching was the best route to recovery.

The Other H's

When the National Marine Fisheries Service (NMFS) unveiled its draft biological opinion of the Columbia River hydropower system (see main text) on 27 July, it was accompanied by a broader strategy written by nine federal agencies covering all the factors implicated in salmon decline. Fisheries scientists have long identified these factors as the "four H's": hydropower dams, harvesting, habitat degradation, and hatchery misuse. According to the interagency plan, known as the "All-H Paper," improvements in the other three H's will provide benefits that are more certain and widespread than those from dam breaching. To be successful, this new strategy must overcome environmentalist opposition and gain the cooperation of state governments, Native American tribes, and private landowners. And because addressing the other H's may be even more costly than breaching dams, NMFS will have to convince Congress to pump more money into salmon recovery.

Harvest. In some ways, harvest is the easiest factor to understand and control, because its effects on mortality are direct and easily measured. Protecting the endangered runs while allowing harvest of others that migrate at the same time is problematic, however. Fishers have no way of knowing whether a Chinook salmon on the line is from a plentiful Washington-coast run or a critically endangered run on the Snake River.

For most of the endangered fish in the Columbia Basin, harvest rates are already so low that further restrictions are politically difficult—and unlikely to contribute to recovery. The All-H strategy calls for continuing these low rates, while tagging most hatchery fish to enable fishers to tell them apart.

Multiple threats. This young coho will face many obstacles before it returns to spawn, including habitat degradation, harvesting, competition from hatchery fish, and, of course, hydropower.

Habitat degradation. Like overharvesting, habitat degradation has been a problem since the late 1800s. By extracting ore with high-pressure hoses, miners drew water away from streams and returned a flow of sediment, burying the gravel needed for spawning. Sometimes they mined the stream itself, extracting gravel, sand, and limestone as well as gold. And logging removed trees from forests adjoining streams, increasing stream temperatures and covering spawning beds in eroded dirt.

In addition to wreaking damage directly, dams made it possible to irrigate the dry, eastern parts of the region. But irrigation takes water from streams, which harms spawning and rearing habitat. And the cattle that accompanied irrigation, if not fenced out of streams, can stir up sediments with similar effects.

Habitat degradation is pronounced in the Columbia River estuary, where the young salmon make the transition from fresh water to saltwater. Dredging to improve navigation, filling in wetlands to expand urban areas, and flood control measures have made this habitat less salmon-friendly.

The All-H strategy makes habitat protection its centerpiece. Major programs include improving stream flows by acquiring private water rights; protecting fish habitat in the lower Columbia estuary by purchasing wetlands and adjoining land; and accelerating habitat restoration on federal lands in areas identified as high priority. But these measures will require the cooperation of big private landowners, historically a problem for the Endangered Species Act.

Hatcheries. Each natural stock adapts to the characteristics of its spawning ground, including temperature, depth, flow, and distance from the river mouth. If salmon from one environment mate with salmon from another or from a hatchery, the offspring are likely to lose sets of coadapted genes, decreasing their fitness for a particular environment. For this reason, the practice of breeding hatchery fish from whatever eggs were available, regardless of species, river, or season, is a thing of the past. But because hatchery populations today dominate salmon species, they still affect their wild cousins. To make up for losses in wild runs, for example, hatcheries allow many more young fish to survive to adulthood, relaxing the selective forces at that stage. If the hatchery fish interbreed with the wild ones, the genetic makeup of the population will likely be adversely affected.

The All-H strategy takes an aggressive stance on the hatchery issue, arguing that all existing hatcheries should be reformed to minimize the harm to wild fish. Any federal agency operating a hatchery must develop a genetic management plan, including drawing from the gene pool appropriate for a particular location. But drastically changing or cutting back hatchery operations will be resisted by the tribes, whose treaty rights to salmon and steelhead have increasingly been satisfied by harvesting hatchery fish.

Although the agencies declined to place a price tag on addressing the "other H's" strategy, rough estimates put it at billions of dollars. The funding will have to come quickly, as NMFS intends to reevaluate salmon status in 2008 to ascertain whether dam breaching is necessary after all.

–C.C.M. AND M.L.P.

CREDIT: AP

For some PATH members, the debate was over: The dams had to go. In March 1999, eight team members signed on to a highly publicized letter to President Clinton that claimed that "a building scientific consensus" showed that "bypassing four dams on the Lower Snake River" was "the surest way to restore" the endangered salmon. But other PATH scientists declined to sign the letter. One, James Anderson, the main developer of the UW model, argued that PATH gave too much credence to older, suspect data. Recent, more accurate data, he contended, were a good fit with his model, which pointed to the ocean as the major source of salmon problems. Soon after the letter was sent, Anderson told a congressional committee that "the best we can say at this time is that the work is not finished." Designed to unify scientific opinion, PATH instead ended up splintering it further.

A different approach

Meanwhile, NMFS was becoming disenchanted with PATH. According to Michael Schiewe, head of fish ecology at the NMFS northwest science center, "PATH provided very hydrocentric work," examining the dams "in isolation" from the other H's. What's more, PATH had analyzed just Snake River ESUs, but by spring 1999 the agency had added eight more Columbia River ESUs to the endangered list.

That year NMFS asked its own scientists for a broader, less "hydrocentric" take on salmon science: the Cumulative Risk Initiative (CRI, www.nwfsc.noaa.gov/cri). Peter Kareiva, a fish ecologist, joined NMFS to direct the effort. Kareiva's team began with a general risk analysis of 11 of the 12 endangered Columbia Basin ESUs. Released in draft form this April, the analysis found that the Snake ESUs, though diminished, are not the most endangered in the Columbia Basin. That dubious honor belonged to upper Columbia spring/summer Chinook and three steelhead ESUs, each of which was decreasing at a rate of 10% or more per year.

Supplementing this grim overall picture was a reanalysis of the two Snake River ESUs treated by PATH. CRI argued that attempts to isolate the dams' effects from other factors, as PATH had done in its comparison of Snake River and lower Columbia stocks, were inevitably confounded by the poor quality of the historical data and the changes in the ocean conditions. Nor did they embrace the PATH supermodel approach, which they regarded as unmanageably complex and incomprehensible for policy-makers.

Instead, CRI used a simple demographic model that divided the complex salmon life cycle into different stages. Plugging in mortality and fecundity estimates for each stage, CRI derived its own assessment of the population growth rates for the Snake ESUs. Using these growth rates as an index of health, CRI identified the stages in which conservation measures could do the most good.

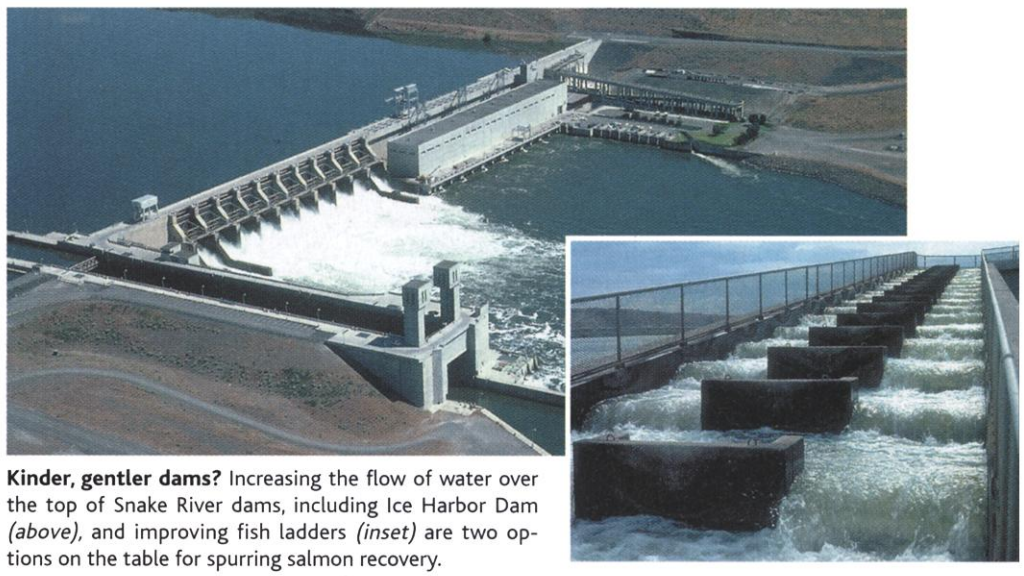
For both ESUs, the dams had their greatest impact in a single stage: the second year for spring/summer Chinook, and the first year for fall Chinook. But, the CRI team argued, other stages offered the most potential for improvement. For the spring/summer Chinook, the most promising stages were the first year, before they migrated, and later, when the fish were in the Columbia estuary and near-shore ocean, well away from the dams, so breaching them would not help much. Breaching appeared to offer more help to the fall Chinook. Unlike the spring/summer fish, they spawn in the main branch of the Snake River and migrate through the dams in their first year; breaching the dams would reduce mortality at that stage and also improve habitat. But even for fall Chinook, protecting habitat in other ways and reducing harvest seemed equally likely to be effective.

Scoffing at CRI's analysis as politically motivated, American Rivers, an environmental group, hired biological consultant Gretchen Oosterhout to critique it. Kareiva concedes that CRI might look "haplessly timid" about the politically charged dam decision. But he insists there are "solid scientific reasons for favoring more certain actions such as stopping the dewatering [removing water for irrigation and other purposes] of streams and of rivers before those four dams are breached."

Victory for CRI?

NMFS's 27 July plan was part of the agency's long-awaited draft biological opinion on the impact of all Columbia River federal dams. To avoid jeopardizing listed salmon and steelhead, NMFS declared, improvements would have to be made in habitat protection, hatchery operations, and harvest limits. Dam operation would also have to improve—but the dams did not have to go, at least not yet. The plan uses the CRI analysis to set standards for gauging the recovery of salmon stocks. If after 8 years the fish have not sufficiently recovered, says the opinion, NMFS will recommend that the dams be breached.

George T. Frampton Jr., acting chair of the White House Council on Environmental Quality, admitted that the decision was in part political. Breaching the Snake River dams would take a decade or more, given the fierce opposition. "There is not a single elected representative in Congress from the region that in any way supports breaching," Frampton said. "The fish need more immediate action."



Kinder, gentler dams? Increasing the flow of water over the top of Snake River dams, including Ice Harbor Dam *(above)*, and improving fish ladders *(inset)* are two options on the table for spurring salmon recovery.

CREDITS: U.S. ARMY CORPS OF ENGINEERS

To conservationists, the 8-year wait is unacceptable, and plans are already afoot to sue NMFS over the final biological opinion. While the dispute continues, political groups will keep latching onto whichever science best fits their goals. American Rivers, for example, maintains a remove-the-dams Web page (www.removedams.org) that makes numerous references to PATH-based scientific works—but has no links to CRI documents. Across the political divide, the Columbia River Alliance, a small coalition of dam supporters, gives a lukewarm nod to the CRI results on its Web page (www.teleport.com/~cra/aa99/aa0416.htm)—and completely ignores PATH.

The "objective, science-based process" touted by Gore will never be able to resolve political wars, says Taylor, the environmental historian. "Science can provide us with information about choices, but it is not going to deliver the Holy Grail."

–CHARLES C. MANN AND MARK L. PLUMMER

Mann and Plummer are the authors of *Noah's Choice*.