ECOLOGY

Yellowstone Rising Again From Ashes of Devastating Fires

YELLOWSTONE NATIONAL PARK—Lanky and bespectacled, Jay Anderson towers over half-meter-high Douglas fir seedlings, a giant among thousands of dark-green midgets. The budding conifer forest has risen from the ashes of fires that torched more than a third of the park in the summer of 1988. "After the fire, this place looked totally sterilized," says Anderson, an ecologist at Idaho State University in Pocatello. "It was hard to believe anything would survive here." To his delight, however, the charred landscape near Tower Junction rebounded quickly, giving birth the next summer to a carpet of pinkish-purple fireweed and other herbs. Grander changes are unfolding more gradually: It wasn't until last year, for instance, that the Douglas firs "started poking their heads up" above the shrubs, says Anderson. "We breathed a sigh of relief."

Ten years after a conflagration that razed an icon and rekindled a debate over fire management in U.S. parks, scientists have found ample evidence that Yellowstone's ecosystems are thriving. "Mother Nature is taking care of herself pretty well," says Anderson. Defying early predictions that the fires might open territory to invading weeds or shift the balance toward species that once struggled to maintain a niche in the park, the postfire ecosystems are shaping up to be essentially the same as those that prospered before the flames.

But this pretty picture of resurrection is not the whole story, scientists reported at a meeting* last week at Montana State University in Bozeman. Spurred by the fires, they have done studies showing that climate change may do what the fires of 1988 did not: drastically alter Yellowstone's ecosystems. Past climate changes have shifted vegetation patterns and the frequency and severity of fires. And computer models suggest future warming could do the same thing, turning Yellowstone within decades into a park that—apart from the spectacular geysers and other thermal features—bears little resemblance to the one that exists today. According to geographer Cathy Whitlock of the University of Oregon, Eugene, who is leading one modeling effort, "the projected changes we're seeing are dramatic and astonishing."

The fires—a conflagration the likes of which has occurred only every 200 to 300 years over the past few millennia—"stimulated an incredible body of research that has shaped how we think about landscape processes," says Norman Christensen, dean of Duke University's School of the Environment. He and others say the blaze provided an unprecedented opportunity to study a large disturbance in ecosystems protected from logging and development. "This is a unique natural experiment," says William Romme, an ecologist at Fort Lewis College in Durango, Colorado.

To most experts, the fires in the Yellowstone area were an inevitable consequence of three converging factors: extreme weather, an accumulation of woody debris on the forest floor, and mature living trees that could burn well. Lightning ignited the first fire of 1988 on 24 May; rain extinguished it later that day. But 248 more fires triggered by lightning and people raged in Yellowstone over the next 6 months, thanks to the driest summer in 112 years. By the time it was over, more than 321,000 hectares—36%—of the park had burned, says Don Despain, a biologist with the U.S. Geological Survey (USGS) in Bozeman. The fires consumed an area that's "an order of magnitude bigger than anyone alive had ever experienced," adds Romme.

The flames also touched off a firestorm of criticism over the federal fire policy, which since 1972 has been to allow fires to burn unless they threaten people or property. When this policy was put to its biggest test in Yellowstone that summer, researchers now acknowledge, the public was generally unaware of fire's benevolent side. "Ten years ago, most folks had a pretty poor understanding of the ecological effects of fires," says Robert Gresswell of the USGS in Corvallis, Oregon. For example, after surveying charred swaths of the park, former Senator Alan Simpson (R–WY) predicted it would not recover in 1000 years. Under intense pressure from local business owners who feared losing tourist revenue, Yellowstone officials departed from their own policy on 21 July 1988 and ordered all fires in the park suppressed; but despite efforts by some 13,000 firefighters and military personnel, the fires raged on.

After the smoke had cleared, however, scientists swooped in to start long-term studies of Yellowstone's recovery. Among the early predictions were that large mammals, such as bear and elk, would suffer severely from food shortages and that aspens would gain ground on lodgepole pine, the region's dominant tree for the past 10,000 years.

J. ANDERSON / IDAHO STATE UNIVERSITY

Ashes to trees. Barren landscape after the fires *(top)* is now dotted with lodgepole pine *(bottom)*.

The forecast of a carcass-littered park turned out to be off the mark. "The effects of the fires were relatively insignificant," says Michael Coughenour, an ecologist at Colorado State University in Fort Collins. Researchers watched as elk, bison, and other mammals foraged far more than expected on sugars in the charred debris—"caramel candy," as some scientists refer to it. Although the mammal death rate rose after the fires, much of the blame can be pinned on the severe winter of 1988–89, says symposium organizer Linda Wallace, an ecologist at the University of Oklahoma, Norman. "We were very, very surprised" that the fires did not take a higher toll, she says. Even fish in charcoal-choked streams survived mostly unscathed. As for the park's forests, killing temperatures from the rapidly moving fires penetrated only an inch into the ground. "No land was made unfit for plant growth," says Despain.

Equally surprising was the failure of aspen, the only deciduous species common in the park, to claim more of the scorched ground. Its territory has been shrinking for decades. "As mature trees die, they aren't being replaced," says Romme. He and others thought the fires might open up new habitat for aspen, a species whose root system can span hectares and sprout shoots even after the trees die; an

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* Yellowstone National Park 125th Anniversary Symposium, 11 to 23 May.

entire stand is often a single individual.

As predicted, the fires were a good tonic for aspen, triggering intense sprouting from roots and something "almost never seen in the wild," says Romme: young aspens growing from seeds. But the shoots are a favorite food of elk, and every winter since the fires, elk have zeroed in on aspen shoots sticking out of the snow. As a result, says Romme, the fires have actually "hastened the demise of some stands." The story is not over, however: Roots continue to send up shoots, and if the trees are able to mature, aspen "could still become a key component of succession," Romme says. "We should have interesting results in a couple of years."

Scientists have also tried to put the fires into a historical context. After studying more than 50 fire-related debris flows—landslides that sweep through denuded land and can travel up to 100 kilometers an hour—that have occurred in Yellowstone over the past 3500 years, geologist Grant Meyer of Middlebury College in Vermont says he has found that "big fires ... are strongly controlled by climate." Such flows were much more common from A.D. 900 to 1300—known as the "Medieval Warm Period"—than during the period from 1300 to 1900, called the "Little Ice Age," Meyer says.

Oregon's Whitlock and grad student Sarah Millspaugh have come to similar conclusions after studying charcoal-laced sediments at the bottom of Yellowstone lakes. These studies on past fires have prompted Whitlock to gaze into the future to try to forecast how climate change might alter vegetation patterns and, perhaps, fire frequency and severity. Whitlock, along with Patrick Bartlein and Sarah Shafer, has created computer models to predict the changes in species distributions in the Yellowstone region that may occur in response to global changes from a doubling of atmospheric CO_2. According to results reported in *Conservation Biology* in June 1997, the team predicts that warmer, wetter winters could help alter the ranges of various species in the U.S. Northwest, causing larch, scrub oak, and other trees not now found in Yellowstone to spread into the park. This new landscape could be vulnerable to more frequent, possibly smaller fires, Whitlock says.

The prospect that the Yellowstone ecosystem is poised for a makeover is spurring fire ecologists and colleagues from other disciplines to try to organize a lasting Yellowstone research program affiliated with the National Science Foundation's network of Long-Term Ecological Research sites. But the fire policy won't change, say park officials and researchers. "If our mandate is to manage Yellowstone for future generations as an unhindered ecosystem, then putting out fires is counter to that mandate," says Despain. "The fires have brought home the inevitability of change," adds Duke's Christensen, "and the process of renewal that accompanies it."

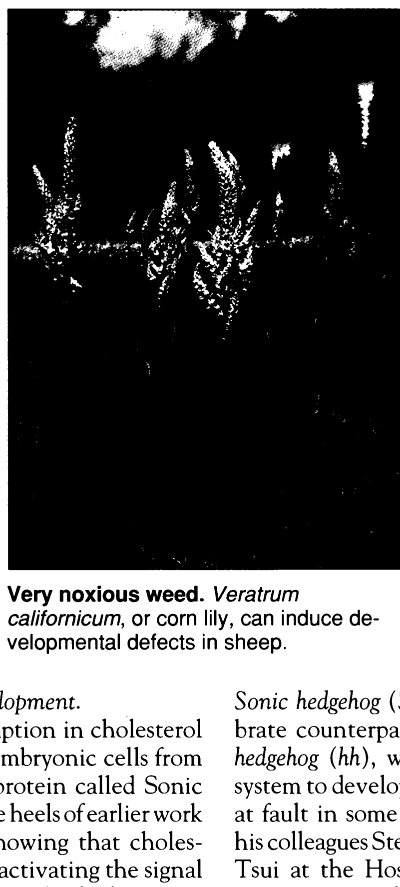
–**Richard Stone**

DEVELOPMENTAL BIOLOGY

One-Eyed Animals Implicate Cholesterol in Development

In ancient times, Homer depicted the one-eyed Cyclops as a terrifying and mysterious monster. Today we recognize infants born with cyclopia—marked by a single large eye—as victims of a defect that derails the normal development of the brain and face. But just how this developmental pathway ordinarily works has been far more mysterious than the ways of Homer's gods and heroes. Now biologists are dissecting it. At its heart, they are glimpsing a familiar molecule, cholesterol, in an entirely new role.

Cyclopia and milder forms of the same developmental disorder result from a failure of the embryonic forebrain to subdivide properly. Defective genes can disrupt this process in people and animals, but so can certain toxins, some of them found in wild plants, and their workings are giving scientists new insights into the developmental pathway. As Philip Beachy, a molecular biologist at The Johns Hopkins University School of Medicine in Baltimore, and his colleagues report on page 1603, these toxins make the cells unable to respond to a critical developmental signal, perhaps because they interfere with the normal traffic of cholesterol within cells. A second group, at the University of Washington, Seattle, has carried out similar experiments, to be published in an upcoming issue of *Development*.



D. SOKELL / VISUALS UNLIMITED

Very noxious weed. *Veratrum californicum*, or corn lily, can induce developmental defects in sheep.

The idea that a disruption in cholesterol transport may prevent embryonic cells from heeding the signal—a protein called Sonic hedgehog—comes on the heels of earlier work by the Beachy group showing that cholesterol also plays a role in activating the signal in the first place. Together, the findings provide some of the first clear evidence that cholesterol, long known as a structural component of cell membranes and as the raw material that the body converts into steroid hormones and bile acids, can also influence the signaling paths that guide development. "Everyone knew that cholesterol was important," says Yvonne Lange, a cell biologist at Rush-Presbyterian-St. Luke's Medical Center in Chicago. "But that it could act on a [developmental] signaling process was entirely unanticipated. This work opens up a whole new role for cholesterol and raises a lot of interesting questions."

Among the most tantalizing: whether a mother's diet and cholesterol metabolism play some role in determining the severity of the birth defect that, in its most extreme form, manifests itself as cyclopia. One in 16,000 babies is born with some form of the defect, technically known as holoprosencephaly (HPE), says Maximilian Muenke, a human geneticist at the National Human Genome Research Institute in Bethesda, Maryland, and the Children's Hospital of Philadelphia. Early in pregnancy, before nature exerts quality control and flawed embryos are spontaneously aborted, the rate is much higher: one in 250. People with the mildest form of the disorder have signs as minor as a single upper front incisor; severe cases are marked by one eye in the middle of the face, below a protruding nasal structure, and serious brain abnormalities. Infants with full-blown cyclopia die soon after birth.

In 1996, Beachy's group found that HPE-like symptoms, including cyclopia, develop in mouse embryos that lack a normal *Sonic hedgehog* (*Shh*) gene. *Shh* is the vertebrate counterpart of a fruit fly gene called *hedgehog* (*hh*), which instructs the nervous system to develop properly. The same gene is at fault in some human cases, Muenke and his colleagues Stephen Scherer and Lap-Chee Tsui at the Hospital for Sick Children in Toronto soon showed. Muenke says he has also found that mutations in other genes affecting the Shh signal can cause HPE. But many cases of HPE have not been traced to specific genetic lesions, opening a possible role for environmental factors.

At least in animals, toxins that interfere