patterned out of a conductor, semiconductor, or insulator. The pattern for each layer is created by a lithography process, where a beam of light—visible light, ultraviolet, or x-rays—passes through a patterned mask to expose a photosensitive material. The image of the mask that is produced on the photosensitive material then provides the template for the next processing step—laying down a series of conducting lines, for instance, or doping certain areas of a silicon layer. The chip's resolution is limited by how accurately patterns can be reproduced on the photosensitive material.

X-ray lithography offers several potential advantages over optical lithography. One is increased resolution—the wavelength of x-rays is shorter than that of visible or ultraviolet light, and it is the wavelength that ultimately determines how fine a feature can be resolved. Practical engineering problems limit optical lithography to a best resolution of about twice the wavelength of visible or ultraviolet light, or about 0.5 micrometer, while the practical limit to the resolution of x-ray lithography should be around 0.1 micrometer, Wilson guessed. A second advantage of x-rays is that they pass through some objects that visible or ultraviolet light cannot, so that, for example, dust particles on a chip are less a problem in x-ray than optical lithography. A third plus is that x-rays can expose a much larger chip at one time because they do not have to pass through a lens as does optical light.

Transforming those potential advantages into a commercially superior system is the problem facing chip manufacturers. They must learn to use x-ray beams, to fabricate x-ray masks, to align the masks to greater accuracy for each of the successive exposures, and to expose and process the chips in a new setting. IBM's announcement signals they have done all that, at least at the level of making a few chips. "All of the elements necessary are there," Wilson said.

What remains to be done? "Next is the throughput," Wilson said. "We've not demonstrated 80 wafers per hour, but we've demonstrated that the system is capable of that." The company also must reduce defects to a commercially acceptable point. And it needs a small, specialized source of x-rays dedicated to a manufacturing process. For the demonstration, IBM used a beamline at the National Synchrotron Light Source at Brookhaven National Laboratory, but the company is having a smaller synchrotron designed for it by a company in England. Wilson said at least one company in Japan is close to offering a commercial synchrotron to provide x-rays for lithography, but he knew of no American company aiming at one. ■ ROBERT POOL

Ecologists' Opportunity in Yellowstone's Blaze

The recent fires that spread through half of Yellowstone National Park offer insights into important ecological questions

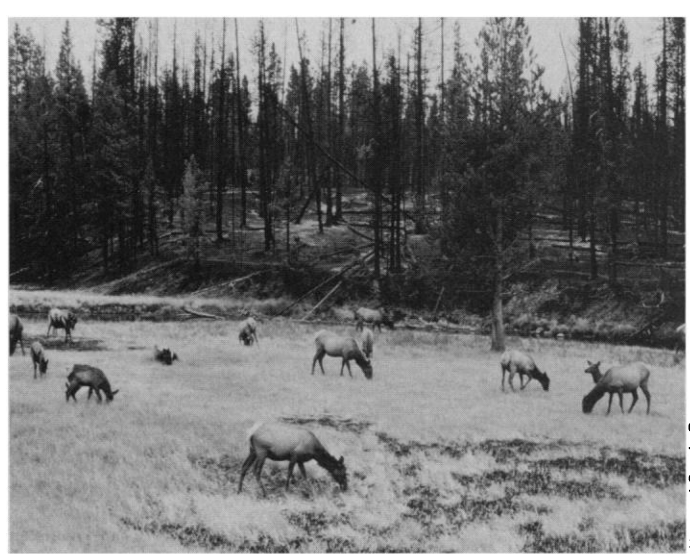
IN 2 WEEKS TIME Montana State University will host a workshop on the aftermath of this year's massive fire that has devastated 800,000 acres of Yellowstone Park's 2.2 million acres. "The concern of many people is that we've lost a national treasure," says John Jutila, who is organizing the gathering. "But the workshop will reveal opportunities that we've not had before, particularly in the scientific area." About 100 investigators are expected to attend—including ecologists, economists, and representatives of the National Park Service and the U.S. Forest Service—and they plan to draw up a wide range of research programs, some of which will extend a decade and more.

"There is a special opportunity here," says Linda Wallace of the University of Oklahoma. "There have been many previous studies of fires, but for the most part they have been on a much smaller scale. Here we have a chance to study the response of the entire ecosystem, not just parts of it." It was Wallace who initiated the idea of having the forthcoming workshop, but her original focus on ecological studies has been widened to include socioeconomic issues, such as the impact on tourism.

The ecological focus itself is rather broad, encompassing ecosystem-level studies on nutrient flow and sediment dynamics, community-level questions on succession, and interactions between just a few species, such as large grazers and the grasses and herbs they eat. The decomposition of huge quantities of organic matter will have a great impact on the immediate ecological response to the fire. Although some proportion of the potential nutrients generated by the fire will have been lost through volatility, the ecosystem will receive a large nutrient fix, one result of which will be a boost in primary productivity.

One aspect of this boost, says Willam Romme of Fort Lewis College, Colorado, will be "a vigorous growth of grasses and herbs." With many of its former food resources destroyed, the grizzly bear will find new ones here, because the new growth of grasses and herbs will support large populations of insects and rodents. Such is the interconnectedness of things.

Romme's principal interest, however, will be in monitoring the recolonization of razed areas, the community-level process known as succession. "It's an excellent opportunity to test some of the theories of succession," says Romme. The current theories—known respectively as facilitation, tolerance, and inhibition—were proposed by Joseph Connell and Ralph Slatyer a dozen years ago, and address the issue of how, in a mature



Alan and Sandy Carey

Life continues: *Elk graze in a patchily burned area of Yellowstone. Grasses and herbs are already beginning to sprout in locations burned a few weeks ago, but hard times are likely to lie ahead for these large mammals, at least in the short term.*

ecological community, a small number of species usually come to dominate.

"We will be able to study this process in various settings left by the fire," explains Romme. "We can expect to see different things at the edge of burned areas compared with in the middle, in small burned areas compared with large, and so on. The effect of unburned areas on neighboring burned areas will also be important."

For the past 10 years Romme, in collaboration with Don Despain of the National Park Serve, has been studying the history of fires in Yellowstone. "We see a pattern of repeated small fires throughout the study area, but you have to go back to the early 1700s to see anything nearly as big as this year's," Romme told *Science*. "As far as we can judge, that one burned about one third of the area."

Although Romme is dealing with only two events, separated by some 250 years, he speculates that they may be part of a cycle dictated by the park's dominant vegetation, the lodgepole pine. "Lodgepole pines don't burn very readily until they are about 200 years old," explains Romme. "From then on they become more and more combustible." Once a huge fire has swept through the area it paves the way for the establishment of extensive, even-age stands of lodgepole, all of which becomes combustible at about the same time. In other words, says Romme, "the big fire of 1988 was to some extent inevitable." How far this putative 250-year cycle goes back into history is open to question, however.

The driest summer for more than a century must also have contributed to the present conflagration. But, suggests Romme, so too has the management program that was in place in Yellowstone since it was established in 1872, being abandonned just a century later. This program involved complete suppression of all fires, a goal that was achieved with more success after 1945 than before. "The result was an accumulation of fuel, upon which this summer's fires fed," says Romme.

The proper response to fire in national parks and forests has long been a contentious issue, one that has practical and philosophical aspects. Park managers have often taken the view that their responsibility is to preserve the natural resources in their trust. Unquestionably, when life and property are at potential risk, there is a clear responsibility to prevent and control fires. But the question of the proper preservation of natural resources has been subject to fluctuating fashions. "There is a very real danger that the the Yellowstone fire will provoke a knee-jerk reaction," says Norman Christensen of Duke University. "There will be pressure to reverse the current philosophy, which would be too hasty a decision."

Not an all-consuming blaze: *Even a fire of the magnitude of this year's at Yellowstone does not leave everything completely blackened. The heterogeneity of burning will lead to an heterogeneity in the pattern of recovery.*

Christensen has recently chaired a National Park Service Panel on fire policy in Yosemite, Sequoia, and Kings Canyon parks, and is soon to be involved in a similar review process for Yellowstone. "Different parks must have different policies," he says, "and this will depend on the size of the park and the nature of the neighboring land." Generally, however, there is now a recognition that naturally set fires are an inherent part of the ecosystem. Where feasible, therefore, some form of "let burn" policy is favored, though it is never the complete hands-off approach implied by the term.

Before 1963 there was a more or less blanket "no burn" policy, symptom of the heavy interventionist approach to park management as a whole. But the publication in that year of the Leopold report alerted park managers to the danger of fuel buildup as a result of extensive fire control. Since then more and more national parks and forests have used fires—both natural and prescribed—to help prevent fuel buildup.

But the acceptance of fire in a management philosophy has to do with more than just the practical benefit of preventing the inevitable great conflagration. "It is well documented that fire is essential to the maintenance of many different types of habitat," says Ronald Myers of the Nature Conservancy. "Without fires, the tall grass prairies of East Kansas would be woodland, the pine forests of the South East would be hardwood forest, the conifer forests of the west would be completely transformed."

Fire may remove species that would otherwise outcompete what we now see as the dominant species, as in the tall grass prairies and the southeastern pine forests; and it can help promote germination and seedling establishment of current dominants, as in the conifer forests of the West. So, not only does vegetation sometimes shape the pattern of fire, as in Yellowstone, but also fire frequently shapes the pattern of vegetation.

As one of the more important agents of perturbation, fire helps keep ecological communities in a dynamic and heterogeneous state. Without it, habitat diversity would diminish. "Fire itself is extremely heterogeneous in its impact," notes Christensen. "Many people imagine that almost half of Yellowstone has been completely blackened by the fire. Not so. It is a mosaic of destruction, a heterogeneity that will be reflected in the regrowth. We have to ensure that whatever policies we have for fires in parks, we maintain that heterogeneity."

■ Roger Lewin