

Yellowstone in the **Afterglow**

Lessons from the Fires



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Mary Ann Franke

Yellowstone Center for Resources
Yellowstone National Park
Mammoth Hot Springs, Wyoming

2000

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Yellowstone in the Afterglow



Lessons from the Fires



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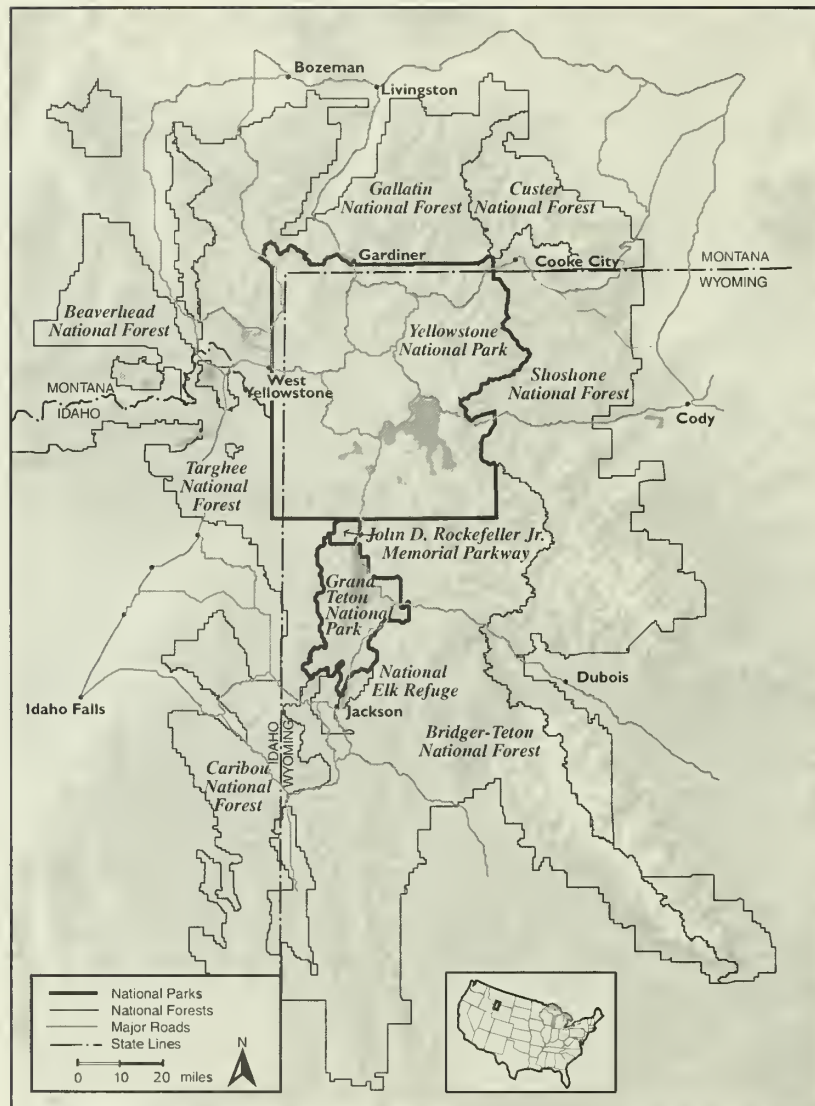


Only one stick is needed to start a fire when lightning strikes in Yellowstone, but it has to be a stick in a site ready to burn, and with a great many other sticks available to keep the blaze from going out. So too, with this book, which has been fueled by the many people who have contributed their time and research on a topic that was ready for an initial summing up.

In this effort to compile the findings of dozens of scientists in a broad range of disciplines, I have sought to do justice to the precision of their work. Any knowledge that may be gleaned from these pages owes much to their labors; any errors made in describing their research are my own. Technical reviews of an initial draft were generously provided by Don Despain and Doug Houston, both with the U.S. Geological Survey, Biological Resources Division, and by Bill Romme of Fort Lewis College in Durango, Colorado.

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I must also acknowledge the wonder and endurance of Yellowstone National Park itself. Only in a country that is rich in both wildlands and in its vision of what it wants to preserve for the future could there be a national park like Yellowstone in which fires like those of 1988 could have taken place.



The Greater Yellowstone Area

Greater Yellowstone is a loosely defined area of about 18 million acres that crosses the borders of Idaho, Montana and Wyoming. About 70% is managed by federal agencies: 7 national forests, 3 wildlife refuges, 2 national parks, and a national parkway. It also includes Indian reservations, state land, towns and rural areas in which more than 300,000 people live. Yellowstone National Park, at the center of greater Yellowstone, covers 2.2 million acres.

A tale of two fires

The fires that swept across 1.4 million acres of the greater Yellowstone area during the summer of 1988 provided compelling evidence of both the power of natural forces and the determination of human nature to bring such forces under control. The fires can be tallied many ways: an estimated 249 fires started in greater Yellowstone, including 45 that began in the park and 5 that started outside and moved in, most of them eventually burning together into eight major fire complexes. There were crown fires, ground fires, and “back-fires” that were deliberately set to try to halt the advancing flames. But afterward, only two kinds of fire seemed to matter: the inevitable ecological event that a landscape underwent as part of a long-term process of renewal, and the wrenching human event that people experienced firsthand or on television.

Fire as an Ecological Event

Although often regarded as a tourist mecca rather than a place to commune with nature, the greater Yellowstone area contains one of the largest remaining wildland areas in the continental United States. Rather than providing the stage for some “balance of nature” suggested by the sunny views of abundant wildlife found in tourist brochures, this Rocky Mountain ecosystem is always changing—from day to day, year to year, and one millennium to the next. Even Old Faithful, named for its alleged reliability, isn’t immune to subterranean influences on its eruptions, and a severe winter or fire can trigger a series of shifts in the number and distribution of plant and animal species.

Despite what Smokey Bear would have us believe, most fires in western forests are caused by lightning, which is not something we’ve figured out how to prevent. In contrast to the traditional “fire is bad” message, lightning-ignited fires are now often referred to as “beneficial” to wildland areas. But as a force of nature, like sunshine and rain, fire will tend to be regarded as good or bad depending on how it affects your own interests.



A beauty not in the eye of every beholder

Instead of fleeing in a Bambi-style panic, Yellowstone's wildlife generally went about their activities as usual and lost few lives to the smoke or flames. But what about the osprey whose nest in a fire-damaged tree is swept downstream in the increased runoff from burned slopes? Or the moose that starves without the canopy of an old growth forest to keep the snow from burying his winter food supply? In a place where the primary goal is to protect ecological processes with a minimum of human interference, looking for "benefits" can get in the way of understanding a force that may disrupt wildlife as well as human routines. Although some plants and animals fare better immediately after a fire than they did before, others find it harder to survive. Then, as time passes and conditions change, the advantages shift to other species. The reason to accept the presence of fires in Yellowstone is not because they are "good," but because they are intrinsic to its ecology.

Fire as a Human Experience

The Yellowstone fires sent mixed smoke signals to their human observers. At the same time that park managers were engaged in an often fruitless effort to persuade the public that the fires were not an ecological disaster, they were helping the surrounding national forests and communities spend \$120 million in a largely futile battle to put the fires out.

More than most forces of nature, such as earthquakes and hurricanes, forest fires provoke frustration because we can often intervene in them to some extent. We may accept our inability to halt an erupting volcano, but fires that burn for months across thousands of acres of land yank away our illusion of fire as something that long ago, in the dawn of human civilization, we learned to control for our own use. Ultimately, according to the official post-fire assessment, the effort made by thousands of firefighters during the summer of 1988 protected buildings, but probably did not significantly reduce the acreage burned in the Yellowstone area.



Since the last glaciers retreated, fire has been one of the forces that determine which plants grow in the Yellowstone area and which animals will survive in such a landscape. To try to eliminate fire in order to keep Yellowstone looking "the way it's supposed to" would be as logical as trying to prevent the rain showers that can spoil a visitor's day. Whether they realize it or not, people come to Yellowstone to see the results of fire and other ecological processes.

Nor did the acreage burned reduce the human presence in Yellowstone, although the efforts to prevent damage to park buildings and private property tested the limits of human endurance. In addition to taking the lives of two firefighters, the fires were a cause of hardship or at least inconvenience for many people who lived in the area, and a source of distress for many Yellowstone enthusiasts. National parks are generally thought of not as evolving landscapes but as collections of photogenic views that our tax dollars are used to keep unchanged. But such a goal for Yellowstone, even if it were feasible, would not be appropriate. Instead, Yellowstone is a repository for the ecological processes that have shaped it, whatever challenges and difficult decisions those processes may pose at times. Just because people who visited the park before 1988 may remember Yellowstone as a place of abundant old-growth lodgepole pine forests, does not mean that is what it always was or always will be.

This may be of no comfort to the grizzly bear whose source of whitebark pine seeds has been reduced, or to the local outfitter for whom the summer of '88 was a financial disaster. But unsparing as the truth may be, Yellowstone's primary mission is not to fill their stomachs. While recognizing the park's role as part of the surrounding human community, we must look beyond the consequences of a drought-stricken summer to a Yellowstone that will endure for the human and wildlife communities to come.

Yellowstone in the Year 2000

The Yellowstone area has always had its extreme aspects. In 1856, a Kansas City newspaper editor rejected as “patent lies” the reports of trapper Jim Bridger describing Yellowstone as the place where Hell bubbled up.” But its thousands of spouting geysers and steaming mudpots were the main reason that Yellowstone became the world’s first national park two decades later. They also provide a constant reminder of its proximity to the elemental forces that shaped the planet. The park’s petrified forests remain as evidence of the sub-tropical trees that were buried by mudslides eons ago, while “extremophiles”—primitive microorganisms that can survive in the boiling temperatures of Yellowstone’s thermal areas—have proved their usefulness in modern technology.

Hence, despite the many witnesses to Yellowstone’s hell-like qualities in the summer of 1988 who thought, “I can’t believe this is happening,” there was a certain aptness to the fact that it *was* happening—that this particular crown jewel of the national park system was burnished by such an extreme rash of crown fires. Compared to the cataclysmic eruption that took place in the middle of Yellowstone 630,000 years ago, spewing volcanic ash across much of North America and destroying all life for thousands of square miles, the changes wrought by the fires of 1988 appear rather trifling, and have been less dramatic than was expected.

Unlike in Alaska, where research has shown that fires stimulated willow growth, Yellowstone’s fires did not resuscitate its waning willow stands as some people had hoped. Nor, as some people feared, did the openings created by fire let in new invasions of non-native plants. The fires did make some long-term changes in habitat and food sources for many wildlife species, but generally with less impact on population numbers than a severe winter would have. Thousands of charred trees remain standing or have fallen over, but a dead tree can be a lively place, a home and source of food for insects and birds that provide food for other animals. In ecological terms, the fires were just another chapter in a book whose pages keep turning.

Similarly, the effect of the fires on human activities has been less than many people were predicting in the fall of 1988. Park visitation, which has fluctuated over the years in response to a variety of factors, dropped 5% in 1988 from the prior year, but climbed to a record high of 2.7 million in 1989, and has continued to remain above that level despite entrance fee increases. These numbers are important because they indicate that Yellowstone is still a place that people want to visit, and that the drop in local tourism revenues, like the decline in greenery, was only temporary. But the people who say, “Yellowstone will never be the same again” are absolutely right: with or without a battalion of firefighters, Yellowstone cannot be kept the same. Change happens.

There are some people, especially in the gateway communities that were hardest hit economically and psychologically during the summer of 1988, who have not forgiven park managers for “letting Yellowstone burn.” But within a few years, most of the park’s critics could be found foraging in other fields of controversy: some believe park policies have caused a deplorable increase in elk or a decline in bears, or that even one wolf is one too many; that there are too many snowmobiles or too few roads groomed for snowmobile use; that park managers should stop trying to “play God,” or that they should be doing a better job of it.



Although enormous fires may be a perfectly natural phenomenon that has been recurring in Yellowstone for millennia, the fires of 1988 happened to occur at a time when they posed a major dilemma for the human species.

Yet although the reports of Yellowstone's death in 1988 were greatly exaggerated, so were the announcements of its "rebirth" that began to emerge along with the first post-fire seedlings. Its fire management policy has been refined, but Yellowstone did not need to be reborn because it had not died. Its ecological processes have continued to function without interruption, producing year after year of new plant growth and new generations of wildlife. Twelve years later, lightning-caused fires that pose no risk to human life or property are still permitted to burn in Yellowstone under certain conditions, and we are still humbled by the power of wildland fire.

The Debate Continues

The 2000 fire season has broken records in many areas of the West outside of Yellowstone, and drought conditions have meant that some fires remained out of control for weeks despite the best efforts of firefighters using the best that modern technology has to offer. The problems began in May when a prescription burn set by Bandelier National Monument to reduce hazardous fuel loads escaped its intended perimeter and destroyed homes in local communities. The fire season came to a close in September with criticisms that the federal government had not done enough to prevent the summer's conflagrations through the use of prescription burns.

While large fires are incompatible with the human communities that now cover much of the United States, research has shown that they are not only consistent with the mission of Yellowstone National Park, but essential in order to let Yellowstone continue to be Yellowstone. The park cannot be born again, but it will burn again.

It is beyond the scope of this book to resolve the debate about what could have or should have been done about the fires of 1988, to determine whether too many bulldozers were used too soon or too few arrived too late, to decide whether the fires could have been halted by more quickly and aggressively suppressing the first ignitions, or whether in the driest summer in the park's history, Yellowstone received too many backcountry lightning strikes to fend them all off. The purpose here is to explain the evolution in the park's fire management policy and the consequences of that policy and the ecological forces with which it must contend. One indisputable benefit of the fires is the opportunity they have provided to learn from watching how Yellowstone has responded in the aftermath—both its human participants and its ecology. Some of what we have discovered since 1988 is summarized in this book. The answers to other questions will not be known until future chapters are completed, after our lifetimes.



August 1988: Old Faithful Geyser is temporarily upstaged by a less enduring aerial display.

Yellowstone's Clouded Crystal Ball

What has not happened since 1988

Whether you agree that Yellowstone became “a blighted wasteland for generations to come,” as announced by one U.S. Senator in 1988 is a matter of personal opinion. But of the more quantifiable predictions that were made about the fires’ long-term consequences, there is not yet any evidence that the following have come to pass:

- Ø A long-term drop in park visitation.
- Ø Flooding downstream of the park because of increased runoff on bare slopes.
- Ø A decline in fish populations because increased erosion silts up the water.
- Ø An increase in fish populations in smaller streams where deforestation and loss of shade could result in warmer water and higher nutrient levels.
- Ø More rapid invasion of non-native plants into burned areas and corridors cleared as fire breaks.
- Ø An increase in lynx following a boom in snowshoe hares as a result of changes in forest structure.
- Ø Increased willow vigor and production of the defense compounds that deter its browsing by elk and moose.
- Ø An increase in the elk population because of improved forage.
- Ø A decline in the endangered grizzly bear population because of smaller whitebark pine seed crops.
- Ø Another big fire season in Yellowstone because of all the fuel provided by so many dead and downed trees.
- Ø Adoption of a program of prescribed burning to reduce the likelihood of future large fires in Yellowstone.

What has changed

Although some of the long-term consequences of the fires remain to be seen, these changes have been caused entirely or in part by the fires of 1988:

- ✓ The replacement of thousands of acres of forest with standing or fallen snags and millions of lodgepole pine seedlings.
- ✓ The establishment of aspen seedlings in areas of the park where aspen had not previously existed.
- ✓ A decline in the moose population because of the loss of old growth forest.
- ✓ Shifts in stream channels as a result of debris flows from burned slopes.
- ✓ An increase in the public understanding and acceptance of the role of fire in wild-land areas.
- ✓ A stronger program to reduce hazardous fuels around developed areas.

As described in this book, researchers have documented many other changes in Yellowstone since 1988, but this list indicates the relatively small number that might be apparent or of interest to the average park visitor.



Yellowstone at a Glance

- **Established:** In 1872, primarily to protect the area's unusual thermal features. Yellowstone contains the world's largest concentration of geysers, including the tallest, Steamboat Geyser, which erupts up to 385 feet.
- **Size:** 2.2 million acres; 63 miles from north to south, and 54 miles east to west, which makes it larger than Rhode Island and Delaware combined.
- **Topography:** About 80% is forested and 13% is meadow and grassland. About three-quarters of the park lies on a plateau with elevations ranging from about 7,000 to 9,000 feet. The highest point is Eagle Peak, 11,358 feet (3462 m).
- **Rivers and lakes:** About 5% is covered by water including more than 220 lakes and 1,000 streams. Yellowstone Lake, which covers 136 square miles and is 400 feet deep, is the largest high-elevation lake in North America.
- **Wildlife species:** More than 300 birds, 18 fish (5 non-native), 8 ungulates (1 non-native), 2 bears, and about 49 other mammalian species.
- **Developed areas:** Less than 5% of the park area has been altered to accommodate visitor use and park administration, including 370 miles of paved roads, 900 miles of trails, historic buildings, campgrounds and other facilities.

Matchsticks from heaven

Since the last glaciers retreated about 12,000 years ago and forests spread across much of the Yellowstone area, fire has been an integral part of its continuing evolution as an ecosystem. Charred trees may be contrary to our idea of a scenic landscape, but periodic fire plays an important role in nutrient recycling and plant succession, and is therefore an essential reason why Yellowstone looks the way it does. The earliest photos of Yellowstone, taken in the late 1800s, show many trees that have been killed by fires and insects. Subsequent aerial photography has made it possible to see the sharp transitions from young to old forest, marking the boundaries of fires that occurred decades and centuries ago.

Recycling Forest Litter

To survive, plants need minerals such as nitrogen, phosphorus, potassium, magnesium, and calcium—nutrients that are usually absorbed by the plant's roots from the soil. Such nutrients may remain in fallen leaves and limbs for years, until bacteria, fungi and other "decomposers" feed on the dead matter, returning the minerals to the soil where they can be used again by other plants. But these decomposers work slowly in the cool, dry areas of the northern Rockies, where even summer nights may bring freezing temperatures. Most of Yellowstone's trees are lodgepole pine, which has shallow roots that make it easily toppled by strong winds; these trees and their pine needles may accumulate as litter on the forest floor for decades, resistant to decay and hindering the growth of leafy plants.

In areas such as Yellowstone, fire is often the most efficient agent for recycling nutrients back into the soil. Thunderstorms that release lightning but little precipitation often occur in the park on summer afternoons, and when sufficient dry fuels have accumulated to carry a fire, they will eventually be ignited. Although lightning may strike Yellowstone



Bunsen Peak, September 1988.

Fire affects plant succession.

thousands of times a year and rip the bark off a tree in a shower of sparks, it usually fails to ignite anything. Up to 58 fires in the park have been attributed to lightning in a single year, but most soon go out on their own because the fuel is too sparse or the weather too damp.¹ Unlike the slow process of decomposition by bacteria and fungi, fire releases nutrients in sporadic bursts that may be separated by decades or hundreds of years.

As a plant community develops, each species is differently affected by climate, fire, and other disturbances, and by the competition it faces in obtaining light, water and nutrients. Whether a plant thrives or dies and becomes part of the litter, it alters the landscape for the plants that succeed it. After a Yellowstone forest has been opened up by fire, the major pioneer plant is usually lodgepole pine, which requires direct sunlight. More shade-tolerant species may then sprout beneath the lodgepole pine, eventually leading to an "old growth" forest containing trees of many size and ages, as well as low shrubs and leafy plants. But without fire, the lodgepole pine may grow old and die without replacing themselves, for their seedlings cannot survive in the shade of a developing spruce and fir canopy.

In Yellowstone's grassland areas, lightning-ignited fires occur more frequently than in the forest, and are part of what keeps them grassy. In the absence of fire, sagebrush can grow large enough to form a significant canopy of shade, and trees begin invading from surrounding wooded areas, creating clumps that may eventually coalesce into forest.

Yellowstone's Fire History

The U.S. government's first attempt to fight fire in a wilderness area began in August 1886 with the 50 U.S. cavalrymen who arrived in Yellowstone to serve as the park's first rangers. They spent the rest of the summer trying to put out dozens of fires, many of them set by frontiersmen who were rankled by the park's infringement on their hunting grounds. But Yellowstone did not begin keeping a formal fire record until 1931, when lightning ignited the Heart Lake fire. Fought with the techniques available at the time, the Heart Lake fire burned about 18,000 acres before rain put a damper on it. It was the largest fire in the park's history until 1988.

Nature's fire ledger.



Not when lightning strikes.

Although park staff have only been tallying fires for seven decades, nature has been keeping its own record in the landscape for thousands of years. In Yellowstone, this fire chronology has been ascertained from three kinds of evidence: the annual growth rings in trees; the sediments that have been deposited in alluvial fans along stream banks for up to 7,000 years; and the charcoal preserved in layers of lake sediments that date back 17,000 years.

When fire burns deeply enough to kill the living cells under the bark on one side of a tree but leaves enough cells alive on the unburned side, the tree survives with a scar. Mature Douglas-fir, which have a thick protective bark, often survive fire and live for up to 400 years. By counting their growth rings, the fire history of an area can be determined as far back as the oldest tree. Lodgepole pine rarely have fire scars, but they are usually well-established within a few years after a stand-replacing fire, making it possible to estimate the last fire from the year in which the oldest trees became established.²

The frequency of fire has varied widely in the Yellowstone area as a result of differences in local climate and vegetation, both of which are affected by altitude. On the lower-elevation grasslands of the northern range, fire scars on Douglas-fir indicate that the fire interval averaged 20 to 25 years for about three centuries prior to the park's establishment in 1872.³ But higher elevations generally have shorter growing seasons and longer periods of snowpack, cold weather, and high fuel moisture, creating conditions less conducive to burning. In Yellowstone forests above 2,000 feet, hundreds of years may pass before enough fuel has accumulated to support a fire that can burn through an entire stand of trees.

Partly to defend the “naturalness” and inevitability of the 1988 fires, it has been suggested that Yellowstone is inextricably tied to a major fire cycle lasting some 200 to 300 years—the time it takes for lodgepole pine forests to mature and create the fuel load needed for extensive crown fires. But although the last fires comparable in scale to those of 1988 apparently occurred in the early to mid-1700s, the area of mature forest has been increasing since the park was established without a corresponding increase in annual burned area.⁴ Yellowstone’s forests have never all burned in the same year, so even areas that have similar elevation, soil type, and vegetation are at different stages of succession and become “ready” to burn again at different times.⁵ And ready or not, virtually all forest types and ages burned somewhere in drought-stricken Yellowstone in 1988; whether a particular area burned was affected by its topography and the wind speed and direction, as well as how long it had been since the last fire there. Similar to wildlife mortality, which varies from year to year but may increase abruptly during an unusually severe winter, large fire is an episodic force that occurs only under optimal fuel and weather conditions.

After all, the fire record provided by tree rings represents only a small interval of environmental history. Researchers looking further into the past have found no evidence of a long-term recurrent cycle. The debris flows that occur in severely burned watersheds during intense rainstorms carry charcoal that is deposited in alluvial fans at the mouths of ravines. By radiocarbon-dating these deposits, geologist Grant Meyer of Middlebury College in Vermont has determined that stand-replacing forest fires have been a major factor in sediment export from tributary basins in Yellowstone for the last 10,000 years, and that such fires have been more frequent in warmer, drought-prone periods, such as from 900 to 1300 AD, than in cooler, wetter periods like 1550-1850, known as the Little Ice Age.⁶

An analysis of the charcoal deposits in several Yellowstone lakes led Cathy Whitlock of the University of Oregon and doctoral student Sarah Millspaugh to conclude that fire frequency has been closely correlated to the intensity of summer drought for at least the last 17,000 years.⁷ Long-term fluctuations in the solar radiation that reaches Earth during the summer have caused gradual climate shifts by altering atmospheric circulation. Based on a sediment core from Cygnet Lake on Yellowstone’s central plateau, Whitlock and Millspaugh determined that fires occurred most frequently (15 per 1,000 years) in the early Holocene period, about 9,900 years ago, when summer insolation was peaking, and warmer, drier conditions were present throughout what is now the northwestern U.S. After that, decreased summer insolation brought cooler, wetter conditions, and fire frequency declined to no more than 2 or 3 fires per 1,000 years on the central plateau.

The implications echo the standard warning about investing in the stock market, “Past performance is no guarantee of future success.” While we may look back and perceive certain cycles, nature is no more predictable over the long-term than are economic trends. Based on the length of time since the last big fires in Yellowstone, it appeared the area was due for a blazing summer. But looking at the available data for the park during just the last century, a correlation has been found between certain climate measures (summer temperatures, precipitation, and drought conditions) and annual burned area.⁸ During this time, Yellowstone has seen a trend toward higher summer temperatures and less precipitation from January to June, and if this continues, large fires could occur more frequently. They have become more frequent in the U.S. overall in recent decades, although whether global warming is a factor remains the subject of debate.

No long-term cycle.



More frequent future fires?

“The historic trend toward infrequent severe fires, such as those in 1988, will be short-lived and in all likelihood replaced by a regime of many small fires as a result of dry fuel conditions and more frequent ignitions...The forests of central Yellowstone will change not so much in composition as in stand-age distribution. Thus the disturbance regime will serve to perpetuate lodgepole pine where it now grows and allow its expansion to higher elevations.”

—Millspaugh, Whitlock, and Bartlein (2000)

An Evolving Fire Policy

During the first century of the park's history, until 1972, fire was regarded as a destructive force that should be fought in order to "preserve" Yellowstone. But in the park's early years, the limitations of personnel and firefighting techniques meant that suppression efforts were concentrated on the grasslands of the northern range. This area was relatively easy to reach and travel through, but it constitutes only a small portion of the park. In less accessible areas, by the time a fire was large enough for someone to have noticed it and contacted someone in a position to bring in a firefighting crew, the fire had either gone out or grown to such a size that it could not be extinguished by human effort. Outside of Yellowstone, more than 3 million acres burned in northern Idaho and western Montana during the dry summer of 1910, taking the lives of 79 firefighters and 85 civilians. That remains to this day the most extensive fire in the recorded history of North America.



Two cavalymen with a guide at the the "Wyllie Permanent Camp," 1890.

In Need of a Few Rubber Buckets

"Forest fires raged uncontrolled on every side of the park and destroyed millions of acres," Captain Frazer Augustus Boutelle reported to his superiors in 1890 in a burst of frustration-fueled hyperbole. Describing an attempt to quell a fire in Gibbon Canyon, the park's military commander noted that the ascent of the fiery hills was so difficult that "two men had epileptic fits from the effort." What was probably no exaggeration was his complaint that "Up to a late date last season, there was no fire equipment in the park. The few axes and shovels supplied the troops for garrison purposes were the only tools available."

This was not the last time a park manager would plead for more equipment in order to adequately carry out his job, but it may have been the first time that Yellowstone's dire straits inspired a private donation. Upon learning of the predicament, a park visitor gave Boutelle \$40 because, "If this great United States government has not money to buy you a few rubber buckets for the protection of this wonderful and beautiful country, I have!"⁹

Park-wide fire detection and suppression efforts were not feasible until after World War II, which gave the Defense Department reason to develop firefighting techniques and brought Yellowstone access to pumper trucks, slurry bombers, helicopters, smokejumpers and chemical retardants. But as Stephen Pyne, author of *Fire in America, A Cultural History of Wildland and Rural Fire* (1982) has pointed out, "Pouring more and more money into fire suppression did not lead to a corresponding diminution in burned area... Suppression is not a neutral act. It does not quick-freeze an ecosystem, which changes by having fire withheld as surely as it changes by being burned."

While park managers were making some progress in their ability to predict and control fires, they were also developing a more sophisticated understanding of their role as guardians of Yellowstone's natural ecology. In the 1930s, predators such as wolves and coyotes began returning to favor; in the 1950s, Yellowstone stopped diverting hot springs into swimming pools; in the 1960s, roadside feeding of bears was no longer permitted so that they would return to their natural foraging and predation; in the 1970s, the focus of the fisheries program shifted from maximizing the number of fish caught by visitors to restoring native fish populations. All of these decisions were part of a long-term trend in national park management, away from efforts to maintain a park in some fixed state thought most desirable to visitors and toward preservation of ecological processes in which change over time is expected.

In a 1972 study of fire-scarred trees to determine the fire record on Yellowstone's northern range, biologist Doug Houston concluded that effective fire suppression during the last 80 years had been a key factor in changes in the relative abundance of certain species and in the increase in density and distribution of conifer forests there.¹⁰ Land management agencies had begun to recognize that fire is not necessarily an enemy to be fought but part of the ecosystem they were try-

ing to maintain, and that total fire suppression was unrealistic and an expensive waste of effort. Scientists began to consider whether fire could resume its natural role in national parks without risking human lives or park facilities. By 1972, Yellowstone was one of several parks that had initiated policies that permitted some lightning-caused fires in backcountry areas to run their course. In 1976, this policy was expanded to include the entire park except developed areas and a surrounding buffer zone.

Under “natural” fire management, human-caused fires are suppressed as quickly as possible, but lightning-ignited fires are to be fought only if they jeopardize human life, park facilities, or personal property, or endangered or threatened species. The result, according to historian and former fire crew foreman Stephen Pyne, has been “a better balance between fire use and fire control, more a negotiated settlement with fire than a continued campaign for unconditional surrender.”¹¹

By 1988, the U.S. Forest Service, which is responsible for 10 million acres in seven forests surrounding the park, had also adopted a policy that allowed certain fires to burn, especially in designated wilderness areas. However, the Forest Service has somewhat different objectives from the National Park Service because national forests are managed for multiple uses that include timber yield. Some fires that are acceptable in the park may be subject to suppression as they approach a national forest boundary.

After Natural Fire Management Began

Even after Yellowstone adopted a natural fire policy in 1972, most ignitions in the park failed to spread; they either occurred in an area without sufficient fuel to support them or during a period of wet weather. Lodgepole pine are “self-pruning”—they drop their lower branches when they no longer receive enough light to produce more food than they consume. This eliminates a ladder that could enable a surface fire to climb into the canopy, and lodgepole pine-dominated forests usually lack the flammable understory needed to carry fires across large areas in average summer weather.

Of the 368 lightning-caused fires that occurred from 1972 to 1987, 235 were allowed to burn; 208 of these fires burned themselves out before covering one acre.¹² When fires were fought because they did not meet the prescribed criteria, the use of heavy equipment that could damage the landscape was minimized. No human lives were lost, no significant human injuries or damage to park structures due to fires occurred, and the new policy was certainly saving money. Even in 1981, when Yellowstone had its busiest fire season during this period, only about 1% of the park (21,000 acres) burned.

Then in 1988, a combination of conditions never before seen in the park’s history led to the burning of nearly 800,000 acres in just one summer. One of the lessons of those fires was that there is a threshold between a very dry year and an extraordinarily dry year, and once that threshold is crossed, there’s no closing the door on fire.



Park ranger using a “fire finder” at the Mount Washburn fire tower, 1958.



It’s too dark in this lodgepole pine forest for many species to grow until fire arrives.

Year	% of Normal Precipitation	Number of Ignitions	Acres Burned
1972	155%	21	4
1973	103%	33	145
1974	60%	38	1,307
1975	75%	26	6
1976	166%	30	1,603
1977	119%	29	67
1978	65%	24	14
1979	73%	54	11,234
1980	122%	25	4
1981	77%	64	20,595
1982	118%	20	<1
1983	137%	7	<1
1984	138%	11	<1
1985	90%	53	33
1986	114%	33	2
1987	117%	35	964
1988	32%	45	793,880

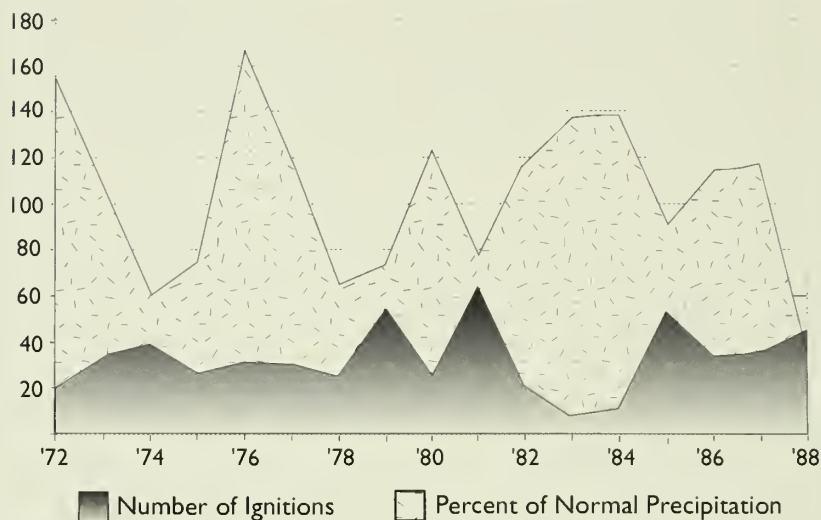
"Normal precipitation" is based on June through September data, 1950-1980.

"Ignitions" do not include fires that started outside the park and moved in, of which there were five in 1988.

(Renkin and Despain, 1991)

When Rain Decreases, Fires Increase

The Yellowstone Record



"Preposterous as it may now seem, the experience with natural fire during the prior 16 years of the natural fire program indicated that the Yellowstone landscape was comparatively non-flammable."

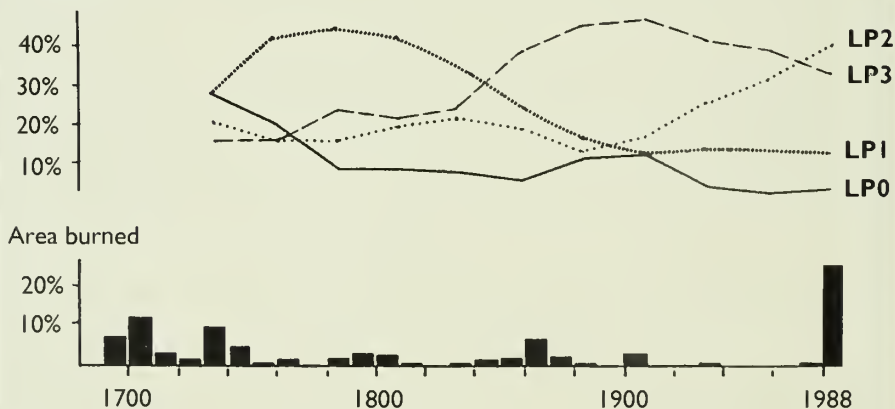
— Final Report of the Greater Yellowstone Postfire Ecological Assessment Workshop



Pinus contorta
Lodgepole pine

As the Forest Ages, the Potential for Large Fires Grows

Area in each cover type



By studying core samples from lodgepole pine trees in a 129,600-hectare area on a subalpine plateau in Yellowstone, a research team was able to reconstruct both the fire history and the portion of the area covered by forests of different ages, LP3 being the oldest (Romme and Despain, 1989).

The type of vegetation, the length of time since the last fire, and the fuel moisture level are key factors in determining when and where fires occur in the park. Different patches of forest are in different stages of development because they began growing after fires that occurred at various times in the past. Don Despain, a plant and fire ecologist on the Yellowstone staff from 1971 to 1993, developed cover type classifications for lodgepole pine-dominated forest that range from LP0 (recently burned forest) to LP3 (the oldest and most flammable).¹³ This mosaic of successional stages tends to be perpetuated over time because lightning ignitions occur more frequently in certain types of old-growth forest, and when a fire starts, more recently burned areas are less likely to burn again. Young, densely packed lodgepole pine forests, in which little sunlight reaches a forest floor almost bare of living plants, can serve as natural fire breaks; the main fuel is in the forest canopy, which a ground fire has no way to reach.

When and where fires occur.

As it ages, the lodgepole pine forest changes in ways that make it more vulnerable to fire. As some trees die, sunlight reaches patches on the forest floor where shrubs and herbaceous plants may grow along with lodgepole pine seedlings, adding to the litter of downed trees that can carry a ground fire. Where soil conditions permit, Engelmann spruce and subalpine fir begin to grow in the shade of the lodgepole pine, forming an understory that can carry a ground fire into the forest canopy.

Close canopy before striking.

The abundant fuel in an old lodgepole pine forest is susceptible to fire, and lightning often provides the spark. But the fuel moisture (the proportion of water to dry material) must be low enough in order for the fire to spread. Fires themselves do not produce enough heat to dry out and consume live fuels that are larger than about ¼-inch in diameter. Dead fuels of larger diameter are consumed, but even in the hottest fires, no more than the outer inch of the tree trunk will burn.¹⁴

Forest Succession in Yellowstone

About 83% of Yellowstone National Park is forested, with five recognizable stages of forest succession based on stand structure.¹⁵ A new successional cycle begins each time fire or another intense disturbance kills the forest overstory.

- LP0: During the first 40 to 50 years of lodgepole pine re-establishment, the only fuels are large trees previously killed by fire that are difficult to ignite, an herb-grass layer usually too green to burn, and small dead woody fuels.
- LP1: As the canopy begins to close, dense stands of small lodgepole pine persist for the next 50 to 150 years post-burn. Fuels on the forest floor consist of rotting logs and a relatively sparse herb-grass layer over a thin carpet of fallen needles, but the primary fuel is the dense and compact crowns typical of even-aged stands.
- LP2: As the even-aged stands begin to break up (150 to 300 years post-fire), a shade-tolerant understory of Engelmann spruce and subalpine fir develops on sites with sufficiently fertile soils; on poor soils, lodgepole pine forms the understory. In the first part of this phase, ground fuels remain relatively sparse, but flammability increases as the canopy thins and the understory proliferates.
- LP3: Stands more than 300 years post-fire are characterized by a mixed canopy of pine, spruce, and fir with a diverse understory. This provides a ladder of live fuels coupled with a large accumulation of dead and downed woody fuel. Understory species eventually replace the mixed canopy and, with ample groundwater, may reach a climax spruce-fir stage that persists until the next major fire or other disturbance. On mid-elevation rhyolitic or other dry soils, spruce and fir cannot thrive, so lodgepole pine dominates both the overstory and the understory.



Picea engelmannii
Engelmann spruce

The fuel moisture threshold.

As part of the National Fire Danger Rating System used by land management agencies, the moisture content of dead and downed fuel more than three inches in diameter is periodically estimated. After the 1988 fires, Roy Renkin and Don Despain on the Yellowstone staff determined that the flammability threshold is achieved in the park's high-elevation lodgepole pine forests when the fuel moisture level drops to 13%.¹⁶ At this threshold, lightning ignitions can result in visible smoke columns and, if fuel conditions are optimal, the fire will quickly spread. However, even when fuel moisture drops to 13%, fire behavior in Yellowstone is largely determined by forest type. Old growth spruce-fir and LP3 forests occupied only 28.5% of the park's total forested area, yet accounted for 70.5% of the stand-replacing fires that occurred from 1972 to 1987. The Douglas-fir forests of the northern range, although they experienced a preponderance of the lightning-caused ignitions, did not undergo any stand-replacing fire until 1988. They tend to have less dead and downed woody fuel than lodgepole pine forests, and a well-developed herbaceous layer.

To analyze information about the annual extent of burned area from 1895 to 1990 (with only rough estimates prior to 1930) in light of weather records for the same period, Robert Balling of the Office of Climatology at Arizona State University used the Palmer Drought Severity Index (PDSI). This widely used index, which is based on precipitation, temperature, and soil moisture data, has a scale that ranges from below -5 for extreme drought to +5 for extreme wetness. Balling found that Yellowstone's PDSI in 1988 was the lowest (-6) of any year on record, and that for the entire period since 1895 the PDSI could account for about one-third of the year-to-year variation in the amount of burned area.¹⁷

The role of weather.

As became evident in the unusual fire behavior of 1988, extreme weather conditions can overwhelm the constraints imposed by forest type. In highly flammable LP3 forests, isolated tree crowns may torch during even low winds, but crown fire in LP1 is maintained only during high winds when fuel moisture is considerably below the 13% threshold. Although that threshold was crossed for long periods in both 1981 and 1988, stand-replacing fires were more widespread in all forest types in 1988, probably because of the prolonged drought that affected both live and dead fuels, and because of the high winds associated with at least six cold fronts that passed through Yellowstone in August and early September.¹⁸



The Difference Between Surface and Crown Fires

Regardless of whether lightning ignites a treetop or a fallen snag, the resulting fire may take on the character of a crown fire or a surface fire depending on factors such as the locally available fuel supply and wind conditions. Both crown fires and high-intensity surface burns may be considered "stand replacement" fires in which most of the trees are killed. But surface fires typically burn only detritus, young or thin-barked trees, and understory vegetation, without consuming needles and branches in the canopy. Because the nutrients contained in the detritus are transferred to ash and most understory plants respond quickly by sprouting, the amount of fine fuels is reduced, but there is little if any impact on total leaf area or erosion.¹⁷

In areas burned by crown fires, both the forest canopy and most of the litter on the forest floor are consumed, greatly reducing the amount of leaf area and evapotranspiration (the amount of water absorbed by the soil and plants), which in turn increases the portion of precipitation leaving the watershed and the potential for short-term erosion.

Why Not Controlled Burns?

At the same time that the role of fire has become better understood, most wildlands have become more tightly surrounded by developed areas, eliminating the possibility of an unobstructed fire regime. The suppression of lightning-caused fires that start outside a wildland and would once have burned into it reduces the number of “naturally-caused” fires in the wildland. Most wildland areas are too small and circumscribed by private property to rely on lightning ignitions for maintaining an ecological fire regime. This is less an issue in Yellowstone, which is large enough to receive many lightning strikes in a typical summer, and where fires that originate in adjacent Forest Service wilderness areas are usually allowed to burn into the park. Yet maintaining a completely unhindered fire regime is not a realistic goal in Yellowstone or anywhere else in the United States, except portions of Alaska.¹⁹ Some constraints are necessary to avoid unacceptable risks to human life and property.

To simulate the role of fire or at least reduce hazardous fuel in areas where a natural fire regime is no longer possible, land managers may deliberately set fires, often called “prescribed” burns. Could the Yellowstone fires of 1988 have been avoided or reduced if the park had followed a systematic regimen of prescribed burns? There are two issues involved: the feasibility of using controlled burns for this purpose in Yellowstone, and the appropriateness of doing so.

The park has a hazardous fuels management program to reduce the risk of fire to developed areas in or near the park by cutting back vegetation and removing dead wood. Park policy also permits the use of deliberate burns to reduce hazardous fuels or non-native plants, or to compensate for the period of fire suppression on the northern range, during which trees were able to invade the grasslands and grow large enough to resist subsequent surface fires. A plan was developed to burn up to 500 acres in each of two boundary areas, but such proposals were shelved at least temporarily after the prescription burn at Bandelier National Monument went out of control in May 2000.

Hazardous fuels management.

Where There's Smoke

- **Natural fire.** Any fire that is not the result of human presence in the park is considered “natural;” the ignition source is usually lightning. Whether it's suppressed depends on whether it is considered “prescribed” or “wildfire.”
- **Prescribed fire.** Any fire that is permitted to burn because it meets approved criteria is considered a “prescribed fire” or “within prescription,” regardless of whether it started “naturally” or was deliberately set to meet specified land management goals.
- **Wildfire.** It may have been caused by lightning, a dropped cigarette or a deliberately set burn that got out of control, but any fire that threatens human life or property, or does not meet other prescription criteria is considered a “wildfire” and must be suppressed.



A prescription burn to remove non-native plants outside Roosevelt Arch, 1998.

However, it would not be feasible in Yellowstone to systematically burn the thousands of acres necessary to avoid fires like those of 1988. Superintendent Barbee's dismissive comment to a *Billings Gazette* reporter that September, that anyone who thought prescription burns could have made a difference was "chewing lotus seeds," was lacking in scientific rigor. But in a presentation to the American Association for the Advancement of Science in 1989, James Brown of the U.S. Forest Service's Intermountain Research Station stated that to prevent fires of the 1988 magnitude, prescription burns would have had to be roughly one mile wide and several miles long, covering about 50,000 acres a year for a period of years.²⁰

Prescribed fires are smoky too.

Anyone proposing such fires would have faced overwhelming public opposition for the same reasons that the 1988 fires were so unpopular: because of the smoke, the expense, the inconvenience, the risk to human safety, and the loss of scenic vistas. Instead, prescription burns would have been set only during moderate fire conditions, with the result that only small areas would have burned. Brown believed that even if the park had initiated an aggressive program of prescribed burning in 1972 when natural fire management began, the amount of area burned in 1988 would not have been significantly reduced.

Another difficulty with prescribed burns in Yellowstone is the infrequency with which the environmental conditions are suitable. For most of the year, the park has too much snow on the ground or moisture in the air to get a large fire going. Even in the summer, a large prescribed forest burn could be either difficult to keep going, or hard to control once it was started. As evident in the pre-1988 fire record (see chart on page 12), very little land burns during the typical Yellowstone summer despite frequent lightning strikes, and only in very dry years do substantial areas burn. Large-scale prescription burning would have to be done under conditions that are very close to the threshold at which fires are difficult or impossible to contain.²¹

Playing with fire in Yellowstone?

Even if it were feasible, however, the widespread use of prescribed burns would not be an ecologically appropriate way to manage the park. Writing after the fires in 1988, Alston Chase claimed that "whereas small, relatively 'cool' fires regenerate critical vegetation and wildlife habitat, hot, so-called 'crown' fires destroy everything—including seeds and organic matter in topsoil, leading the way to soil erosion."²² But as the research summarized in this book has shown, that kind of destruction did not occur in the crown fires of 1988. Yellowstone's lodgepole pine forests have evolved within a regime of infrequent, high-intensity stand-replacement fires that have a different impact from that of more frequent, low-intensity, controlled burns. A fire that is deliberately set to reduce the risk of a large conflagration entails a choice of fire intensity, size, location, and timing that cannot simulate that of a naturally occurring fire. In ways not yet fully understood, large fires may set in motion processes that are not replicated by the combined effect of many small fires.²³ To preserve its ecological processes, Yellowstone must be subject to the haphazard risk of large, lightning-caused fires.

"...we have already heard from people who believe that if we had had the foresight to clearcut the park and crisscross it with roads and human-set burns, we could have prevented the fires of 1988. But if we treated the park like that, who would care if it burned?"

—Varley and Schullery, 1991



THE SUMMER OF 1988

A time to burn

By the 1980s, about a third of Yellowstone's forests were more than 250 years old and reaching their most flammable stage. While it was only a question of time before they would burn, it could have been a matter of weeks or years. It was a question of when a summer with the right conditions would arrive. Although 1979 and 1981 had relatively active fire seasons, with a total of more than 30,000 acres burned, for the last decade Yellowstone had generally been having dry winters and wet summers.

Drought Sets In

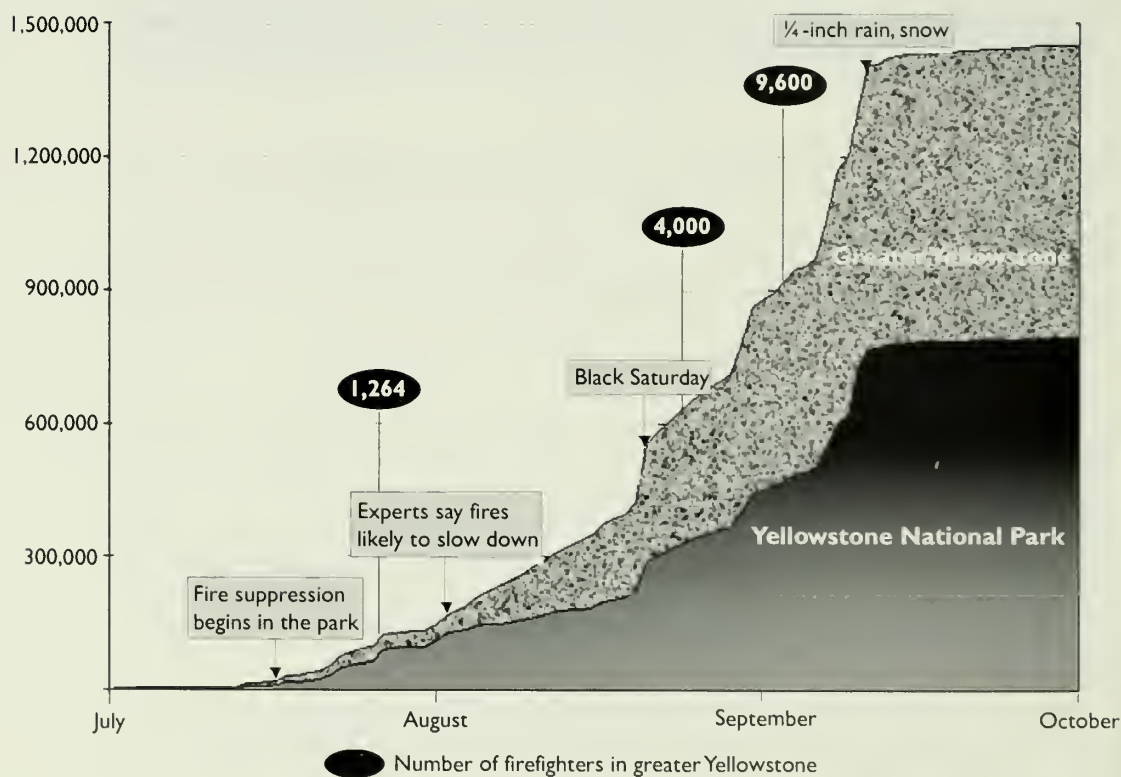
By the end of 1987, the greater Yellowstone area was in a mild drought. That winter's snowpack was only 31% of the long-term average, but precipitation was 155% of the average in April and 181% of the average in May. The 20 lightning-caused fires that started in the park in late May and early June were each evaluated before being allowed to burn, and 11 soon went out on their own. Others were still smoldering in mid-June, when the weather turned dry again, but as late as July 11, the National Weather Service was predicting normal July rainfall for the area.¹

In late July, a team of fire-behavior experts met for two days in West Yellowstone to forecast fire activity for the coming month, the first time such a lengthy forecast had been attempted. Information about historical weather patterns, fire behavior, and the ages of the forests in the path of the fires was fed into a computer to generate a map in which 43 configurations of colors and symbols showed the location of Yellowstone's vegetation zones. When the fire managers assembled on August 2 to make decisions about allocating crews and equipment, the experts estimated that nearly 150,000 acres in greater Yellowstone had burned and that although "as much as another 100,000 acres" could be added to the tally, they predicted the worst was over "because of shortages of fuel."²

But by the time the greater Yellowstone fires had all gone out, they had burned about 1.4 million acres and all types of vegetative fuel. Where the experts went wrong was in underestimating the influence of the weather and over-estimating the effect that multi-aged forest stands would have in limiting the spread of fire. The summer of 1988 turned out to be the driest in the entire 112 years of park records: precipitation for June, July, and August was 36% of the long-term average. The relative humidity in greater Yellowstone was consistently below 20% and occasionally below 10%, reaching a record low of 6% in the park at Tower Falls on August 22. As the humidity dropped, so did the fuel moisture content, sometimes as low as 5% in downed trees, making the vegetation more flammable.³ July and August also brought dry storms with more than double the usual number of lightning strikes and flame-fanning winds up to 60 miles per hour, but none of the rain that would have extinguished or at least limited the extent of fires in a more typical summer.

It was a heavy fire season throughout the West, with more than 3.7 million acres burned in the lower 48 states and several million more in Alaska. By August, more than 15,000 firefighters were at work across the country, many of them in greater Yellowstone, where more than half of the total burned area was initially ignited by fires that started outside the park.

Acres Burned in 1988



This graph shows the relative increase in burned area in greater Yellowstone from July 1 to October 1, 1988, as derived from both the estimated daily growth in the fire perimeter and the total burned area estimated after the fires were out. To eliminate large unburned patches from the estimate, the park was surveyed at a smaller scale than the rest of greater Yellowstone, for which the estimate is therefore even more approximate.

Although the fires' size, remoteness, and smoke made precise mapping impossible, the National Park Service worked with the U.S. Forest Service to map daily fire advances. The position of the fires was estimated by incorporating data from aircraft using infrared scanners, satellite imagery, ground surveys, and reconnaissance flights.

Measuring the burned area.

Both during and after the fires, a variety of methods were used to measure the burned area and widely varying estimates were obtained. Some differences can be accounted for by the scale at which an area was examined; a "fire perimeter" will include large patches of unburned area, and burned area may be mistaken for unburned area when interpreting aerial photographs or satellite data. In October 1988, an interagency team from the National Park Service, the U.S. Forest Service, the National Aeronautics and Space Administration, and Montana State University conducted three flights to obtain infrared photography at a nominal scale of 1:63,360 and followed up with ground investigations to develop a map of the burned areas with a unit size of 200 acres. They estimated that the burned area covered 1,405,775 acres,⁴ not including three fires that lay entirely outside the boundary of Yellowstone National Park (Hunter, Fayette, and Corral Creek), which totalled approximately 47,000 acres.⁵ Richard Rothermel of the U.S. Forest Service later arrived at an estimate of nearly 1.7 million acres for the entire greater Yellowstone area, but his focus was on daily fire growth and excluded only the largest unburned patches within the fire perimeter.⁶

The fire maps created using satellite data suggest that most of the burned area lay within the park's boundaries, and preliminary estimates of nearly 1 million acres burned in the park have appeared in many descriptions of the fires. However, a presumably more accurate estimate of 793,880 acres (36% of the park) was determined in 1989 using ground surveys, satellite data obtained in October 1988, infrared photography at a scale of 1:24,000, and a minimum map unit size of 5 acres.⁷

Fire behavior is affected by the weather, available fuels, and topography—the lay of the land, especially the steepness of the slopes, their elevation and the direction they face, which affects what grows there and the impact of winds. In 1988, wind played a major role in determining which areas and how much area burned. The fires often advanced 5 to 10 miles a day, even through less flammable vegetation that would not have burned in a more typical fire season. On "Black Saturday," August 20, wind-driven flames pushed the fire across another 150,000 acres, and ash fell on Billings, Montana, 60 miles northeast of the

The role of wind.

Burned Area Within Yellowstone National Park

Burn Type	Acres	Percent of Park
• Crown fire: consuming the forest canopy, needles, and ground cover and debris	323,291	15%
• Mixed: mixture of burn types in areas where most of ground surface was burned	281,098	13%
• Meadows, sagebrush, and grassland	51,301	2%
• Undifferentiated: variety of burn types	37,202	2%
• Undelineated: surface burns not detectable by satellite because under unburned canopy	100,988	4%
Total Burned Area	793,880	36%
Total Unburned Area	1,427,920	64%

Data from the Geographic Information Systems Laboratory,
Yellowstone National Park, 1989

nearest fire. Airplanes and helicopters were grounded, and the fires grew so intense that all attempts to slow them were futile. Some fires generated enough energy to create their own windstorms, putting up convection columns with cumulus cloud caps; hot air rising from the fires drew the flames even higher. Battered by these windstorms, many trees had already toppled when the flames reached them.

About 40% of the burned area in the park (15% of the total park acreage) underwent a crown fire, which has the biggest visual and long-term impact on the landscape. Nearly all of the burned areas (95%) had been forested before the fires; the remainder was a mix of meadow, grassland, and sagebrush.⁸

How “Natural” Were the 1988 Fires?

The fire policy that Yellowstone initiated in 1972 is referred to as “natural” fire management because it permits certain lightning-caused fires to run their course. However, it was understood that the park’s fire regime would continue to be affected by human activities, including accidental ignitions and the need to put out fires that threaten human lives or property. It is impossible to know exactly how much the 1988 fires’ timing, severity, and pattern were affected by the variety of human interventions that occurred in Yellowstone before and during the fires. The large size of the fires was blamed by some people on the park’s “natural” fire policy, and by others on the park’s previous “unnatural” policy of fire suppression that created artificially high accumulations of fuel. Both groups may have assumed that humans have more control over this force of nature than they actually do.

The legacy of fire suppression.

In the heat of the moment, park managers on the defensive were apt to attribute the magnitude of the 1988 fires at least in part to the suppression policies of their predecessors. But in the more careful post-fire assessment, it was recognized that effective suppression had been possible for only about 30 years. In forests where trees live to be hundreds of years old, this had not been long enough to add significantly to the fuel accumulation, and during extreme burning conditions such as those of 1988, crown fires burned irrespective of fuel loads. The fact that the first 16 years under the natural fire management had passed without any large fires also seemed to belie the possibility that fire suppression had created a monster out of accumulating fuel loads.⁹ On Yellowstone’s northern range grasslands, where fires occur more frequently and fire suppression efforts had been effective for a longer period of time, the resulting higher fuel loads could have affected fire intensity and behavior, but these were among the last areas to burn in 1988 and only a small portion of the total burned area.



Digging a fireline: at left, in 1933; above, in 1988.

After looking at historical records on weather, lightning ignitions, and fuel loads, Romme and Despain determined that Yellowstone's forests were probably ready to produce large fires in the type of dry summer that occurred six times between 1946 and 1966, and that such fires may have been postponed for several decades because of fire suppression.¹⁰ They also believed that, as a result of fire suppression, more area burned in a single summer rather than over a period of years, as occurred during the last large forest fires in Yellowstone, in the late 1600s and early 1700s. Areas that have recently burned can serve as fire breaks, and if there had been no fire suppression, Yellowstone would have had more such areas in 1988.

But it is unclear how much difference having more recent fires would have made, since virtually all vegetation types burned in 1988. By late summer, the unusual drought and wind conditions were pushing fires through or over areas of up to nearly 4,000 acres that had burned 10 to 50 years before, and embers carried the fire over areas more than a mile wide. Although fire suppression may have had some influence on the spread and severity of fires in 1988, Romme and Despain concluded that the large scale of the fires was primarily due to the coincidence of an extremely dry and windy summer with fuel that had accumulated for hundreds of years through natural plant succession. Although Yellowstone had become highly vulnerable to large fires because of the age of its forests, that vulnerability was part of the area's ecology, not a result of human intervention.¹¹

It is also unclear whether the 1988 fire suppression efforts had any significant impact on the extent of fires outside developed areas. Firefighters were unable to extinguish any of the large fires, but they may have altered fire patterns somewhat through the use of backfires, which are deliberately set to reduce fuel in front of an advancing fire front.

Two of the largest 1988 fires, the North Fork and the Hellroaring, began with acts of human negligence—a tossed cigarette and an untended campfire. The Huck fire, which was ignited when a tree fell on a power line, was also considered “human-caused.” However, during a summer when the park was recording up to 2,000 lightning strikes a day, the weather conditions and age of the forests had made them so flammable that lightning-caused fires could easily have started in or spread to these same areas.¹² As with fire suppression and “artificial” fuel loads, it is impossible to determine to what extent these “artificially” started fires may have affected the results of the 1988 fire season in Yellowstone.

The role of human-caused fires.

A Theory of Natural Relativity

“Some human interventions are more, others less natural, depending on the degree to which they fit in with, mimic, or restore spontaneous nature. Any paint on a campground water tank is unnatural, but green is more natural than chartreuse. Restoration of wolves as predators would be more natural than culling elk by sharpshooters.

“Given these distinctions, it does not help to label all restored nature faked, myth, or ideology. Compared with pristine nature, there is diminished naturalness, but the naturalness that remains is not illusory. A broken arm, reset and healed, is relatively more natural than an artificial limb, though both have been medically manipulated. Except for hairline bone scars it may be indistinguishable from the arm nature gave. Likewise with a restored forest or range, the historical genesis has been partially interrupted. But henceforth, spontaneous nature takes over as before. Trees blow over in storms, coyotes hunt ground squirrels, lightning causes burns, natural selection resumes...”

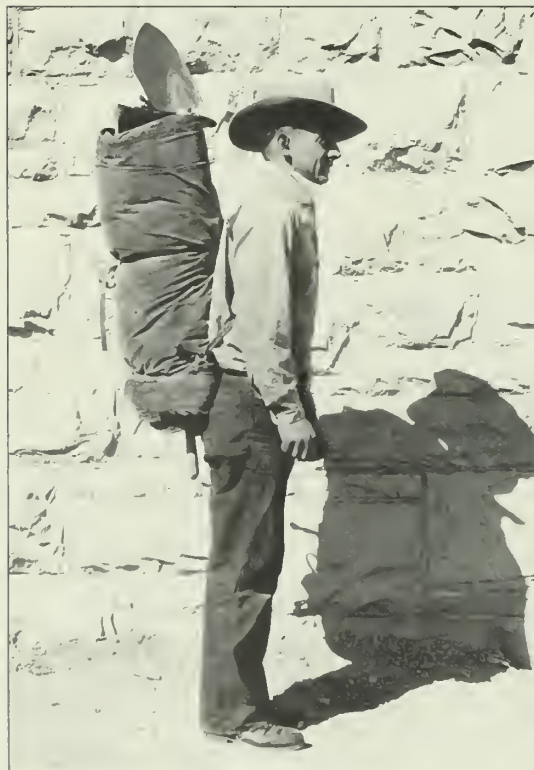
— From “Biology and Philosophy in Yellowstone,” by Holmes Rolston, III,
Department of Philosophy, Colorado State University, 1989

The Fires as a Human Adversary

The first fire suppression efforts of the 1988 season in greater Yellowstone began on July 2 in the Gallatin National Forest north of the park, when the decision was made to counter the Storm Creek fire that had been burning for several weeks. By July 12, when lightning ignited the Falls fire near the park's south boundary, about 6,000 acres had burned in greater Yellowstone and nine fires were blazing in the park without human opposition. On July 15, when the park's public affairs office began distributing the first map of the fires, most looked like specks on Yellowstone's vast rectangle; two were still less than an acre in size.

Although the U.S. Forest Service (USFS) had specific criteria regarding fuel moisture, fire size, and location that dictated when fire suppression must begin, the National Park Service (NPS) did not. Instead, the decision of when to declare a fire "out of prescription" was left to a committee of park managers, and they had agreements with the surrounding national forests to allow certain fires to cross mutual boundaries. On July 13, when USFS Supervisor John Burns notified Yellowstone Superintendent Robert Barbee that the Targhee National Forest would not "accept" the Falls fire, the interagency rules required Barbee to stop the fire before it reached the Targhee. This fact of bureaucratic life as well as mounting public pressure led to Barbee's announcement on July 15 that all new fires in the park would be suppressed unless they were lightning ignitions adjacent to existing fires.

On July 21, when fires had crossed about 17,000 acres of greater Yellowstone and were threatening Grant Village, West Thumb, and Lewis Lake Campground, the NPS and the USFS officially joined forces to counter all fires, both new and existing. The North Fork fire began the next day when a woodcutter left a smoking cigarette in the Targhee National Forest less than 200 yards west of the park, which it entered within hours, eventually becoming the largest fire in greater Yellowstone and causing more damage to park facilities than the other fires combined.



The dressed-for-success Yellowstone firefighter: at left, 1936; at right, 1988.

Once the decision to try to suppress all fires had been made, three factors determined how and where that effort was undertaken: the safety of the firefighters (no one wanted to put crews at the head of potentially lethal blazes); the availability of resources (there were not enough experienced crews and equipment to safely manage all the fires in greater Yellowstone, so priority was given to those threatening communities, private property, and park facilities); and land management policy.¹³ In national park and national forest wilderness areas such as the Absaroka-Beartooth, established policies sought to minimize the “unnatural” damage to the landscape that would be caused by the use of motorized equipment, fire camps, and other fire suppression activities.

Fire suppression techniques.

Within these constraints, the most modern technology available was used: fire commanders received infrared maps made during high altitude flights the preceding night; helicopters and air tankers dropped water and flame retardant on the flames. But although wearing better protective gear, many firefighters were doing exactly what prehistoric people would have done to protect their homes from an approaching fire: remove small trees and low limbs that could provide fuel for a surface fire and create a fire break by clearing a line of all burnable ground cover. This is slow and laborious work using hand tools, but considered the only reasonable option in the park’s backcountry; teams of pack horses and mules hauled supplies to spike camps where firefighters slept on the ground. Even in more accessible areas, the use of bulldozers and explosives, which cause more enduring scars to the soil than does fire, was regarded as a last ditch effort. It was hoped that natural features such as open meadows, cliffs, rivers, and lakes would serve as natural firebreaks.

While many firefighters accepted the principles of natural fire management, others were confused by or critical of the “light hand on the land” approach to fire suppression and park managers’ occasional obstinacy in enforcing regulations. In one incident, a park ranger threatened to ticket a California Division of Forestry crew for driving a truck across a meadow to fight a fire.¹⁴

But sometimes even chainsaws and bulldozers cannot stop a fire on the move. Attempts to create a firebreak by digging lines or setting “burnouts” in front of an advancing fire were ineffective in conditions where winds quickly carried embers across unburned areas to jumpstart another fire a mile away in another tinderbox of dry fuel. In late August, one flank of the North Fork fire broke over a containment line that had held for a month. Most of the hundreds of miles of fireline dug in greater Yellowstone in 1988 could not halt fires that were capable of hurdling the Grand Canyon of the Yellowstone, unvegetated geyser basins, highways, and parking lots. When a fire reaches that intensity, it is not only impossible to contain, but foolhardy to try, for a fire crew in front of the advancing flames can easily be overrun or trapped between fires.

When bulldozers aren’t enough.

How a Forest Fire Grows

Once a fire is ignited, it spreads until it runs out of flammable fuel. Until then, its behavior may vary enormously and unpredictably. A fire may spread rapidly through fine, dry fuels and slowly in coarse or moist fuels. Slow fires that burn the ground cover and spread within the forest duff, sustained by glowing combustion, may advance only inches a day, leaving the upper tree crowns untouched and the trees alive. Faster fires spread through the grass, herbs, and dead twigs with a flaming front, and may be driven rapidly upslope by wind. If the fire has enough fuel from shrubs and small trees, it may become more intense and spread to the tree crowns in abrupt surges, responding to its own wind system. When the fire is “crowning,” it can spread rapidly from one treetop to another, and sparks from exploding trees may ignite new fires meters or miles away. In 1988, extreme weather conditions eliminated the need for smaller trees to serve as “fire ladders,” and crown fires burned irrespective of fuel loads.

Although a fire will typically “lay down” at night as the temperature drops and the humidity rises, in the summer of 1988, Yellowstone’s fires refused to go to bed. The humidity often remained low at night and the fires active, adding to the danger of falling trees for night crews and the impossibility of holding fires behind lines constructed during the day.

The strategy therefore gradually shifted from one of traditional “perimeter control” to protection of lives and property in the fires’ advancing path. Some new ignitions were not suppressed because of the lack of available crews and equipment, concern for firefighter safety, or the likelihood that they would soon burn into existing fires anyway. After the North Fork fire came through Madison Junction on August 15 and vaulted the Gibbon River, crews were sent to prepare the Norris Geyser Museum and Canyon Village by thinning the surrounding woods, carting away dead timber, and dousing the buildings with fire retardant. Others were dropped off in the backcountry by helicopter to hike with gas cans, water bags, shovels, chainsaws and other heavy equipment, cut several miles of line, return to their drop-off point, and then get up at 5 A.M. to do the same thing the next day.

Sending in the Marines.

By mid-August, when the Boise Interagency Fire Center requested assistance from the Department of Defense, many of the 3,500 firefighters in the Yellowstone area had been working 14 hours a day for weeks with few days off.¹⁵ The military began putting soldiers through a two-day course in firefighting, and on August 23 the first two Army battalions arrived at Yellowstone with eight helicopters. Three days later, it was announced that, because the fire situation was worsening all over the West, some of the regular fire crews and aircraft were going to be pulled out of Yellowstone for deployment where human lives and property were at greater risk. But more military personnel continued to arrive in Yellowstone—the Army, the Navy, the Air Force, the Marines, and the Wyoming National Guard—their numbers cresting on September 17 at 4,146 in uniform, heightening the perception that Yellowstone was a place under siege.

Local residents also pitched in to help. On September 5, the same day that the total number of firefighters in greater Yellowstone peaked at about 9,600, farmers and college students arrived at West Yellowstone with trucks of irrigation equipment and a water cannon to dampen 700 acres of forest, creating a buffer zone between the town and the North Fork fire, and saving the electrical substation that powered the buildings at Old Faithful.

While some people remained convinced that not enough was being done to put the fires out, others felt that the effort to suppress the fires was a waste of money that the federal agencies involved had to undertake for the sake of their public image. Those who favored letting the fires take their course objected that firefighters should not risk their lives to save something that was not meant to be saved. In the gateway communities and ranches outside the park, flames of suspicion were fanned: park managers didn’t actually want the fires suppressed; it was a plot, a radical environmentalist conspiracy to wipe the tourist-oriented gateway communities off the map. Such fears were not entirely irrational, given the



Fighting fire with water (above) and foam (right).

“jokes” going around about how the fire break had been built on the “wrong” side of Grant Village. In a lamentably frank moment after the fires, a National Audubon Society board member told the Idaho Conservation League, “The greatest environmental disaster coming out of the Yellowstone Park fire was its failure to burn up West Yellowstone... What a wonderful thing it would have been to reduce all that neon clutter and claptrap to ashes.”¹⁶

During late August and early September, the heavy smoke created a visibility danger for pilots and an irritation if not a health hazard for local residents. They were advised to avoid strenuous outdoor activities, stay indoors, and close the windows; people with respiratory problems were encouraged to leave the area. In response to residents’ concerns, air quality was monitored at four locations by the park and the Montana Department of Health and Environmental Sciences. The recommended standard for particulate concentrations was exceeded on 19 days in Gardiner, Montana, just outside the park’s north boundary, and on 7 days in Mammoth, Wyoming, inside the north boundary. Although concentrations were extremely high during the first week of September in West Yellowstone, Montana, they did not exceed the standard there, nor in Cooke City, Montana.¹⁷

Health and safety issues.

In what some regarded as an unnecessarily risky and nuisance-causing effort to limit the fires’ impact on the local economy, the park remained open to visitors except for September 10, when even the park headquarters in Mammoth had to be evacuated. Most of the developed areas in the park and several surrounding communities had to be evacuated at least once as fire fronts approached. Cooke City and Silver Gate, Montana, outside the park’s northeast entrance, were ordered to evacuate on September 4; an attempt the next day to set backfires was foiled when the wind reversed, blowing the fire to within 50 feet of Cooke City, outside of which 17 cabins and storage sheds were destroyed. But three days later at Old Faithful, the fire was deflected around the historic inn constructed of lodgepole pine and locally quarried stone—perhaps with some help from the oft-derided expanse of parking lot. On September 11, a quarter inch of mixed rain and snow marked the beginning of the end of the 1988 fire season.

By November 18, when the last fire was officially declared out, more than 25,000 firefighters had been to Yellowstone. They had experienced bee stings, minor burns, broken bones, and respiratory problems because of smoke and dust inhalation. In thermal areas, crews walked cautiously to keep from breaking through the thin crust of earth next to hot pools, and several firefighters had to be treated at a Yellowstone clinic after they inhaled gas from the ignition of sulfur deposits. But given the thousands of people involved and the long hours spent in hazardous conditions, it was extraordinary that only two fire-related human fatalities occurred, both of them outside the park and beyond the flames. Pilot Don Kuykendall was killed on September 12 when his plane that had been transporting fire crews crashed on its return to Jackson, Wyoming. Ed Hutton, a Bureau of Land Management employee helping with cleanup operations in the Shoshone National Forest, died after being struck by a falling tree on October 11.

Injuries and fatalities.



The bottom line.

With heroic effort, the firefighters were able to protect human life and property. But the fire suppression effort probably had no significant impact on the number of acres that were engulfed by flames. Once burning under such extreme climatic conditions, the fires were unstoppable by human effort.¹⁸

Of the \$120 million spent on logistical support for fire suppression efforts, about \$33 million were direct payments for services such as gasoline, meals, lodging, rental items, and wages for non-government help such as camp crews. (These figures do not include overtime, hazard duty pay, and other compensation paid to employees already on the government payroll.) Most of the expenditures were made in communities within greater Yellowstone.¹⁹

The Size of the 1988 GYA Fires

- 1988 was the driest summer in 112 years.
- The first major fire began on June 14; the last was declared out on November 18.
- Fires often advanced 5 to 10 miles a day, sometimes 2 miles in a single hour.
- About 1.4 million acres burned within the GYA, including 793,880 acres (36%) of Yellowstone National Park.
- 67 private and government-owned structures were destroyed, mostly cabins and mobile homes; 12 were badly damaged.
- More than 10 miles of power lines and 300 utility poles were damaged or destroyed.
- About 30,000 acres of timber suitable for harvest was destroyed in the surrounding national forests.

The Size of the Firefighting Effort

- A total of more than 25,000 firefighters participated, including 11,700 military personnel and up to 9,600 firefighters at one time.
- 665 miles of firebreaks were dug by hand and 137 miles were bulldozed.
- More than 100 fire engines and 100 aircraft were used, including 77 helicopters using 150 newly created helispots.
- Helicopters carried more than 10 million gallons of water into the park in a canvas bucket or slings attached to a 100-foot steel cable.
- Fixed wing aircraft dropped 1.4 million gallons of fire retardant in the park.
- 18,000 flight hours were logged in the park.
- \$120 million was spent on logistical support.

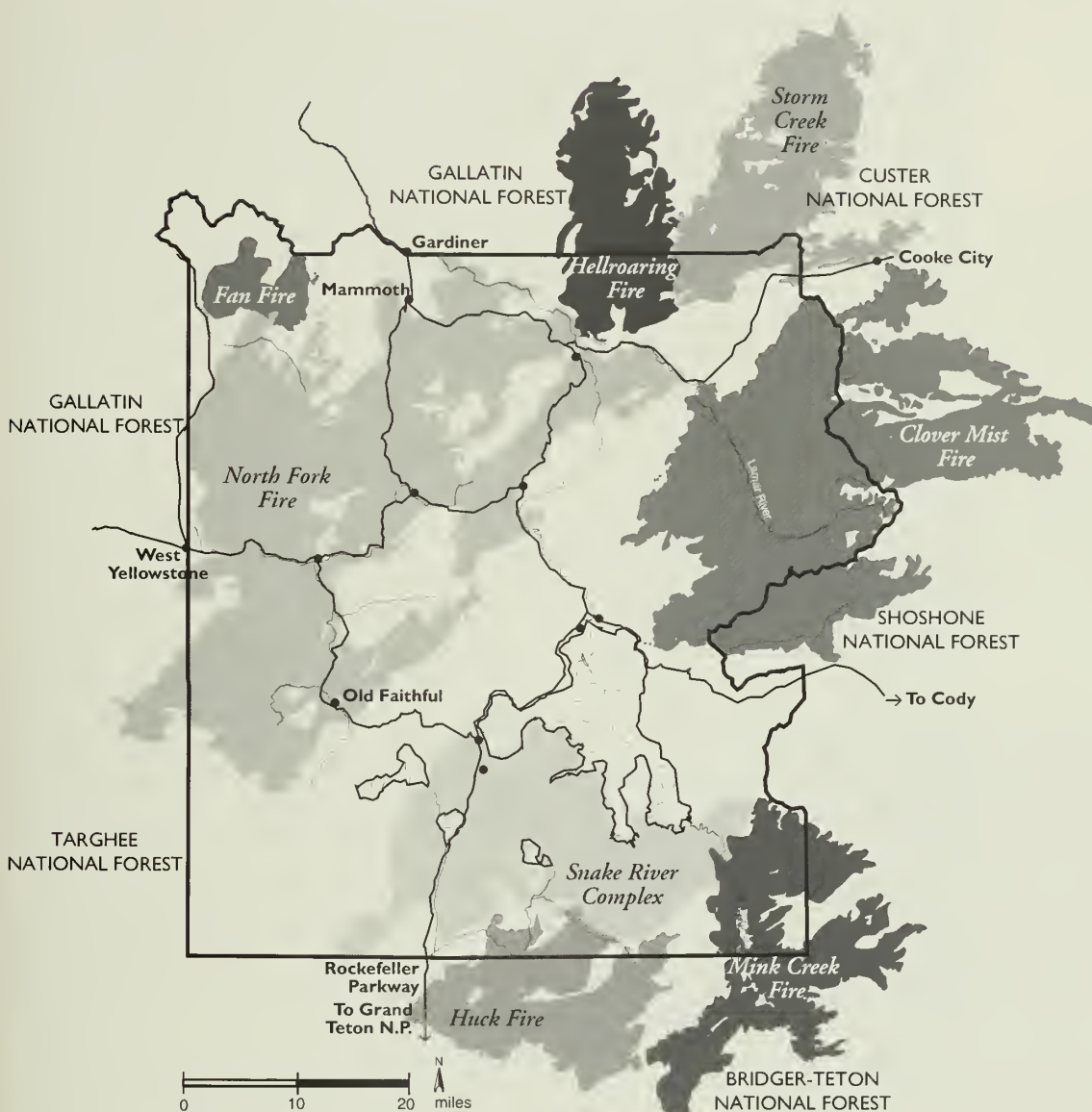


If a tree burns in the forest, and no one sees it...

Just as it was nature that determined when conditions were ripe for the Yellowstone fires to start, it was nature that began lowering the curtain on them with a quarter inch of rain and snow on September 11. On November 18, the North Fork fire was the last to be declared out.

Or was it? Like those trick birthday candles that only appear to have been extinguished, a column of smoke was reported the following June in the backcountry near Broad Creek. An investigation found no evidence of recent ignition, so it must have been a remnant of the North Fork fire. And there may have been other embers that died out later, unobserved by any human.

1988 Yellowstone Fire Perimeters



Fire	Origin	Period	Estimated Acres*
• Storm Creek	Custer NF	June 14 – Sept. 17	95,000
• Snake River	YNP	June 23 – Sept. 19	172,025
• Fan	YNP	June 25 – Sept. 6	20,900
• Clover Mist	YNP	July 9 – Oct. 10	319,575
• Mink	Bridger-Teton NF	July 11 – Sept. 18	116,325
• North Fork	Targhee NF	July 22 – Nov 18	504,025
• Hellroaring	Gallatin NF	Aug. 15 – Sept. 11	66,725
• Huck	Rockefeller Parkway	Aug. 20 – Sept. 18	111,200
Total Burned Area			1,405,775

*Data from the Greater Yellowstone Burned Area Survey, 1988

The Fires as a Media Event

Although local media had been closely covering the story for weeks, the Yellowstone fires did not show up on the national screen until the North Fork fire entered the park on July 22 and headed toward Old Faithful. During the next two weeks, park staff responded to more than 3,000 media requests in person or by phone. Every major newspaper, radio, and television network in the United States was represented, as well as many magazines and foreign correspondents. The Yellowstone Public Affairs Office (PAO) in Mammoth Hot Springs served as the clearinghouse for media assistance as well as phone calls from the general public. As interest in the fires grew and the PAO began receiving more than 200 media inquiries over the phone and in person a day, it was open from 6 A.M. to midnight, seven days a week, and the two public information officers were assisted by 41 park employees from other divisions. Even so, the large volume of calls meant that those from the general public often had to be routed to park staff in other offices.

The PAO also assigned more than 15 employees to serve as information officers in the field as "Incident Command Posts" were set up. An additional information office headed by a U.S. Forest Service public affairs director with a staff of seven was opened in West Yellowstone when the Greater Yellowstone Area Command was established there on July 23 to coordinate firefighting efforts. As of November 15, 1988, the park was still receiving 40 to 70 information requests per day concerning the fires.

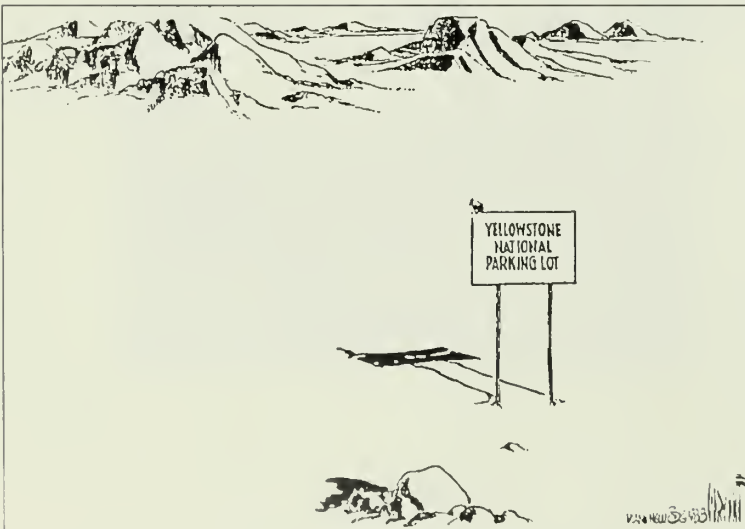
False alarms?

When the Yellowstone fires first hit the headlines, most people were unaware of the "natural" fire policy that had been adopted in many national parks. President Reagan, roused to comment on the policy, admitted that he had been oblivious of it until it was pointed out to him on September 14. Americans associated wildland fires with the Forest Service's Smokey Bear campaign, which was designed to reduce human-caused fires and left the impression that all fire is bad because it destroys forests. The alarmed reactions of media, politicians, and the general public to the Yellowstone fires indicated the widespread misunderstanding of the role of fire in wildland areas.

The media, playing its natural role, tended to emphasize the fires' most dramatic and visually impressive aspects, sensationalizing the issue with images of towering flames, charred trees, dead animals, and outraged citizens. Fire ecology was of less immediate concern and therefore less likely to be reported on than was the perceived risk to national landmarks by

allegedly inept land managers. For similar reasons, Yellowstone became the target of media attention in 1988 rather than the Scapegoat Wilderness between Missoula and Great Falls, Montana, which had equally intense fires, or Glacier National Park, where more lives were lost, or even southern California, where there was more property damage and threat to human life.

To create a substantial scandal, it appears, you must be of substantial renown. A two-year study of television coverage of "environmental risk" found that the mass media paid relatively little attention to the scientific degree of risk or the actual severity of a natural disaster.²⁰ "Cultural proximity" (as measured by the number of U.S. tourists visiting the area) was the strongest predictor of coverage, and a small catastrophe in an "important" place was deemed more newsworthy than a bigger one in an unimportant place.



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Park staff soon felt as besieged by the media as the gateway communities did by the fires, but the media were not entirely to blame for the resulting public relations debacle. The National Park Service was unprepared at the park, regional, and national level to handle the media demands, and correcting the deficiencies was not a task that could be fully addressed under the enormous pressures of the moment. The park made the best use it could of staff who were both good communicators and had some familiarity with fire suppression issues, but the level of knowledge and ability to keep posted on the latest developments varied from person to person, creating confusion as incomplete or inconsistent information was given out. The media heard both that “Fire is good and we need to let it burn,” and “These fires are bad and we are doing everything we can to put them out.”²¹

Garbled smoke signals.

Sometimes the same spokesperson, deliberately or inadvertently, managed to convey both messages, as was evident in reports on the press conference held by Interior Secretary Donald Hodel at Old Faithful Inn on July 27. NBC announced, “Firefighters reverse policy and use aggressive tactics at Yellowstone,” while the *Billings Gazette’s* headline ran, “Hodel Supports Yellowstone’s Natural Burn Policy.”

The media’s depiction of the fires may have been skewed by the provocative sound bites offered by outspoken residents and business owners who felt their way of life was threatened. According to a study done by Conrad Smith, a journalism professor at Ohio State University, many reporters echoed local residents and politicians who said the fires were still burning after “Black Saturday” on August 20 because of the park’s fire policy.²² The news coverage helped whip up the controversy about Yellowstone’s presumed fire policy without always explaining its rationale, its support from scientific and environmental groups, or the “full suppression” mode in which the park had been since mid-July. Instead, many people received two overall messages from the media: Yellowstone had been reduced to ashes, and it was the fault of park managers. Such coverage led to calls for Superintendent Barbee and National Park Service Director William Mott to be fired.

Catastrophe of the month.

After looking at 936 reports about the fires that appeared during 1988 in three Yellowstone-area newspapers, three national newspapers and in the evening newscasts of the three major television networks, Smith found that most of them focused on the fires themselves rather than on their role in the ecosystem. In a subsequent study of 589 reports about the fires that appeared in seven major newspapers and five magazines from January 1989 through August 1993, he counted only 29 reports that included ecological information in the first three paragraphs, and only five that went beyond a description of the fires’ immediate effects to explain their long-term ecological impact. Many reporters covered the story the way they would an urban or residential fire, where fire is an enemy force that humans must vanquish.

Yellowstone National Barbecue Pit

“As one bleak moonscape after another appeared on the screen, NBC’s correspondent offered a sad benediction on the world’s first national park: ‘This is what’s left of Yellowstone tonight.’ It was a moving, high-impact piece of television. It was also wrong.... Though many Americans were led to believe that Yellowstone had come to look like the bottom of a barbecue pit, its best known features—the steaming geysers and fumaroles, the towering waterfalls along the Grand Canyon of the Yellowstone, the wildlife—survived more or less unscathed. If the first job of the media is to convey accurate information, then we failed in our job.”

—T.R. Reid, writing in the *Washington Post* on July 23, 1989



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Sea of Fire Engulfs Once-Splendid Park

— *Milwaukee Journal* headline, August 12, 1988

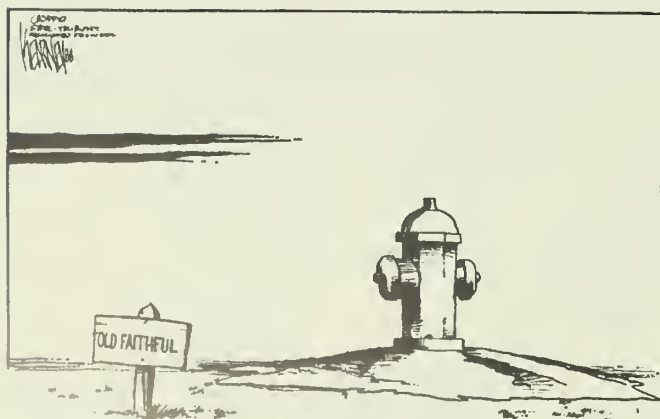
Smith's follow-up surveys of the reporters and their sources showed that many recognized the fires had been poorly reported. The network correspondents who did the most reporting about the fires acknowledged afterward that they had exaggerated the impact of the fires. They attributed the problem to ignorance, preconceived notions about fire, logistical problems in the park with access and communications, deadline pressure, and the sometimes inept Park Service spokespersons.

But commentators such as Micah Morrison, who covered the fires for the *American Spectator*, have argued that the press accurately reflected the most important story—the confusion in Yellowstone over what the park's fire policy was. In his 1993 book, *Fire in Paradise: The Fires in Yellowstone and the Politics of Environmentalism*, Morrison contends that “a review of articles and network footage shows that most reporters were careful to note that the whole park had not been ‘destroyed’ and to try to explain the natural fire policy.” He believes that what the press misreported was the not fires themselves, but the follow-up. “Finding themselves on the ‘wrong side’ of an environmental issue in the immediate aftermath of the fires, they sought to make amends with the spate of ‘rebirth’ articles.”

The retrospective articles that have been done on the Yellowstone fires, which are feature stories rather than hard news, have been more likely to address the fires' ecological aspects rather than the “devastation” they caused. Although many of these post-fire articles have been scientifically superficial, most have expressed a more positive attitude toward Yellowstone than did those published in 1988. In Smith's study of post-fire stories, scientists were named as sources more than three times as often as were tourists and area residents, almost inverse the ratio of stories in 1988.²³

But not everyone's attitude toward the Yellowstone fires has mellowed with time. Some local residents as well as members of the general public remain angry with park management about what happened that summer. An article that appeared in *Science* magazine on the 10th anniversary of the fires in 1998, “Yellowstone Rising Again From Ashes of Devastating Fires” by Richard Stone, failed to convince at least one reader, whose letter appeared in a subsequent issue. “Ecologists who defend the controversial ‘let forest fires burn’ policy that could well destroy the rest of our national parks if it is applied inappropriately do not fully take into account the vast cemetery of burned, rotting, and bug-infested tree stumps that is all that remains of 320,000 hectares of once-beautiful Yellowstone forests, the millions of small animals that were incinerated, and the thousands of tons of topsoil that have washed into stream beds because the stabilizing vegetation was destroyed.”

To help counter such misinformation, the park has bolstered its own efforts to educate visitors about wildland fire. Special inserts on the fires and their impacts were distributed with the park newspaper during the first two years after the fires and again in 1998. A “Yellowstone and Fire” exhibit, which opened in June 1989 at the Grant Village Visitor Center, explains the role of fire in nature in general and at Yellowstone in particular. A 1½-mile boardwalk trail with wayside exhibits winds through burned lodgepole pine and sagebrush communities next to the Madison River to tell the story of the 1988 fires and how they may continue to shape the park in the years to come.



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The Terms of Endurance

In September 1988, when a reporter from a Wyoming radio station asked Superintendent Barbee for his “best estimate as to how much of the park will be lost because of the fires,” Barbee struggled to suppress his disdain. “Lost?” he demanded. As far as Barbee knew, Yellowstone was still the same size it had been before the fires.

It is the “D” words often used to describe the fires’ consequences that still make some park staff cringe: death, defoliation, demise, desolation, destruction, devastation. Although fires can be destructive of human lives, property, and livelihoods, such negative terms are considered inappropriate when referring to fire as an ecological process that is neither good nor bad, but just part of the system.

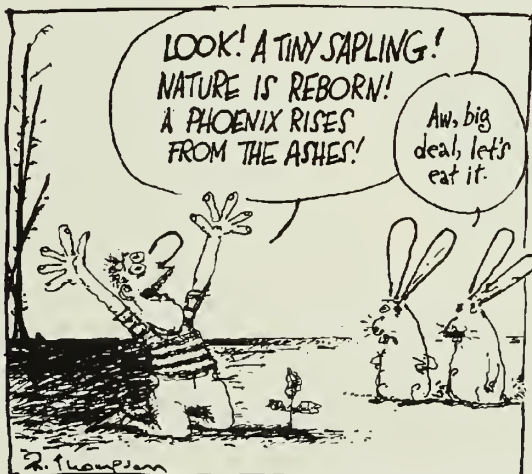
Yet the “R” words often used to describe Yellowstone since the fires are also problematic: recovery, rehabilitation, renewal, resurrection, restoration, rebirth. “Recovery?” the environmental purist may object. “That would imply that Yellowstone was sick or injured as a result of a perfectly natural process of raging infernos—that there is something wrong with a vista of charred trees, that Yellowstone should be restored to its pre-fire state. Bug-infested tree stumps are beautiful too.”

However, the ecological term used to refer to events such as fire, hurricanes, earthquakes, oil spills, and other sudden impacts on the environment, both natural and human-caused, is another “D” word—disturbance—with clearly negative connotations. It may be a limitation of the English language, or it may indicate that even ecologists are biased in favor of the status quo. For there’s no way you can say, “Yellowstone experienced a major disturbance in 1988” without it sounding like something bad happened. And what comes after the disturbance? The term often used by ecologists is “recovery.”



HOMELESS IN AMERICA

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Scarred Park Shows Signs of Rebirth

— Milwaukee Journal headline, June 21, 1998

Taking stock

To improve cooperation on issues that cross their boundaries, the Greater Yellowstone Coordinating Committee (GYCC) was organized in the 1980s with representation from Yellowstone and Grand Teton national parks and six national forests. In the wake of the 1988 fires, the GYCC assembled 15 interagency teams to collect data and make initial assessments on topics ranging from air quality to recreational use.

Post-Fire Assessment and Research

A panel of scientists, chaired by Norman Christensen, a botanist from Duke University with extensive experience in fire research, was selected by the GYCC to prepare an independent evaluation of “the apparent ecological impacts and implications of the 1988 fires as they related to the area’s watersheds, fisheries, wildlife, forests, soils, ranges, and biological diversity.” With 10 other scientists from academic institutions across the country and two researchers from the U.S. Forest Service, Christensen also developed a list of post-fire research needs. The GYCC assessment and the findings of this panel are among the many documents that served as references for this book.¹

Most of the previous research on fire impacts in wildland areas had been done in relatively small areas and after the fact. The Yellowstone fires, which prompted large-scale research and monitoring projects on a variety of topics, demonstrated the importance of having baseline data that was collected before the fires for comparison purposes. The pre-fire records that had been compiled by government agencies and academic researchers have



The Yellowstone Tourist: Was the abundance or distribution of this species affected by the fires of 1988?

made it possible to answer many questions on how the 1988 fires have affected various components of the Yellowstone ecosystem. For example, since a number of elk studies were already underway, the fires provided an unprecedented opportunity to document fire effects on a large elk population. But for topics on which no pre-fire data was available, such as amphibian abundance and distribution, many questions remain unanswered.

More than 250 research projects have been initiated in the greater Yellowstone area to study fire effects since 1988. The National Park Service provided more than \$6 million to support 32 projects involving scientists from 70 institutions; some of this funding came from a special Congressional appropriation for a post-fire research program, and the remainder was diverted from other programs at Yellowstone and other national parks. In 1991, of the 204 projects for which research permits were granted in Yellowstone, 60 were focused partly or entirely on fire impacts.

Results from 58 studies relating to the 1988 fires were presented at the park's second biennial science conference in 1993, and about half of these papers were compiled in *The Ecological Implications of Fire in Greater Yellowstone* (1996), edited by Jason Greenlee and published by the International Association of Wildland Fire. By 1996, the number of research projects in the park that related to fire impacts had dropped to 10. The rapid decline in fire-related research in Yellowstone reflects both the loss of funding specifically designated for it, and the speed with which the once headline-grabbing fires moved to the back pages of ecological concerns in Yellowstone. When it became evident that, with a few possible exceptions such as aspen and moose, the fires would have little impact on species diversity and abundance in the park, research attention turned to more pressing concerns, such as bison management and the reintroduction of wolves.

But some of the researchers whose names appear in the following pages have been willing and able to obtain funding to carry on long-term monitoring projects, and Yellowstone continues to provide the stimulus for new fire-related research. In the spring of 2000, David McGinnis brought the first group of ecology students from the University of Iowa to spend two weeks measuring "forest-meadow edge re-establishment patterns" in the park. Updated annually with new slides, John Burger's lecture on "The Yellowstone Fires: A Force for Change and Regeneration in a Natural Ecosystem" at the University of New Hampshire remains his most popular, now presented to biology students for whom 1988 was more than a half-life ago.

Burn it and they will come.

A stimulus for new research.

Yellowstone: A Cause for Universal Joy

"Momentous questions are now agitating the scientific world, calling for experiment and observation which are daily becoming less possible, owing in a great measure to the obliterating influences of modern civilization...

"Much has already been said concerning the benefits to be derived by science from the setting aside of this tract of land and the protection of its natural features. In fact, this was one of the inducements offered for the passage of the bill [establishing Yellowstone National Park] in both houses of Congress. Dr. Hayden, in speaking of this bill says, 'I believe it will mark an era in the popular advancement of scientific thought not only in this country, but throughout the civilized world. That our legislators, at a time when public opinion is so strong against appropriating the public domain for any purpose however laudable, should reserve for the benefit and instruction of the people, a tract of 3,578 square miles, is an act that should cause universal joy throughout the land. This noble deed may be regarded as a tribute from our legislators to science, and the gratitude of the nation and of men of science in all parts of the world is due them for this munificent donation.'"

— Theo. B. Comstock, geologist participating in the 1873 Yellowstone expedition²

Damage to Park Facilities

Although 5% of the park is zoned as “developed,” only about 1% of the park’s land area has been paved over or otherwise built upon. Despite the large portion of the park that was swept by fire, the firefighting priority given to protecting these developed areas kept them largely intact in 1988. Nearly all of the damage to park facilities occurred in the Old Faithful area, where 19 buildings in a complex of 400 were destroyed, including 12 concessioner cabins. Six buildings were damaged but salvageable. Sprinklers had previously been installed in many of the buildings and on the roof of the Old Faithful Inn, and the spraying of buildings with chemical foam retardants as the fire front approached helped minimize the losses. Of the 38 backcountry patrol cabins, only the Sportsman Lake cabin was destroyed, but the others had varying degrees of damage from water or the fire shelters that had been nailed on.³

Structural rehabilitation in the park also included repair or replacement of bumper logs, signs, posts, snow poles and guardrails along roads; drainage ditches and culverts clogged with ash and debris; 23 picnic areas and campgrounds (out of 61) that were damaged by fire or used as fire camps; about 29 miles of frontcountry trails and boardwalks damaged by fire or falling trees; trail signs, boundary markers, and the wooden water bars used to prevent erosion on backcountry trails; 73 backcountry bridges; backcountry campsites that had been burned over; smoke detectors damaged by prolonged exposure to smoke; and more than 10 miles of power lines, 300 utility poles, and 8 telephone pedestals.

Most of this rehabilitation was completed by the end of 1989. As soon as the fires had passed, crews began cutting the thousands of trees that could threaten public safety by falling in developed areas or across power lines. This chore will need to continue for as long as fire-damaged trees remain standing in the park, their root systems slowly weakening.



*The Sportsman Lake cabin: pre-fire (constructed in 1912) and post-fire (completed in 1989).
It will take a while longer for the trees to grow back.*

Fire Suppression Impacts

Like many of the fire management decisions made in 1988, the attempt to minimize the use of heavy equipment was controversial. Even after fire suppression efforts began in mid-July, they were sometimes restricted not because of a “let it burn” attitude, but because of a “don’t damage the park” goal. Disturbances to the landscape that result from fire suppression activities are considered destructive in a way that naturally occurring fire is not. Areas in which fireline was constructed are more susceptible to erosion than are most burned areas, which remain protected by duff, roots, and needles, and still contain the organic material that will be the basis for revegetation. Environmental impacts also resulted from the dropping of water and fire retardants, the use of wetting and foaming agents on buildings, and from the transport and housing of thousands of firefighters. Off-road travel left meadows riddled with vehicle tracks, in some places three miles from the nearest road, that may remain apparent for decades. Scars left by firefighting done in the park up to 50 years ago, when less was understood about landscape rehabilitation, are still visible today.⁴

National Park Service policy now requires rehabilitation of this type of human-caused disturbance. For Yellowstone after the fires of 1988, there were two goals. One was purely aesthetic, comparable to cosmetic surgery: to minimize the visual impact of fire suppression activities by making these areas appear to the park visitor as though they’d never been hit by a shovel, much less a bulldozer. The other goal was ecological, analogous to reattaching severed flesh: to return the topsoil and other organic debris that had been dug out to create firelines to as near its original position as possible. This would protect the genetic integrity of the native seed source, instead of using seed from external sources.⁵

At times up to 200 people were working on the rehabilitation effort, including crews from the National Park Service, the U.S. Forest Service, the Student Conservation Association, the Youth Conservation Corps, and private contract fire crews, with overall supervision provided by Eleanor Clark, Yellowstone’s chief landscape architect. Most of the following information and the photographs on this page came from her report to the park.⁶

Derived primarily from volcanic material, many Yellowstone soils are relatively infertile and highly erodible, particularly when disturbed. Organic matter is slow to decay in the cold, dry climate, and development of soil capable of supporting vegetation may take thousands of years. Protecting the accumulated organic matter was therefore of primary importance in preparing for the eventual rehabilitation of disturbed areas. The groundwork was laid as soon as fire suppression efforts began in July, when the park’s landscape staff provided on-site guidance to the fire commanders on how to minimize the damage of firelines by limiting their depth, using curvilinear rather than straight lines, avoiding timbered areas,



*Top photo: Bulldozer line for the North Fork fire, October 1988.
Bottom: Same site after rehabilitation and the natural falling
of some dead trees, July 1991.*

feathering the edge of the corridor, and setting aside the removed topsoil and organic debris for later restoration. The techniques used were similar to those employed when park land must be dug up to install a sewer line.

Bulldozer and hand firelines.

Nearly all of the fireline constructed in the park was done for the North Fork fire. It was fought from its start in the Targhee National Forest on July 22, with 30 miles of bulldozer line and 320 miles of hand line, but its perimeter encompassed more than 500,000 acres by the time it was declared out on November 18. The Clover Mist fire, which started a month earlier in the park from a lightning strike and was initially allowed to burn, attained a perimeter around nearly 400,000 acres but had only 90 miles of hand line and no bulldozer line.

Construction of bulldozer fireline, typically 12 to 24 feet wide, was the most destructive suppression technique used in the North Fork fire. It typically requires removal of all surface vegetation, root material, and one or more foot of soil with heavy excavating equipment. However, by angling the bulldozer blade and reducing the depth of cut to usually no more than six inches, only the necessary organic material for vegetative growth was removed and set aside in windrows immediately adjacent to where it had been taken. Slash from cut trees and shrubs was piled to the side of the fireline away from the approaching fire front.

Firelines created by bulldozers, which were usually accessible from established roads, were rehabilitated using a rubber-tired excavator to scarify the upper six inches of compacted subsoil, allowing for root growth and water infiltration. The upper layer of organic material that contained most of the viable seed was returned as near to the surface as possible. Then larger trees, deadfall snags, and boulders were replaced. A hand crew followed the excavator to take care of soil raking, small slash replacement, and stump removal.

Rehabilitation efforts intensified in mid-September in order to lessen damage to the organic soil layer before winter, and priority was given to steep areas with the most potential for erosion. By November 21, when the project was shut down for the season, crews had been working on snow-covered ground for several weeks, but most of the firelines and helispots for the North Fork fire had been rehabilitated and backcountry trash removed.

Chainsaws, shovels, and the combination hoe and axe named a "pulaski" after its inventor were used to dig firelines by hand, often in areas accessible only by trail or helicopter. Trees, shrubs, pine needle duff, sod, and organic debris were removed along a line two to four feet wide within a wider corridor cleared of large vegetation, leaving a windrow of topsoil and organic material pushed off to the side.

Erratic fire behavior and frequent burn-over of fireline resulted in irregular fireline locations, multiple lines that were built as the fire moved, and severe soil compaction as the lines were used as access trails by the fire crews. But limiting the width of the fireline corridor, using curvilinear routes and following animal trails where possible minimized the visual scar.

Because of their location, hand firelines had to be rehabilitated using hand tools, flush-cutting stumps and constructing water bars of rocks or weathered logs before returning topsoil, sod, duff, and other organic debris as near to the original position as possible. Stumps were blackened with ash or covered with duff or soil to foster breakdown. Slash was scattered over the rehabilitated area to protect the surface from wind and water erosion, and feathered away from the disturbed area to blend it in with its surroundings.



Firefighter at North Fork dozer line.

Dynamite, which can clear a fireline of varying width depending on the type and strength of the charge, is especially useful in sagebrush, grass, and other low shrubby vegetation, where it can quickly be set up with a detonation cord. However, the explosion removes most of the topsoil and seed sources in the fireline, making rehabilitation difficult. Unlike the bulldozer and handlines, the scars left by 18 to 24-inch wide explosive fireline near the Madison River are still visible today, even to the untrained eye.

Explosive fireline.

About 255 acres in the park were used for fire camps, staging areas, and helispots. Base camps were established in areas with road access to provide temporary shelter for fire crews; spike camps were set up in the backcountry. At the command center for the Snake River fire, carpenters and electricians assembled a makeshift town of mess halls, medical units, latrines, light poles, showers, and supply caches, rumbling night and day with the sound of trucks, helicopters, and generators. Soil compaction caused by vehicle and foot traffic was minimal at many of the spike camps; more severe impacts occurred at base camps such as Madison Campground, which supported hundreds of firefighters for several months. During rehabilitation, aeration and raking were done to relieve soil compaction and promote regrowth. Site monitoring in 1989 and 1990 indicated that the rehabilitated areas were generally stable and revegetated with minimal erosion.

Fire crew camps.

Creating backcountry landing zones for helicopters required removal of vegetation and loose organic material. Meadows were favored because of safety concerns and the presence of vegetation that would recover quickly from blowing. Helispots that required felling large trees created significant intrusions that were difficult to visually rehabilitate, but by enlarging natural openings, or creating irregularly-shaped openings that mimicked natural ones and felling trees in the direction they might have blown down, within a few years a rehabilitated helispot could appear to be a natural opening or windstorm area.

Helispots.

Several million gallons of water were dropped by helicopter, drawing down some smaller streams and ponds, and some stream channel disturbance occurred where impoundments were constructed to facilitate water removal. More than a million gallons of ammonium phosphate base fire retardant were dropped within the park boundary, much of it on the North Fork fire. This killed some fish and could temporarily increase the nutrient load in runoff, but there has been no evidence of a long-term impact (see page 93). The chemical foaming agents used in developed areas to protect structures were low toxicity detergents that appeared to have dispersed into the soil during snowmelt the following spring.

Fire retardant and water drops.



*When smoke gets in your clothes:
Madison base camp, September 1988.*

Archeological Sites

Archeological evidence of humans in the Yellowstone area dates back to more than 11,000 years ago and extends through the first explorations by Euroamericans in the early 19th century and the first park administration in 1872. Although only a very small portion of the park has been surveyed for archeological remains, more than 1,100 sites have been documented, including prehistoric burials near Fishing Bridge and small campsites indicated by only a few obsidian chips, rock shelters, and tipi rings.

Because of Yellowstone's long history of fire, by 1988 there were unlikely to have been many prehistoric sites in the park that had not been exposed to it before. Wickiups (small tipi-shaped shelters of wood once used by American Indians) had deteriorated over the years in the harsh climate, and some that had so far gone unrecorded may have vanished entirely in 1988. However, all of the wickiups that were known to have survived until the summer of 1988 were still present afterward, although most of the poles at one wickiup were charred at the base.⁷ Such structures cannot be preserved forever, but the fires demonstrated the need to document such sites before they disintegrate any further.

Most surface rock in the park appeared to have been unchanged by the fires, which probably moved too quickly to heat it to temperatures at which breakage could occur (about 350°C for some types of rock). Obsidian Cliff, a National Historic Landmark because of its use as a quarry site by American Indians, showed signs of having been burned over in the past; the shattering, feathering, and surficial weathering that resulted from the 1988 fires were less severe than if this had been the first time it had burned.⁸

When soil has no protective layer of duff or lies beneath burning deadfall, it may be subjected to such high temperatures (500° to 700°C) that it will oxidize, leaving a stain that is visible in recently burned areas. Depending on the timing and intensity of subsequent rainfall, the stain may remain as part of the sedimentary record.⁹ Even the most intense fires will rarely heat soil more than 7 to 10 cm below the surface, so buried artifacts are unlikely to be affected by the fires themselves. National Park Service staff from the Midwest Archeological Center in Lincoln, Nebraska, examined three burned areas in northwestern Wyoming in the fall of 1988 that included both lodgepole pine and meadow habitat. In the lodgepole pine study area between Canyon and Norris, where a thin layer of soil covering bedrock or glacially deposited cobbles was covered by a layer of forest duff, they found that the 1988 fires burned the duff and left the soil below unaltered.¹⁰



Wickiup

However, forest fires may affect artifacts more than 10 cm below the surface where the root system of a tree has burned or organic material has accumulated. In one meadow site with highly organic soil that was charred and still burning in the fall of 1988, smoke rose from a depth of 20 cm and metal parts of the excavation equipment became too hot to handle, making it impossible to ascertain the possible depth of the charred material.¹¹

Changes in soil chemistry and the loss or reduction of ground cover can increase erosion and cause freeze-thaw processes to penetrate to a greater depth, increasing site perturbation. Archeological material at the top of a slope may erode and be redeposited further down, while that at the bottom of a slope may be buried by sediment. Treefall also increases pedoturbation (mixing of the soil through biological processes) and creates a hollow that may catch eroding charred soil and charcoal and be mistaken for an archeological feature. However, be-

cause archeological sites are generally not located on steep slopes, they are less likely to be affected by the most severe erosion that may result from fire.

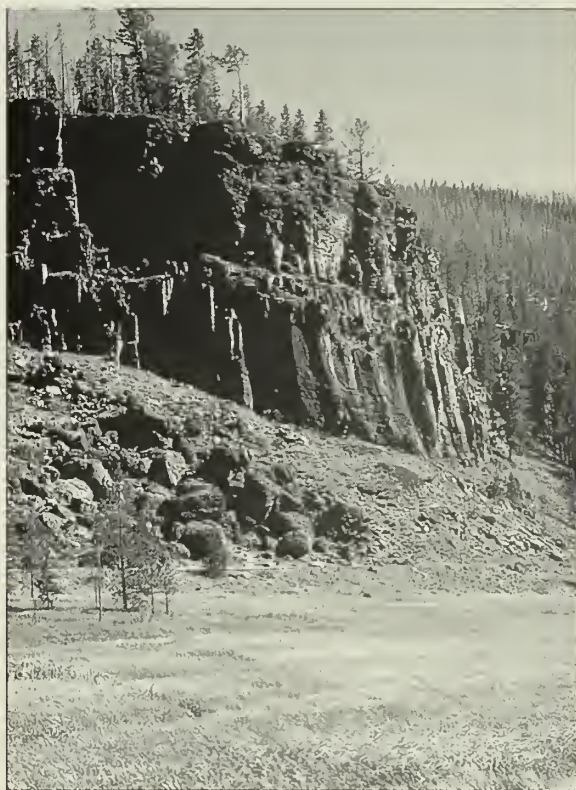
Fires may change the landscape in ways that complicate the interpretation of an archeological site, but by clearing away deadfall and underbrush, they can increase the likelihood that new sites such as lithic scatters will be detected, and make it possible to conduct more thorough examinations of already known sites. For example, behind Obsidian Cliff lies a 20-square-mile plateau that was a major source of the obsidian used and traded by American Indians across the West for thousands of years. Although the lack of trees in a 1878 photograph of Obsidian Cliff was probably due to fire, by the 1970s the plateau was heavily forested with lodgepole pine. After many of these trees burned in 1988, the quarry sites could be documented for the first time, but easier access by the public has required more frequent patrolling of the area to deter and penalize theft and vandalism.

The Baronett Cabin, named in 1870 for the man who constructed the first bridge across the Yellowstone River, remained in use until about 1920. But by the time the site was recorded in 1985, the cabin's roof and upper walls were gone, and tall grass and dense clumps of sagebrush made ground visibility difficult and survey transects impossible. When the site was re-examined in the fall of 1988 by Ann Johnson, now the park archeologist, more features and artifacts were visible, including a wagon road, the remnants of several outbuildings, tin cans, and glass bottles. The remaining walls of the cabin had burned, leaving a trench where the bottom row of logs had been. Johnson expected that the fill that had been inside the cabin, including many artifacts, would shift into this trench over time. Within a year, lush regrowth concealed the site entirely.¹²

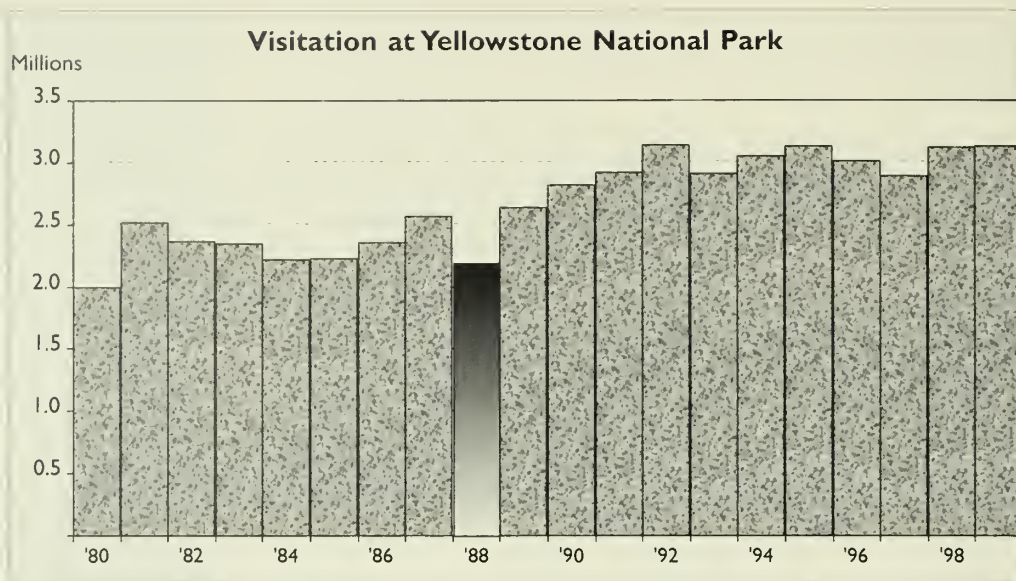
To take advantage of the brief period before regrowth, archeologists surveyed specific burn areas in the park during the summers of 1989 and 1990 to document sites and any damage that may have been caused by the fires or suppression efforts, and identify sites that might be disturbed by post-fire rehabilitation activities. While they were there, they also evaluated sites' eligibility for placement on the National Register of Historic Places. Ground visibility ranged from 100% in areas that had sustained very intense fires and revegetation had not yet occurred, to near zero in areas that were already densely vegetated by new growth. About 224 miles of trails, bulldozed firebreaks, and hand-cut fire lines were surveyed, along with more than 160 acres slated for rehabilitation. In 1989, 96 sites were documented for the first time, including two prehistoric sites along the Yellowstone River. In 1990, another 11 previously unrecorded sites were documented, six prehistoric and five Euroamerican.¹³



Creating a firebreak may expose archeological sites.



Obsidian Cliff, 1999.



Visitor and Economic Impacts

September 10, 1988 was the first day in Yellowstone's 116-year history that the entire park was closed. However, throughout that summer visitors often had to suddenly alter their routes because of road and facility closures, or were required to travel in ranger-led convoys that were subject to long delays. About 4,000 people were evacuated from Grant Village on July 23, and again on August 21. On August 24, Canyon lodging and campgrounds were evacuated. Old Faithful was evacuated on September 7, and Mammoth Hot Springs, where the park's headquarters are located, on September 10. Visitor accommodations in the park, which in previous years had remained open until late September or mid-October, all closed for the season on September 8. In addition to these disruptions, many people found their park visits marred by the smoke which often obscured scenic vistas, and by the aircraft that could be heard almost constantly during the height of suppression activities. But some visitors were thrilled at having the rare opportunity to witness an ecological phenomenon of this scale and impact.

How visitors are counted.

The number of vehicles coming through each park entrance is mechanically counted and used to derive an annual visitation estimate. Although October 1988 visitation increased 40% over the same month in 1987, with 175,000 people coming to see what all the fuss was about, total visitation for 1988 was nearly 400,000 (15%) less than in 1987. This drop in visitors translated into economic losses for many local enterprises, especially those that earn most of their income during the summer. Some did a brisk business in supplying the thousands of firefighters and journalists with food and lodging, but some outfitters lost their fall revenues due to trip cancellations and national forest closures that occurred because of the fire danger.



Traffic delay on the West Entrance Road, August 1988.

Paul Polzin, a management professor at the University of Montana in Missoula who studied park visitation data, found that although the number of visitors dropped in 1988, the average length of stay remained fairly constant (about 3.5 days, of which 2 were spent outside the park), as did the proportion of expenditures made inside (46%) and outside the park (54%).¹⁴ The proportion of visitors coming into the park through each of its five entrances also remained fairly constant. Although Polzin assumed this was because "the fires were dis-

tributed throughout the park, affecting all areas,” it may have been simply that people who came to Yellowstone in 1988, before or after the fires, did not make their decision based on the presence or absence of charred trees.

Polzin also believed that park visitation and tourism revenues in the surrounding communities were lower in subsequent years than if the fires had not occurred. Based on the overall trend in park visitation since 1971, the increases in tourist visits to Montana and national forests, and nation-wide travel activity in subsequent years, he projected that without the fires, Yellowstone visitation would have risen 8.8% in 1988, 8.4% in 1989, and 19.9% in 1990—reaching a record high each year. Based on the park’s visitor count for 1987, that would have brought visitation to 3.6 million by 1990. The study did not extend its projections past 1990, noting that “it is unknown how long this potential lag in growth will continue.” For those who accept Polzin’s projections and are concerned about visitation growth, this “without fires” scenario may be cause for regarding the fires as a blessing. With fires, the highest visitor count since 1988 has been 3.1 million, which has been reached in four years since 1988.

But the loss of hypothetical visitors can be converted into the loss of millions of hypothetical dollars. Based on tourists’ average daily expenditures for lodging, travel, food, and other recreation-related items from June through September, 1988–90, Polzin projected how much more would have spent in the park and the five gateway communities if the fires had not occurred and his projected visitation levels had been reached. He concluded that a total of nearly \$60 million would have been added to the actual tourist expenditures of about \$240 million in the three peak seasons during that period. (This estimate assumes that none of the would-be visitors who did not enter the park because of the fires visited a gateway community anyway.) Although government expenditures of about \$33 million for fire-related supplies, equipment, and services in 1988 partially offset the loss of tourist dollars, the study noted that only about \$10.8 million of these payments went to the seven “primary impact communities.”

Except for 1988, annual park visitation did increase each year from 1985 through 1992, by a total of about 41%. A study by David Snepenger, a business professor at Montana State University, found that tourism in Montana rose 54% during that same period (as measured by accommodation tax receipts), with the increase concentrated in four counties, including one of the two Montana counties that border the park.¹⁵ While this disparity may suggest that park visitation after 1988 was less than it would have been had the fires not occurred, it could also be taken as evidence that the fires were not a major factor in Montana tourism revenues.

How many people visit Yellowstone each year is influenced by a variety of factors, including the weather, the price of gasoline, and shifts in the popularity of other recreation options. It would therefore be difficult to prove that the fires had any long-term impact on Yellowstone’s visitor count. The prospect of seeing vistas of dead trees may have kept some people away, but others have been drawn by curiosity. Total visitation reached a record 2.7 million the year after the fires, and has repeatedly exceeded 3 million since then. The park’s geothermal features, which are among its most popular tourist attractions, were not altered by the fires, and today the only areas of the park where public use may still be affected by the fires are backcountry trails and campgrounds where falling snags pose a nuisance and safety threat.

More visitors without fires?

Impact on tourism revenues.



Ignoring the eruption of smoke in the distance, undaunted visitors await Old Faithful, July 1988.

Public Attitudes Toward Fire

The Yellowstone fires occurred at a time when the problem of “exurban” fire was becoming more widely recognized. As Stephen Pyne observed the following year, “How to cope with fires in sprawling residential and recreational communities nestled in wildlands (in areas without clear jurisdiction for fire services) has become a national, even international conundrum.”¹⁶ For many people, fire is as destructive in a national park as it would be in their backyard, and an increasing number of people have backyards near wildland areas, affecting their reaction to the scenes they were witnessing on their television screens.

On an aesthetic level, the Yellowstone fires evoked a negative response that 16 years of natural fire management had done little to prevent. Even park employees who appreciated the ecological importance of the fires and had to defend the park’s firefighting efforts over phone lines buzzing with outraged citizens, mourned the transformation of a favorite view or hiking trail. As reports of the advancing fire fronts came in that summer, their pleas went up in the smoke. “Oh no, not Fairy Falls! Don’t take Fairy Falls too!” Of course, Fairy Falls is still there, tumbling down 200 feet over the rocks. It just doesn’t look quite the way they remember.

Alistair James Bath examined attitudes toward the fires for his Ph.D. dissertation at the University of Calgary, Alberta during a nine-month period beginning in June 1989.¹⁷ He

obtained data from more than 4,500 respondents, including interviews conducted in the park, surveys filled in by visitors leaving the park, and randomly sampled residents in Montana and Idaho who were mailed surveys. (A portion of the visitors participating in the interviews and exit surveys would have been from Montana and Idaho, but their opinions were grouped with those of other park visitors.) More than half of the survey participants had been to Yellowstone at least once before the fires. Interviewed visitors who had seen the effects of the fire had the most favorable attitudes overall; Montana and Idaho residents who had not seen the fire effects were the most negative. Although most respondents disagreed with the statement, “All fires in Yellowstone National Park should be suppressed regardless of how they start,” those who had seen the fire effects tended to disagree more strongly.

After visitors had seen the fire effects, they regarded some fire management practices more favorably, but knowledge of fire ecology remained meager. When asked whether nine statements about the 1988 fires were true or false, respondents who were seeing post-fire Yellowstone for at least the second time had the highest score; area residents who hadn’t seen the fire effects had the lowest. Only slightly more than half of the survey participants who had visited after the fires knew that the statement, “The fires of 1988 destroyed habitat for many big game animals,” was false.

On Second Thought

Most Montana and Idaho participants in a 1989 mail survey agreed with the statement, “The Yellowstone National Park fires should have been put out when they first began.” Visitors surveyed at Yellowstone were less critical of park management. However, more visitors agreed with the statement, “The National Park Service handled the recent fires properly,” before they entered the park than they did when they were surveyed after their visit.



Visitors focus on a grizzly bear, undeterred by the standing snags, October 1992.

Renewing Yellowstone's Fire Policy

As a result of the controversy surrounding the Yellowstone fires, all natural fire management programs at national parks were suspended in 1988 pending further study. Three congressional hearings were held and the Secretaries of the Interior and Agriculture appointed a committee to evaluate fire management policies for national parks and wilderness areas. Their report, issued in May 1989, upheld the need for fire in maintaining a wildland ecosystem, but criticized several aspects of the National Park Service's fire management plans, finding that agency budgets and the training and experience of many fire managers were inadequate.¹⁸ Fire behavior analysts under-estimated the potential size and intensity of the fires because of their inability to accurately predict weather trends and take into consideration the effects of prolonged drought. Reduction of hazardous fuels near developed areas prior to the fires would have eased the chore of keeping the fires at bay.

The committee also called for specific criteria that would be applied to determine under what circumstances fires would be permitted to burn, taking into account weather conditions, the availability of firefighting resources, and the potential impact on neighboring communities. "The ecological effects of prescribed natural fire support resources objectives in parks and wilderness, but in some cases the social and economic effects may be unacceptable." In the same way that most people's immediate reaction to the fires was prompted by their impression of what Yellowstone had looked like in recent decades, the park's fire plans and those of other land management agencies had been driven largely by observations of fire behavior over the previous few decades. Like park visitors, fire managers would have to adopt a longer view about fire's potential role in Yellowstone.

More specific guidelines.

Although the public comment period brought little scientific disagreement on the basic principles, Yellowstone's natural fire policy remained on hold and all fires were fought until the park formally adopted a revised wildfire management plan in May 1992. The plan strengthened the coordination mechanisms between the park and the surrounding national forests, established criteria to determine which fires must be suppressed, and clarified the policy regarding protective "buffer zones" near gateway communities. As under Yellowstone's prior policy:

- Any fire that is human-caused or that threatens human life or property is considered "wildfire" and suppressed as quickly as possible using methods that will minimize damage to the park's natural and cultural resources.
- Naturally ignited fires that do not threaten human life or property may be allowed to burn if they are "within prescription"—if they meet certain criteria pertaining to fire behavior, weather, and fuel moisture content.

However, to classify a naturally ignited fire as within prescription, park managers must now also give consideration to the regional and national fire situation, including the number of fires underway and the availability of firefighters and equipment. Once a fire has been determined to be within the prescription, it is monitored daily to make sure that the criteria are still met and that adequate suppression resources are available to ensure that it will remain within the prescription during the next 24 hours, given the forecast for weather and fire behavior.

Considering the fire situation outside the park.

In 1995 the Secretaries of the Interior and Agriculture for the first time issued a joint fire management policy to ensure that federal land management agencies would have compatible, coordinated programs. They also confirmed that, "Wildland fire will be used to protect, maintain, and enhance resources and, as nearly as possible, be allowed to function in its natural ecological role." Agreements between Yellowstone and the surrounding national forests that permit some fires to burn across forest boundaries into the park and vice versa have been revalidated since 1988. Each year before the fire season begins, the fire management officers from the national parks and national forests in the greater Yellowstone area meet to review fire severity predictions and plans.

Fire management personnel.

The size of the fire management staff at a national park is now determined using a formula that takes into consideration the length of the fire season as well as the likelihood of large fires. Yellowstone's wildland fire staff has about tripled in size since 1988, and there is also more fire management expertise at the regional and national levels of the National Park Service. Yellowstone uses funds provided by an NPS-wide program to support three year-round fire management positions, a seasonal crew, and part of the cost of a summer helicopter operation. Several other full-time positions are paid for directly out of park funds, and each summer more than 100 Yellowstone employees qualify for their "red card," indicating that they have received the necessary training and passed the fitness test required for assignment to a fire crew if the need arises. Just as Yellowstone must turn to other government agencies for help in case of serious fires, these employees assist in areas outside the park when called upon.

Fuel and weather monitoring.

The most significant change in Yellowstone's fire management program since 1988 has been the increased use of computers and access to "real time" weather data over the Internet. Working with the National Interagency Fire Center in Boise, Idaho, park staff use computerized software programs to monitor fire risks. In addition to manually collected data on temperature, precipitation, relative humidity, wind, and fuel moisture, three automated weather stations in backcountry locations transmit data on fire-related climate conditions to park headquarters so that fire danger can be assessed.

Fuel loads in developed areas that are considered hazardous are reduced by physically removing the debris or prescribed burning. Reducing the possibility of fire in developed areas in and around the park increases the likelihood that a naturally ignited fire will be able to burn within prescription. While a prescription fire is underway, fire monitors check the site daily to assess weather conditions, fuel load, and rate of spread. Fuel samples are weighed, oven-dried, and re-weighed to determine the moisture content and how intensely and quickly the fire may spread.



In July 2000, a study plot was set up in an unburned area adjacent to the Two Smoke Fire underway on Pitchstone Plateau. Data was collected on aspects such as vegetation composition, tree density, fuel load, and litter depth. As anticipated, the fire soon burned through the study plot, making possible an immediate pre-and post-burn comparison, as well as an assessment of revegetation in future years.

Since 1988, the extent of both human- and lightning-caused fires in Yellowstone has been relatively insignificant, but has fluctuated from year to year depending largely on environmental factors. The 10 fires of 1993 burned less than one acre combined, but because of dry conditions in 1994, the most active fire season

since 1988, only four of the 48 lightning strikes met the criteria for a prescription fire. There were also 16 human-caused fires in 1994, including four that started from sparks off falling power lines.

Although the 2000 fire season has been called “the worst in 50 years” for the West, Yellowstone was relatively unaffected by the drought and its burned acreage was less than half of that in 1994. The revised fire policy does make a difference in such years, however, and reduced the acreage that would have been allowed to burn if only concerns for safety and protecting developed areas in and around the park had been considered. But because the available firefighting resources were being stretched to cover the many fires burning elsewhere in the country, Yellowstone’s skeleton fire crew was theoretically supposed to immediately suppress all fires, even those from lightning ignitions in areas that were far from developed areas and will have to burn eventually.

The post-1988 rationale for the policy was clear—Yellowstone shouldn’t take the risk of allowing small fires to grow big at a time when there’s no one to call for help—but it bore seeds of bureaucratic illogic waiting for the right conditions to sprout. It is precisely in “bad” fire seasons such as that of 2000 when many of Yellowstone’s own “red-carded” employees have been sent elsewhere that the park is least able to immediately suppress every lightning ignition. Every fire is monitored, but the reality is that park managers must allocate the available staff to deal with the more potentially serious fires and some fires that make “ecological sense” are suppressed. Such a predicament provides one rationale for setting controlled burns rather than waiting for lightning to do the job: by conducting burns in areas ripe for naturally-caused fires at times of less risk, the potential for serious fires when firefighting crews are most in demand would be reduced. (See page 15 for more information about the use of controlled burns in Yellowstone.)

Yellowstone’s fire policy, although far more widely understood and accepted than it was in 1988, remains unsatisfactory for those who object to any strategy other than an immediate effort at total suppression, and for those who favor the use of prescribed burns to prevent large fires. The controversy about fires, like that about wolves or snowmobiles, usually reflects a difference in view about Yellowstone’s role as a national park. At one end of the spectrum are those who criticize park managers for not doing enough to keep nature in its proper place, who want Yellowstone to be managed as “safe and attractive forests,” as advocated by Thomas Bonnickson, head of the Department of Recreation and Parks at Texas A&M, who testified during the Congressional hearings on the Yellowstone fires.¹⁹ At the other extreme are those who object to any intervention in Yellowstone to suit the convenience or preferences of the human species, and who value Yellowstone according to the extent to which it remains “wild” and uncontrolled.

The controversy continues.

Yellowstone Fires Since 1988

Year	Number of Fires		Acres Burned
	Prescription	Suppressed	
1988	*	45	793,880
1989	*	24	10
1990	*	43	247
1991	*	29	270
1992	15	14	485
1993	5	5	< 1
1994	4	60	16,238
1995	9	7	<2
1996	13	11	3,261
1997	12	1	< 1
1998	11	2	125
1999	11	4	10
2000**	2	31	7,209

*After the natural fire policy was suspended on July 15, 1988, all fires in the park were suppressed until the revised policy was approved in 1992.

**Estimate as of September 21. Nearly all lightning-ignited fires were at least theoretically to be suppressed because of the difficult fire season elsewhere in the West.

A manifest destiny

While fires are part of Yellowstone's natural landscape, many people found it only natural to respond to televised scenes of it burning with offers to plant trees and donate seedlings of more "fire-resistant" species. "We will have growing in Western states a piece of New Jersey," Governor Thomas Kean announced on September 17, 1988, as he held a bundle of seedlings at a statehouse ceremony, "to help restore green to the blackened acres of Yellowstone National Park."

Without casting aspersions on the generosity of the Garden State, it must be said that Yellowstone is no place for a piece of New Jersey. It had its own seeds to sow. Yet as late as 1994, a sixth grade teacher in Fayetteville, Arkansas, was writing *Country Living* magazine to thank them for their continuing sponsorship of a reforestation fund. "My students wanted to put conservation into practice, so they voted to raise money to replant trees in Yellowstone National Park." Actually, the 118,290 seedlings that had been planted in the magazine's campaign to "speed the recovery of acreage destroyed by the Greater Yellowstone Fires of '88" had gone into the adjacent Gallatin National Forest.

Letting Nature Decide

However well-intentioned, such contributions to the park were unnecessary and misinformed. In a national forest where future timber harvests are at stake, intervention may be appropriate after a fire to direct the replanting. In the Gallatin, Shoshone, and Targhee national forests, some of the burned acreage was planted with seedlings, and helicopters dropped tons of grass seeds on steep slopes and along waterways to reduce erosion. But Yellowstone after the fires was no more in need of replanting than is a park that is thawing out at the end of the winter.



The self-seeding forest, October 1998.

Many plant species sprout within weeks after a fire, responding to increased levels of minerals and sunlight, and it is part of Yellowstone's mission to let this transformation proceed without human interference. A hillside of charred trees that has spilled down toward the road after a windstorm may evoke reactions of, "What a mess!" But the park's maintenance crews only remove trees that pose a hazard to visitors' safety, not to their aesthetic sensibilities. The jumble of fallen trees is otherwise left as arranged by nature, to provide the habitat needed by a variety of birds, insects, and small mammals, and as the trees decay, to nourish the soil for the next generation of seedlings.

In Yellowstone, "rehabilitation" was required only for fire-damaged buildings and places where fire suppression efforts had altered the landscape. For the rest of the park, when and where and how the landscape would respond was left to be determined by ecological processes.

Variation as the Constant

On the whole, the research in Yellowstone since the 1988 fires has shown that an ecosystem can be highly variable from place to place and from one year to the next. Lodgepole pine was quick to sprout in many areas in widely varying densities, but not everywhere. Some grasses and flowers, such as fireweed (*Epilobium angustifolium*) and dragon's head (*Dracocephalum parviflora*), thrived only in the first years after the fires, while others such as pinegrass (*Calamagrostis rubescens*) and showy aster (*Aster conspicuus*), have slowly but steadily increased. Sometimes wildlife appeared to prefer foraging in burned patches, other times they favored unburned areas. Erosion was accelerated in some places, but the amount of soil loss and sediment deposits in streams varied greatly, and in most cases was within the normal range of variation observed before the fires. Just as climate was the main factor affecting the timing and extent of the fires, it has also been a primary factor in determining how the ecosystem has responded in the years since the fires.

Within a few years, Yellowstone's grasslands had largely returned to their pre-fire appearance, and sagebrush areas may be next, in another 20 to 30 years. But the burned forests are still in the early stage of a succession process that may unfold for more than a century, with lodgepole pine seedlings and saplings well-established in many areas, and the first seedlings of Engelmann spruce, subalpine fir and Douglas-fir beginning to emerge. Visitors can still see the stunning sight of acre after acre of charred and singed trees, and hillsides of green pocked with dark scars. As the root systems of the standing dead trees decay and lose their grip on the soil, the trees are gradually falling down, often with the help of a strong wind, but many will remain upright for another decade or more. Remnants of the larger fire-killed trees will still be decomposing on the forest floor 100 years from now, but they will no longer be visible to the untrained eye.

Aside from climate, the key factors in post-fire revegetation are soil moisture and nutrients, and the plant community that was present before the fire. Fertile soils with good water-holding capacity that had a dense, diverse vegetation before the fire were likely to respond quickly with a variety of species and nearly complete plant cover following the fire. Poor, dry soils that had less vegetation before the fire showed a slower response. A secondary factor is elevation, with lower elevations generally responding more quickly.

The key factors in revegetation.

Pollen analysis of pond sediments has shown that the basic vegetation patterns present in the park have been relatively stable for thousands of years. However, these patterns had begun undergoing gradual shifts because of fires and long-term climate changes long before 1988. Because the oldest coniferous trees in the park are more than 500 years old, evaluation of possible climatic effects on vegetation goes back to the Little Ice Age, the coldest part of which occurred in Yellowstone from roughly 1650 to 1890. Tree rings dating from 1751 suggest that the winters of the 1860s and those from about 1885 to 1900 were unusually cold, and the heaviest winter precipitation since the mid-18th century occurred from about 1877 to 1890.¹

Pre-1988 vegetation changes.

Whether as a result of human alterations to the atmosphere and/or natural fluctuations in the length of the solar cycle or other factors, much of the northern hemisphere has reported a warming trend since the beginning of the 20th century. Average temperatures in Mammoth Hot Springs have risen more than 1°C and, despite an increase in summer precipitation, overall precipitation has declined because of drier winters.²

In *Yellowstone and the Biology of Time* (1998), Mary Meagher and Doug Houston compared photographs taken since the 19th century to document changes in the landscape. The vast tracks of lodgepole pine-dominated forests that characterize the central and southern parts of the park, most of which lie between 2,300 m and 2,600 m, had changed little in appearance or extent during the century before the 1988 fires. However, as has been common throughout the northern and central Rocky Mountain region, historic photographs of Yellowstone indicate that conifers at many high-elevation locations have been expanding into adjacent meadows since the mid-1880s. Meagher and Houston believe the major cause of this tree invasion may be a long-term regional trend toward warmer and wetter growing seasons.

Although the relatively short period of effective fire suppression probably had very little effect on most of the Yellowstone landscape, where fires had historically occurred at intervals of 200 years or more, it did contribute to the more dramatic vegetation shifts that took place in the lower portions of the park, where fires had previously occurred at intervals of 20 to 25 years. Much of the northern range, where firefighting efforts could have a bigger impact, has not burned in more than 100 years, despite the fires of 1988. In these areas, landscape diversity has decreased as lodgepole pine and Douglas-fir forests expanded into grassy meadows and drier bunchgrass steppes; Engelmann spruce and subalpine fir increased to a much lesser extent, mainly along streams.³

The northern range is an area of 540 square miles that crosses the park's north boundary and is used by many elk, bison, antelope and deer, especially in winter, when because of its lower elevation the snowfall is lighter and the forage more accessible than elsewhere in the park. Some people believe that the presence of a large elk population on the northern range since culling stopped in 1968 has resulted in "over-grazing" and contributed to the decline in aspen and willow.

The Trees That Grow in Yellowstone

Elevation in the park ranges from about 1,800 meters along the Yellowstone River in the north to more than 3,000 meters on the high peaks of the east and northwest. Different vegetation patterns appear within the park based on differences in climate, which varies according to elevation, with mountainous sites being generally cooler and wetter than valley sites. On a broader scale, the central and southern areas of the park tend to have dry summers/wet winters, while the north has wet summers/dry winters.

About 80% of the park is covered with conifer forests dominated by lodgepole pine; subalpine fir and Engelmann spruce are the next most abundant trees. The areas at lower elevations in the north support sagebrush grasslands, with Douglas-fir forests in damper locations and aspen in small groves along forest-grassland boundaries, flood plains, and stream banks. At lower elevations in the Gardner and Lamar valleys, Rocky Mountain juniper and limber pine grow along streams, as do narrow-leaved poplar and water birch. On the cooler subalpine plateaus, extensive lodgepole pine forests are broken by occasional meadows and sagebrush grasslands. The highest ridges may have forests of spruce, fir, and whitebark pine, with subalpine meadows and boulder fields on the more exposed sites. (Based on Meagher and Houston, 1998)



Pseudotsuga menziesii
Douglas-fir

But Meagher and Houston believe that the most striking change in forests below about 2,400 m prior to 1988 was the reduction in area and density of aspen. Sites once occupied by aspen on floodplains, wet swales, and springs on south slopes had become sagebrush grassland or non-native timothy grass meadow, which not only dominated the understory but may have displaced native forbs. Meagher and Houston noted that photos taken outside the park's north, east, and south boundaries show similar increases in forested area and shifts in species composition: aspen declined and conifers increased.

The extent of diversity found in a landscape is the result of two overlapping vegetation patterns: the limits on species distribution set by factors such as elevation and soil moisture, and the patterns of disturbance that occur within the plant communities along those gradients.⁴ Instead of advancing as a solid wall of flames that consumes everything in its path, fire sends out probes along the lines of least resistance in the landscape, as determined by fuel load and topography, and it can leap large distances in a single bound. As a result, fire generally increases the heterogeneity of the landscape by fragmenting blocks of older forest with burned patches that will grow new forests. During the preceding century Yellowstone had experienced only relatively small fires, so by 1988 the landscape included a patchwork of successional stages, but also many large, homogenous expanses of mature lodgepole pine.⁵

The fires of 1988 placed a new mosaic of different burn severities atop the patchwork that was already there, while leaving unburned areas across the park in sizes ranging from inches to miles. This jigsaw-puzzle pattern of young, middle-aged, and old forest provides a variety of habitats that can support a variety of animal species. However, the 1988 fires occasionally became so large and powered by wind that they were largely impervious to the effects of local vegetation and topography. Some burned areas therefore became *less* heterogeneous than the previous mosaic had been. That is, where the fire effects were patchy in 1988, they increased the landscape's diversity, but where large areas were intensely burned, the landscape may appear more uniform than it was before the fires.⁶

Researchers have found, though, that even in forests dominated by a single tree species, differences in burn severity and the availability of seeds can result in large-scale patterns of varying tree density and size that may persist until the next stand-reducing fire. In a 1990 study of burned sites, the lodgepole pine density was 4 to 24 times higher in the moderate burns, but the seedlings grew faster and accumulated more biomass per unit of height in the severe burns.⁷ A decade after the fires, some areas that had previously been characterized by conifer forest now had pine stands ranging in density from 10,000 to nearly 100,000 saplings per hectare, while other areas were now non-forested or only marginally forested, with fewer than 1,000 saplings per hectare.⁸

Because few species other than Engelmann spruce and subalpine fir can survive on the dark floor of a mature lodgepole forest, the opening of the forest canopy by fire is generally expected to increase the

Metric Measures

The measures used here to describe the Yellowstone landscape and the research that has been done in the park are those the researchers used themselves, which usually means the metric system.

- 10 centimeters = 3.9 inches
- 1 kilogram = 2.2 pounds
- 10 kilometers = 6.2 miles
- 1,000 meters = 3,280 feet
- 100 milligrams = 3.5 ounces
- 1 hectare = 2.47 acres

Landscape diversity.



Lodgepole pine saplings on the Mirror Plateau that sprouted after the 1935 Wrong Creek fire; photograph taken in 1973.

diversity of both the plants growing there and of the animals that can use these plants for food or habitat. In the 1960s, Dale Taylor, a biologist later affiliated with Everglades National Park, censused the plant, bird, and small mammal species at six lodgepole pine sites in Yellowstone that had burned at various times up to 300 years before.⁹ Species diversity in all three categories increased with age at the three youngest sites, which still had open canopies: from a total of 55 species at the 7-year site to 112 species at the 25-year site. Biodiversity had declined at the three oldest sites, all of which had a closed canopy: 39 species at the 57-year site and 38 species at both the 111- and 330-year site.

Species diversity.

Although the patchiness of fire is generally assumed to increase the variety of habitats, the overall effect of the 1988 fires on biodiversity is difficult to assess. Insofar as they did not entirely eliminate any habitat type or create one that was not already present in Yellowstone, the fires were unlikely to cause the disappearance of a species or make it possible for a new species to survive in the park. By changing the mix of habitats available for plant and animals species, however, fires may increase or reduce their relative abundance and distribution, at least over the short term.

For example, a decade after the fires, it appears that aspen may have at least temporarily extended their range in Yellowstone (see page 58). But compared to the age of a stand of lodgepole pine, which may endure for centuries, we are still looking at relatively short-term responses to the fires of 1988. Shiny-leaf ceanothus, which was infrequently seen in the park before the fires, sprouted from seeds waiting in the soil and began a shrub layer that may be around for many decades before it is crowded out by growing Douglas-fir trees. Bicknell's geranium also responded to the heated soil by sprouting, but as a biennial it lasted only a few years before retreating to the cover of soil until the next fire.

In any event, although biological diversity is important, it is not the only worthwhile conservation goal, and efforts to maintain maximum species diversity are not always compatible with Yellowstone's primary goal, which is to maintain the park's ecological processes. If biodiversity were the sole criteria, Yellowstone would not be particularly valuable; except for the microorganisms that thrive in its hot springs and some plants that depend on geothermal heat, the park's cold winters and relatively infertile soils do not support flora or fauna that are significantly different from those found elsewhere in the Rocky Mountains.

Soils

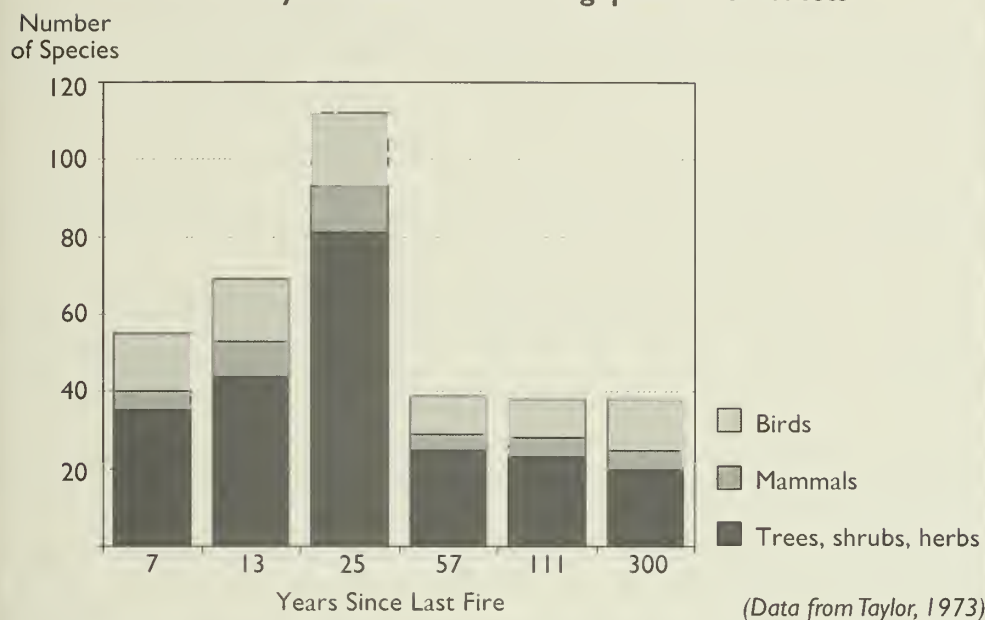
Providing a reservoir for plant nutrients and moisture, soils play a major role in determining which plant species can grow where. Soil develops as the underlying mineral material (clay, silt, sand, gravel, glacial till, or bedrock) is mixed with dead organic material and living organisms. The two major soil types in Yellowstone, andesitic and rhyolitic, are derived from bedrock that was deposited during two major volcanic events. Andesitic soil, which contains more clay, can hold more plant nutrients and moisture than rhyolitic. The extensive forests of the Yellowstone plateau developed on acidic, infertile soils that originated in the rhyolite lava flows of the Yellowstone caldera, while the drier climate and more productive soils of the Lamar and Yellowstone river valleys, derived largely from andesitic volcanic rock, fostered grasslands with sagebrush. Such differences may explain why a meadow may retain the same shape over time despite fire and other disturbances.¹⁰

Some soils in Yellowstone supported very little vegetation before the fires and have continued to have very little since then. Areas that appear barren and highly erosive did not necessarily become that way because of fire. Crown fires generally have little impact on the soil; it is the slow-moving surface fires that smolder in the forest duff and rotten logs that affect revegetation and erosion. When the soil is burned deeply and long enough, seeds and other reproductive plant material may be killed, and the soil's ability to repel water may be altered. Although some soils are inherently "hydrophobic," this trait may increase when



Ceanothus velutinus
Shiny-leaf ceanothus

Biodiversity in Yellowstone's Lodgepole Pine Forests



organic compounds are heated so intensely that vapors condense on the soil, forming a coat that inhibits percolation of water and increases runoff.

Sampling at hundreds of burned areas after the 1988 fires found that in small patches totaling less than 0.1% of the burned area in the park, the soil became hot enough (1,200°F) to kill nearly all the seeds, roots, bulbs, and rhizomes that would otherwise regenerate after a fire.¹¹ But even these patches were still capable of propagating seeds that may disperse from surrounding areas. The increased hydrophobicity was not expected to significantly affect erosion except in part of the Shoshone National Forest that experienced especially intense burning. (See page 88 for more information about erosion-caused soil loss.)

Scorched earth.

When water filters through the ash of a burned area, it leaches the nutrients from the burned plants back into the soil, where they become available for new plant growth. By analyzing the chemical components of wood ash collected in 1988 before any precipitation had fallen on it, Donald Runnels and Mary Siders of the University of Colorado were able to determine that the ash had lower concentrations of nutrients a year later, and was continuing to release nutrients during "wetting episodes."¹² Different nutrients were released at different rates, resulting in a continually changing soil chemistry.

Soil nutrients after fire.

But the nutrients may filter through the soil if the fire has killed the plant roots that would otherwise intercept them. To test a sampling method that simulates the action of roots in taking up nutrients, scientists from Montana State University compared burned and unburned sites at two locations representative of large areas of the park.¹³ They analyzed soil from depths of up to 30 cm using both the standard lab tests, which provide a snapshot of conditions at specific times (in October 1988 and after 30 months), and their *in situ* "resin capsule accumulation" method, which monitored nutrient changes throughout the study period. The resin capsule analysis showed that ammonium and nitrates at the burned Virginia Cascades sites declined during the first 20 months post-fire, then began increasing after 30 months. The Mount Washburn soil, in which ammonium and nitrate levels were naturally much higher, showed little change post-fire. This suggested that when plant roots at the Virginia Cascades burned sites were absent to take it up, nitrogen was being leached to lower depths; as plants grew back, it was retained in the nutrient cycle.

Forests

Although a forest fire may destroy what many regard as useful wood or attractive scenery, it does not destroy the forest itself. In areas burned by crown fires in 1988 (about 41% of the total burned area and 15% of the park), the forest canopy and most of the litter and duff on the forest floor were consumed. These patches were surrounded by halos of singed trees with brown needles, where the fire was not sufficiently intense for complete combustion. Some of these trees died later on because too many of the needles were singed, because too much of the living cambium layer was burned, or because they become more vulnerable to insect infestation, but many survived with only fire scars.

Post-fire survival.

The survival of conifers after a fire depends on the type and degree of fire injury, tree vigor, and post-fire conditions—the influence of insects, disease, and weather. If there is no trunk or root injury and less than 70% of the crown was scorched, trees of normal vigor are more likely to live than die.¹⁴ Mortality resulting from excessive crown injury generally occurs during the first two post-fire growing seasons, while death resulting from trunk and root injury often does not occur until later. And even trees that are killed may leave left behind seeds that will shape the forest's future.

Although also an abrupt change, the harvesting of trees for timber has a very different impact from fire on forest structure. Fire removes mostly leaves and branches; it may char the circumference of trees, but most of the tree boles remain to cast some shade and provide habitat for animals. Burning also consumes much of the forest floor, exposing the soil and facilitating the growth of seedlings. Tree harvesting, in contrast, removes the entire bole and leaves the branches and foliage in the forest. Erosion and nutrient loss may be greater after an intense fire than after tree harvesting, but the charred wood left by a fire eventually becomes incorporated into the soil.¹⁵

Return of the lodgepole pine.

Nearly all of the burned forests in the park have restocked themselves with seedlings, and nearly all appear to be regenerating plant communities similar to those that were present when the fires of 1988 arrived, primarily because sources of plant reproduction persisted even within very large burned areas.¹⁶ Many of the forests that burned in 1988 were mature lodgepole stands, and this species is now recolonizing most of the burned areas. But although the 1988 fires did not result in vast meadows where forests once stood, lodgepole pine



Yellowstone's forests: past, present and future.

grow slowly in Yellowstone's current climate, and 30 years after the post-fire seedlings have taken root, many may still be less than 10 feet tall. In 50 years, they may form thick stands, 200 to 300 trees to an acre, competing for light, water, and nutrients. And eventually, if there is no other large-scale disturbance or climate change, their crowns will grow together, forming a canopy that shuts off light to the forest floor.

Bark Beetles

Although regarded as pests in forests used for timber, bark beetles are plant-eating animals with an ecological role that is no more inherently malicious than that of elk or bison. Yet certain insects can be just as deadly to a stand of trees as fire and have a similar canopy-opening effect. And like fire, the bark beetle is heavily influenced by climate, is characterized by large fluctuations in abundance over time, and has an interdependent relationship with the objects of its consumption: bark beetles both affect and are affected by conditions such as forest composition and rates of succession.

Some beetle species have periodically reached epidemic levels in Yellowstone, killing a large portion of trees across vast areas and then diminishing until additional cohorts of susceptible trees mature and conditions again favor an outbreak. Although the mountain pine beetle, Douglas-fir beetle and spruce budworm (*Dendroctonus* spp.) can kill healthy trees, other beetles such as the pine engraver (*Ips* spp.) are typically attracted to weak or already dead trees and may have less impact on tree mortality.

Conspicuous consumers.

Lodgepole pine is most susceptible to infestation by mountain pine beetles (*Dendroctonus ponderosae*) when extensive stands of trees reach at least eight inches in diameter. The last major outbreak in greater Yellowstone began in the Targhee National Forest in the late 1950s and had reached the southwest corner of Yellowstone National Park by 1966. The beetles spread into through an extensive portion of the park's higher elevations, infesting more than 965,000 acres in greater Yellowstone by 1982.¹⁷

Based on sampling in study plots set up near Bechler Meadows in the southwest corner of the park in 1965, two U.S. Forest Service entomologists estimated that mountain pine beetle infestation had reduced the number of lodgepole pine trees larger than five inches in diameter from 211 to 156 per acre, with mortality peaking in 1969 and subsiding by 1972.¹⁸ In 1990, these researchers, Douglas Parker and Lawrence Stipe, found that more than half of the trees killed from 1966–72 were still standing and, despite widespread crown fire in this area in 1988, the growth of surviving trees had increased the number of live lodgepole pine to 184 per acre.

Canopy fires usually burn or severely scorch the inner bark on which insects feed, reducing the likelihood of widespread infestation, but the crown and bole injuries caused by a surface fire increase the trees' susceptibility to attack. Trees that have escaped fire injury may be exposed to the spread of insect attacks from nearby injured trees. However, assessing the extent of fire damage is often difficult, making it equally difficult to determine the extent to which insects are the agents of death rather than opportunists attacking already mortally injured trees.¹⁹

Gene Amman and Kevin Ryan of the U.S. Forest Service, who surveyed thousands of trees in unburned and surface burned areas of Yellowstone National Park and Rockefeller Memorial Parkway after the 1988 fires, observed that most trees that had received severe crown scorch or severe bole injury had died within three years; few of the remaining trees had more than half of their crown damaged by fire, and many had no crown injury at all.²⁰ The mortality of trees after the fires was most often due to fire injury, but insect infestations were a significant factor even for trees with minor crown and bole injury; the level of infestation increased with the percent of the tree's basal circumference killed by fire. Even



Dendroctonus ponderosae
Mountain pine beetle
(larger than actual size)

unburned areas had relatively high levels of infestation, suggesting that insect populations increased in fire-damaged trees and then spread to undamaged ones.

For example, of the more than 1,000 Douglas-fir trees sampled in 1991, 32% were dead by 1992, including almost one third of those that had appeared alive after the fires. Of this delayed mortality, Ryan and Amman attributed 19% to fire injury and 13% to insect infestation, mostly by the Douglas-fir beetle (*Dendroctonus pseudotsugae*). Infestation rates ranged from 16% of the uninjured trees to 80% of the trees in which more than 80% of the basal circumference had been girdled by fire.

Lodgepole pine infestations.

Of the nearly 5,000 lodgepole pine sampled in 1991, half were dead by 1992; 31% because of fire injury and 18% because of insects. The foliage on many of these trees did not fade until they became infested by pine engravers (*Ips pini*) or twig beetles (*Pityophthorus* and *Pityogenes* spp.) three or four years after the fires, and the infestation of uninjured trees increased from 2% in 1991 to 7% in 1992. Infestation rates ranged from 22% of the uninjured trees to 67% of the trees in the 81-100% basal injury class. The pine engraver accounted for most of the infestation; twig beetles and wood borers were also present, but mountain pine beetles were found in less than 1% of the lodgepole pine.

The mountain pine beetle has been a significant cause of lodgepole pine mortality in the West, but populations were low in greater Yellowstone prior to the fires and remained low afterward; these beetles seldom breed in trees injured or killed by fires in numbers sufficient to increase their population. Ryan and Amman were uncertain whether some beetle species would continue to spread to unburned forests, but "historic evidence from other fires suggests major epidemics are unlikely in the absence of additional stress from drought or other sources."

According to the 1997 report on ground and aerial surveys conducted across most of Montana by the U.S. Forest Service in conjunction with the Montana Department of Natural Resources and Conservation, "Bark beetle populations have been again in a general decline except for ongoing outbreaks of mountain pine beetle mortality to lodgepole pine in extreme western Montana."²¹ Many groups of insect-killed Engelmann spruce and Douglas-fir were observed in the northeast corner of the Yellowstone National Park that were "remnants of those which built up following the fires in 1988 and the ensuing several years of drier than normal weather. They are gradually returning to endemic levels."

Which came first, the beetle or the fire?

Although the increased vulnerability of fire-damaged forests to beetle infestation is well documented, the reverse is more debatable: are beetle-damaged forests more susceptible to fire? Some scientists such as Parker and Stipe contend that by providing a ready fuel source, the abundance of beetle-killed trees in Yellowstone made the remaining forest in these areas more likely to burn. But Don Despain points out that although the southwest corner of the park has been under nearly continuous beetle attack for more than 50 years, "the vegetation has still not been converted to another timber type, and large fires are no more frequent there than in other parts of the park."²² Fires as rapacious as those of 1988 showed no apparent preference for beetle-killed trees. Despain has suggested that this may be because beetles actually reduce the fuels suitable for crown fires. Flammability may increase during the first year or two of infestation, but with dead pine needles and twigs falling off and leaving less fuel in the canopy, crown fires that entered areas with many beetle-killed trees in 1988 typically turned into surface fires.



Ips pini
Pine engraver

From this perspective, although the presence of fire-damaged trees may encourage the growth of bark beetle populations, infestations appear to be driven more by drought than by fire. Despain notes that both of the major outbreaks that occurred in Yellowstone in the 20th century began during droughts and ended during wet periods.

A slender tree used by Indians to make lodges and tepees, the lodgepole pine is a sun-loving species, and the only conifer capable of producing fire-resistant seeds. Lodgepole pine's ability to provide an abundant seed source that scatters over the ground within days after a fire gives it an advantage over conifers whose seeds are more easily destroyed by fire and must be brought into a burned area from other another site by wind or animals.

Before fires swept through about a third of the park, it was said that about 80% of Yellowstone was covered with forests dominated by lodgepole pine, and that's still true. Although they may not be most park visitors' idea of forests, thick with tall living trees, nearly all burned lodgepole pine areas are still considered forest habitat, containing primarily forest species. As expected, lodgepole pine seedlings were among the most abundant pioneer species on many burned plateaus during the first years after the fires.

But the density of lodgepole pine seedlings that sprouted in burned areas after the 1988 fires varied greatly, depending on factors such as elevation, fire severity, the abundance of serotinous cones, and seedbed characteristics. Lodgepole pine seeds seldom disperse more than 60 meters from the parent tree.²³ Because the major seed bank for lodgepole pine is in the canopy, seed survival after the fires was greater in areas of surface burn than of crown fire, which may cause cone ignition or substantially reduce seed viability even in serotinous cones. Analysis of video footage showed that tree crowns were most often completely burned in 15 to 20 seconds, while the maximum opening of serotinous cones (37% to 64%) occurs after the cones have been exposed to flames for 10 to 20 seconds.²⁴ The initial germination rate for non-serotinous cones is higher, but their survival rate decreases about 1.5% for each second in the flames.

Seed survival in the fires.

In August 1989, Jay Anderson of Idaho State University and Bill Romme of Fort Lewis College in Colorado inventoried plants at 14 plots in the northern part of the park that had been subjected to a moderate burn or a severe crown fire the previous year. Before burning, all of the sites had supported mature, nearly monospecific lodgepole pine stands. After the fire, the density of new pine seedlings was consistently higher in the moderately burned plots, but all sites had mostly the same plant species as before the fire.²⁵ Of the individual plants found in the first post-fire season, nearly one third were lodgepole pine

Some Like It Hot

Lodgepole pine begin producing cones with seeds when they are 5 to 20 years old, depending on the stand density. Between age 20 and 50, some trees start to produce a serotinous cone whose scales are sealed by a resin. The waxy resin will soften enough for the cone to release its seeds only if it is exposed to a temperature of at least 113°F—something that happens in Yellowstone only during a fire.

The proportion of trees in a lodgepole pine stand that bear serotinous cones has been found to range from zero to nearly half, with serotiny more common in even-aged stands and at elevations below 2300 m. This could be because the ratio of serotinous to non-serotinous cones is related to fire frequency, which is generally greater at lower elevations. Many lodgepole pine seeds may be killed by the fire or consumed by birds, squirrels and other animals, but the survivors can sprout from a soil newly rich with minerals and open to sunlight—ideal conditions for the growth of lodgepole pine seedlings, sometimes hundreds of thousands of them per acre. As they grow taller and compete for light and water, only the strongest trees survive. After 200 years, perhaps a few hundred lodgepole pines remain per acre, some with serotinous cones of protected seeds, saving them for a fiery day.



whose seeds had been stored in the canopy; the rest were plants that had survived the fire and grown back. Only about 1.5% of the individual plants and one species (*Dracopis parviflora*) grew from seeds that had been stored in the soil. This biennial species flowered only during the first few years after the fire; its seeds will survive in the soil until the next stand-replacing fire occurs. Dispersal of seeds from adjacent areas accounted for less than 1% the plants present.

Variation by type of burn.

Using paired transects at 12 sites in the park that had supported mature, nearly monospecific stands before the fires, Romme and Anderson worked with two other biologists from Idaho State University to compare the effects of surface burn and crown fire on seedling density.²⁶ They found that by 1990, seedling density increased exponentially with stand serotiny, ranging from 80 seedlings per hectare in a high-elevation stand with no serotinous cones to 1.9 million seedlings per hectare in a low-elevation stand in which nearly half the trees were serotinous. Seedling densities were also consistently higher and the seedlings grew faster in moderately burned as compared to severely burned sites. Even after six years there was no evidence that seedling mortality was density dependent.

This research team found that even most of the “remote” crown fire transects (at least 100m from the nearest possible seed source) in their study area had enough seedlings by 1990 to replace the pre-fire stand. But their analysis of aerial photos taken of the entire park in 1998 suggested that while 10% of the area that had burned in 1988 supported very high-density stands of 10-year-old lodgepole pine trees (more than 50,000 stems per hectare), 10% had very low-density stands (fewer than 100 stems per hectare), and density within the remaining burned area was somewhere between those extremes.²⁷

John Burger, an entomologist now teaching at the University of New Hampshire, has been a frequent Yellowstone visitor since he began his graduate work in the 1960s, and has been returning annually since 1992 to monitor reforestation as a matter of personal interest. He has been surprised at the enormous variation in the rate of lodgepole pine growth between different sites and between adjacent trees in the same site. In a site near the Mount Holmes trail, the post-fire saplings averaged 205 cm in height by July 2000, but the tallest was 340 cm. South of Norris Junction—“This must be the *ideal* site for lodgepole saplings”—some saplings were more than 400 cm, and the tallest was 444 cm (about 14.5 feet).²⁸

Where the forest isn't returning.



Lodgepole seedling, August 1989.

However, reforestation appears uncertain in some areas. After sampling 15 burned sites in the park in 1991 and 1996, Ralph Nyland of the SUNY College of Environmental Science and Forestry noted that the five sites that before the fires had had even-aged lodgepole pine stands (and presumably higher rates of serotiny), now had the highest seedling densities and should have “sufficient trees for a closed-canopy forest to eventually develop.”²⁹ But at the other sites, which had not regenerated well, stand density would increase only when the scattered cohort of initial regeneration begins producing viable seeds, about 10 to 20 years post-fire. And by then these sites may have developed an herbaceous plant community in which lodgepole pine seedlings would compete poorly and may be unable to survive.

Monica Turner, then an ecologist at Oak Ridge National Laboratory in Tennessee, was part of a research group that studied a 3,700-acre area of 400-year-old forest near Yellowstone Lake in which only 1.9% of the pre-fire trees were serotinous.³⁰ Five years after a crown fire in 1988, it still had fewer than 10 seedlings per hectare. Lodgepole pine seeds are viable for less than five years, suggesting that the opportunity for immediate post-fire tree seedling establishment from local sources at this site had been missed. Although the few seedlings present may be producing seeds by now, replacement of the forest would require seeds from outside the burned area, much of which is beyond the likely dispersal distance of conifer seeds. Based on this data “from the earliest stages of post-fire succession,” Turner found that at this site “pathways of succession potentially leading to nonforest communities were initiated following the 1988 fires.”

The whitebark pine has kept its distance from most of the human species, having little commercial value and generally growing on high steep slopes. But it has a significant role in the Yellowstone ecosystem, where it helps stabilize soil and rocks on rough terrain, retains snow, and provides an important food. Its large nutritious seeds are eaten by birds, by squirrels that bury the cones, and by grizzly bears, which raid the squirrels' cone middens.

The whitebark pine typically grows above 2,400 m with other conifers, but it can establish nearly pure stands in cold, dry, windswept ridges that are unsuitable for other trees. Its habitat depends on both where it can compete successfully with other vegetation, and where the Clark's nutcracker prefers to cache its seeds. For whitebark pine cones do not release their wingless seeds automatically; the Clark's nutcracker has a near monopoly on their dispersal, using its long bill to extract the seeds and store them under several centimeters of soil in late summer and fall. Carrying dozens of seeds in its throat pouch at a time, the nutcracker may travel miles to find suitable sites for thousands of caches that contain up to 15 seeds. It can later relocate these caches to feed itself and its young until the next year, but nearly half the seeds may remain unretrieved and some will germinate, often after a delay of one or more years, producing clusters of seedlings and multi-trunked trees.³¹

These buried seeds with their delayed germination and the hardiness of the seedlings on exposed sites can give the whitebark pine an initial advantage in large burned areas over conifers that depend on the wind to disperse their seeds.³² In the absence of fire in more temperate sites, whitebark pines are likely to be shaded out by subalpine fir and Englemann spruce, which are more shade-tolerant and less fire-resistant. However, although whitebark pine frequently survives fire, this slow-growing and long-lived tree is typically more than a century old before it begins producing cones. Consequently, the young trees may die before reproducing if the interval between fires is too short or if they are overtaken by faster-growing conifers.

In much of the northern Rocky Mountains, whitebark pine has been in decline because of a fungal disease known as blister rust. Unlike the bark beetle that causes periodic epidemics in trees (see page 53), whitebark pine blister rust (*Cronartium ribicola*) is not native to the region. Since arriving from Europe around 1910, it has spread to most whitebark pine stands in the moister parts of its range, reaching an estimated mortality rate of 44% of the trees in the Tetons, but only about 7% in Yellowstone's drier climate.³³ Katherine Kendall, a U.S. Geological Survey biologist at Glacier National Park, believes that "the most likely prognosis for whitebark pine in sites already heavily infected with rust is that they will continue to die until most trees are gone," and that to enable the species to continue at a landscape scale, fires must be allowed to burn in the ecosystems they occupy.³⁴

However, a study of whitebark pine stands in greater Yellowstone did not provide evidence of more prolific regeneration in burned areas. To compare moist and dry whitebark pine sites of different burn intensities, in 1990 Diana Tomback of the University of Colorado set up 275 study plots on Mt. Washburn in the park and on Henderson Mountain, northeast of the park in Gallatin National Forest.³⁵ Prior to the fires, both areas had mature whitebark pine communities dominated by subalpine fir and Engelmann spruce; the Henderson study area also included unburned sites. Although whitebark pine seedlings had appeared on all sites by 1991, by 1995 there was no significant difference in regeneration density or seedling survival between the burned and unburned sites on Henderson Mountain.

Planted by nutcrackers.

Plagued by blister rust.



Pinus albicaulis

Aspen

On the decline in the Rockies.

One of the few deciduous trees found in Yellowstone, aspen can support an abundance of bird life and provide a highly preferred food for elk and beaver. Elk eat the tips of aspen sprouts and the smooth white bark of mature trees, which the tree replaces with a thick black bark. Nearly all large aspen stems in the park have such bark extending up as high as an elk can reach.

Most of Yellowstone's aspen are located in the lower elevations of the northern portion of the park. Until after the 1988 fires, which led to a dispersal and sprouting of aspen seeds, the species was almost entirely absent from the high plateaus that dominate the rest of the park. Instead of reproducing through seeds, Rocky Mountain aspen usually reproduce asexually, with suckers sprouting on the horizontally growing root system, referred to as a "clone." Because the suckers already have a root system to draw water and nutrients from the soils, they can grow quickly into new stems. For the last century, Yellowstone's clones have continued to produce root sprouts, but rarely large stems. Aspen now occupy only about 2% of the northern range, compared to about 6% during the late 1800s.³⁶ This decline, which has occurred in aspen stands throughout the Rocky Mountains, has been attributed to fire suppression, high elk densities, a shift to a drier climate, and the resulting greater competition from conifers.

Most of Yellowstone's surviving aspen stands appear to have been established between 1870 and 1890, a period characterized by an unusual combination of a relatively wet climate and low numbers of elk, beaver and moose because trapping, hunting, and wolves were still having a significant impact on the northern range. Infrequent fires and moist conditions may have permitted more rapid growth of sprouts beyond browsing height, and deeper winter snow that made it difficult for ungulates to reach the sprouts; many of the stands are located in depressions and drainages where windblown snow tends to accumulate.

Based on the age distribution of 15 aspen stands on the northern range, Bill Romme concluded that regeneration of large stems was episodic even before the park was established in 1872, and that the right combination of aspen-favorable conditions has not recurred.³⁷ A moist decade in the 1910s coincided with numerous elk, numerous beaver, and no fires. Reductions in the elk population carried out in the 1950s and 1960s to maintain what was

believed to be an appropriate herd size of 5,000 to 7,000, occurred during dry periods when fire suppression was relatively effective on the northern range. A study of 14 aspen stands in the 1960s by park biologist Bill Barmore found that more than 25 "elk use" days per acre resulted in consumption of all aspen sprouts; even at that relatively low elk density, aspen suckers could not grow beyond browsing height.³⁸ There are also areas in Jackson Hole where ungulate browsing has been light, yet few or no tree-sized stems have developed since the last extensive fires in the late 1800s.

Although aspen as a species is in no immediate danger of disappearing from the park, the canopy of mature stems in many stands has been gradually thinning and disappearing as a result of various diseases and other natural



Populus tremuloides

causes, with little or no aspen understory to replace it. When a dominant stem becomes injured, it stops producing the auxins that otherwise inhibit root sprouting. In this way, even if all the large stems die, the root system can persist, perhaps indefinitely, nourished by small sprouts referred to as “shrub aspen.”³⁹

According to Roy Renkin and Don Despain’s calculations, shrub aspen retain a root biomass of about one ton per hectare and grow about 4 cm in height each summer.⁴⁰ They found this shrub condition to be prevalent in aspen across the northern range, as well as in other ecosystems with different elk densities. “Shrub aspen may represent senile yet persistent remnants that germinated and proliferated under more optimal climatic and environmental conditions.”

Aspen as shrubs.

To examine historic browse levels, Renkin and Despain sampled recently fallen aspen trees from each of five clones more than 80 years old across the elevational gradient of the northern range. In 49 of the 50 aspen sampled, previous browsing was evident on the main stem about 33 cm above ground, indicating that current aspen utilization levels are similar to those of a century ago as well as those that occurred during elk herd reductions. Whatever the mechanism was that allowed aspen to grow beyond the browse influence then is not exerting the same influence today.

Meagher and Houston’s comparison of historical photographs suggests that even in the late 19th century, when aspen were more abundant on the northern range, they nearly always appeared as dense clumps of short trees, probably the result of fire.⁴¹ Only one out of 22 photographs of aspen taken prior to 1901 shows a stand of mature trees, while 38 of 42 photographs dating from 1901 to 1944 have stands dominated by medium to tall aspen—a maturation that occurred in the presence of high elk densities. Some stands show successful vegetative reproduction, at least on their margins, into the 1920s.

Also using historical photographs, Charles Kay and Frederic Wagner of Utah State University located 81 sites on the northern range that had aspen dating back to 1871, and concluded that one third of the clones had completely died out, without any correlation to slope, aspect, elevation, distance from surface water, or surrounding vegetation.⁴² In sites where aspen had survived, they occupied an average of 20% of the area that had historically been covered by clones, and many stands that once contained thousands of trees survived only as small numbers of suckers. Aspen had maintained its presence at some locations for up to 60 years with stems that had never reached a meter in height because of repeated browsing; most stems were less than four years old, and the oldest was 15 years.

Kay also participated in a study that used historical research and photographs to evaluate aspen change over time at Yellowstone and five other Rocky Mountain national parks in the United States and Canada where most stands are in decline.⁴³ In photos taken before 1910, most aspen stands at all parks were shrub-like in young age classes, with no sign of browsing and abundant evidence of frequent fire, such as burned snags and new forest regeneration, and the few mature aspen stands showed no sign of elk stripping. This study concluded that burning accelerates clone deterioration, and that the combination of fire and elk browsing had hindered aspen regeneration except in northern Jasper National Park, where elk densities appear to have been reduced by wolves in the 1970s.



Shrub aspen in foreground near Tower Junction.

"A complex interaction, involving elk abundance, climatic variation, fire, and possibly mammalian predators and other herbivores controls the dynamics of aspen tree regeneration [on Yellowstone's northern range]. None of these factors is sufficient in itself to explain the temporal patterns observed."

— Romme et al., 1995

Aspen trees have thin bark and low tolerance for fire, but their insulated root network can survive and sprout suckers. Some optimal fire intensity may be required to maximize this suckering response: a fire of sufficient intensity is needed to disrupt the transport of auxins from the crown to the roots, so that the suckers will sprout, but if the fire is too intense, it will kill the roots from which the suckers arise.⁴⁴

Aspen under fire.

Analysis of aerial photographs has shown that about one-third of the northern range aspen burned in the 1988 fires. They sprouted abundantly during the first two years after the fires, but all sprouts that projected above the winter snow were heavily browsed. To compare the aspen response to fire with and without ungulate browsing, Renkin and Despain identified 18 sites (clones) on the northern range and selected one for a controlled burn in October 1986, and two in October 1987.⁴⁵ Two more sites were added to the study after they burned in the 1988 fires. The resulting data suggested that a pre-burn basal area of about 25 square meters per hectare or a root biomass of 20 tons per hectare is required for optimal aspen stocking and growth after fire; aspen stands with the lowest above-ground biomass before the fires produced the lowest amounts of sucker biomass afterward. At the lower growth rates, it would take more than 25 years of protection from browsing for most aspen buds on the main stem to achieve a level at which they could escape herbivory.

The age class structure of aspen at unprotected sites shows that herbivory alone does not always result in accelerated sucker mortality or in the elimination of aspen. One study comparing fenced and unfenced plots found that elk browsing influenced both sucker heights and age-class distribution, but had no effect on sucker density or mortality five to seven years post-burn. When suckers are browsed, the plant's resources are used to produce new suckers instead of growth in height. Renkin and Despain believe that this response allows for the long-term persistence of aspen in a shrub form despite frequent browsing and "represents a viable strategy to remain a component of the landscape."⁴⁶

Another research project led by Bill Romme compared aspen sprout density and browsing intensity in 6 burned and 12 unburned aspen stands.⁴⁷ In 1990, the highest density of sprouts was found in the burned stands, but by the fall of 1991 they were approaching the density of the unburned stands. There were no significant differences among the sites in the percent of sprouts browsed by ungulates; the percent was very high (mean 45-75%) both years, and the sprouts were generally short (mean height 21-35 cm).

Based on their observations during the first five years after the fires, Renkin and Despain also concluded that although some aspen clones demonstrated prolific sprouting, most of the burned aspen will not regenerate a forest overstory. "Simply burning aspen does not ensure adequate densities and growth rates to overcome herbivory."⁴⁸ Five to seven years post-fire, the shrub aspen appeared to be very similar to their pre-burn condition.

Although Kay and Wagner came to similar conclusions about the lack of improvement in Yellowstone aspen following the 1988 fires, they were convinced that the aspen decline was due to elk browsing.⁴⁹ On 22 plots they had measured before the fires, burning stimulated abundant aspen suckering but not growth in height, stem density, or clonal spread. On "tree-



Counting aspen seedlings, August 1989.

type” aspen that were killed by the fire, the suckers grew significantly taller and were produced at significantly greater densities than on shrub-aspen, a result that Kay and Wagner believed was “probably related to clonal vigor,” because “tree-type aspen is in better condition than shrub-aspen.”

Kay and Wagner found that the shrub-aspen on their burned plots were about as tall in 1992 as they had been before the fires, and long-term aspen sucker height on the northern range appeared to be primarily a function of snow depth, which limits elk browsing. Shrub aspen located along streams or in other areas with supplemental moisture “could not grow into trees even after they were burned, suggesting that climatic effects are unimportant.” Kay has also pointed out that if climate were a significant factor, the condition of aspen in exclosures would be the same as outside.⁵⁰ He believes that the current dieback of aspen clones in Yellowstone and other Rocky Mountain parks is due to a combination of higher elk densities and a decrease in fire occurrence.

Sexual reproduction in aspen is very unusual, especially in the present climate of the northern Rockies. The tiny seeds may be dispersed over long distances by the wind in May and June, but seed production varies greatly from year to year and the seeds contain so little food that they remain viable for only a few weeks after their release. They must find bare mineral soil where they can put down roots quickly, consistent moisture to grow leaves to make food, and no other plants with which they must compete for sunlight for several years—a combination of conditions rarely found in Yellowstone. Its original groves of aspen may have become established at the end of the last Ice Age, when glaciers were melting and the land was wet and bare of plants.⁵¹

Yet thousands of seedlings appeared in different burned vegetation types in 1989, including sites located several kilometers from and at higher elevations than the nearest aspen clones. Bill Romme believes this could be due to the unusual coincidence in 1989 of prolific seed production, extensive burned areas providing bare soil and reduced plant competition, and moist weather in spring and summer.⁵² In subsequent years, not all of these conditions were present, and little or no aspen seedling establishment occurred. Spring and early summer were wet in 1992 and 1993, but plant cover had increased substantially in burned forests by that time. Romme found that aspen seedlings were very patchily distributed throughout the park in 1993, but the greatest concentrations (6 to 340 plants per hectare) were located in burned forests along the Madison and Firehole rivers, east of mature aspen stands growing outside the park’s west boundary. Their genetic diversity is greater than that of mature clones sampled on the northern range, with which they have little genetic similarity.

Renkin and Despain noticed that the establishment sites of aspen seedlings usually had deep ash deposits with abundant moss, suggesting that the fires had enhanced soil moisture-holding capacity and retention in these places.⁵³ They also found about 30 aspen saplings in each of two forest areas that had apparently germinated during the first few years after fires in 1979. Although browsed many times, they had attained heights of 30 to 45 cm.

“The only known way for shrub-aspen to grow back into the types of aspen communities that existed on Yellowstone’s northern range ca. 1870 to 1890 is if all ungulate browsing were excluded for 100 years or longer.”

— Kay and Wagner, 1996

The unusual sex life of aspen.



Research exclosure around aspen seedlings, July 1992.

Survival of the fittest aspen.

In the fall of 1989, Renkin and Despain set up transects in and outside an elk enclosure. They estimated that the initial seedling densities ranged from 500 per hectare to more than 1,000 per square meter. Although browsing caused a significant decline and density generally decreased, all sites still supported aspen seedlings in 1993 and seedling height had increased. Root sprouting was observed in the second growing season on seedlings where the stem had been destroyed by browsing. The relative density of aspen and lodgepole pine seedlings that germinated in 1989 remained about the same, but where lodgepole pine were present, the aspen were two to four times taller than the lodgepole pine.

To document patterns in aspen seedling distribution and abundance, another project involving Bill Romme and Marcia Turner set up belt transects and elk enclosures on portions of Yellowstone's subalpine plateau that had been burned by crown fire.⁵⁴ The most important variable in predicting seedling density was geographic location, followed by fire severity and the size of the burned patch. Seedlings were more abundant in more severely burned areas, and in small and moderate-sized rather than large burned patches. In the late summer of 1991, the researchers mapped the 559 pioneer aspen stems found in eight plots that had been established in an area of crown fire adjacent to a wet meadow at Fern Cascades. Increases in density and height were documented in 1991–92 despite frequent browsing by voles, mice, elk, and moose. Recruitment of new stems greatly exceeded mortality from the summer of 1992 through the summer of 1993. As of 1996, the aspen stems were still elongating slowly (a few centimeters a year) and increasing in density in some places despite browsing on at least half of the stems each year.

"We cannot know whether the newly established aspen seedlings will persist for the next 100 or more years. Our data do show, however, that the seedlings have survived the first eight years, that they are elongating slightly and increasing in density in at least some places, and that they are establishing new clonal population structures. It is possible that all of the new genets will perish in some future drought year or during a period of higher browsing pressure."

— Romme et al., 1997



Where no aspen has gone before:
submerged seedlings at Swan Lake Flats, 1993.

In addition to stimulating aspen suckers, providing bare ground for aspen seedlings, and enhancing soil moisture, fires may assist aspen growth by toppling conifers that protect aspen from ungulate browsing. That was the hypothesis of two researchers from Oregon State University, William Ripple and Eric Larsen, who measured aspen in and around 28 "jackstraw piles" at least 0.8 m in height on the northern range.⁵⁵ They found that during their 1998 sampling period, suckers protected by fallen conifer barriers were, on average, twice as tall as adjacent unprotected suckers.

The debate continues on the relative importance of fire, browsing, climate, competition with other plants, and adverse site conditions as factors limiting aspen growth. But the consensus among researchers seems to be that if for any reason the post-fire seedlings do not grow substantially taller, they are likely to be eliminated from Yellowstone's high plateaus when the post-fire lodgepole pine outgrow them or the climate becomes adverse. In most of the burned forests that now have aspen seedlings, canopy closure could begin to occur in about 40 years and any small aspen plants would likely die from shading.

In the low elevation burned areas of the northern range, elk browsing and trampling are likely to keep seedlings at reduced heights, comparable to trends observed with aspen suckering. However, based on the evidence shown in their paired transects on the northern range, Renkin and Despain proposed that the post-fire aspen seedlings that had established in an elevational zone between 1800 and 2300 m, "particularly within cold-air drainage microsites," had "demonstrated the greatest potential to achieve sexual maturity."⁵⁶

Other Vegetation

Like Yellowstone's trees, most other types of vegetation in the park were not killed by the fires; the portion above ground may have been burned off, but the roots were left to regenerate. The regrowth of Yellowstone's plant communities began as soon as the fire was gone and moisture was available, which in some sites was a matter of days. In dry soils, the seeds and other reproductive tissues had to wait until moisture was replenished the following spring, when yellow arnica, pink fireweed, mountain hollyhock, and blue lupine flowered in burned areas. New seedlings grew even in the few areas where the soil had burned intensely enough to become sterilized. Plant growth was unusually lush in the first years after the fires because of the mineral nutrients in the ash and increased sunlight on the forest floor. Moss an inch or more thick became established in burned soils, and may have been a factor in moisture retention, promoting revegetation and slowing erosion. In some areas such as Blacktail Plateau, such moss was still evident a decade later.

Even in large patches of burned forest, most herbaceous plants came from resprouting survivors and the seeds they provided rather than from dispersed seed from surrounding unburned areas. Monica Turner concluded that differences in depth distribution of rhizomes and seed banks in the soil may therefore be the most important factor in determining post-fire resprouting of individual plants and species.⁵⁷

After sampling nine patches of burned forest in three park locations in the summers of 1990–93, Turner's research team found that the response of herbaceous species that had been present before the fires also varied according to burn severity and patch size. Some species (lupine, grouse wortleberry, and elk sedge) showed a negative relationship between sprout density and fire severity, while others (fireweed and heartleaf arnica) achieved greater densities in more severe burns. Lupine appeared relatively poorly adapted to fire, having heavy seeds with limited dispersal capabilities that require scarification to ensure rapid germination. It sprouted in many areas of the park after the fires, but by 1993 lupine was rare or absent in Turner's study sites if it had been absent before the fires or killed by them.

The aptly named fireweed, in contrast, survives fire in the form of rhizomes (underground horizontal stems) that can live beneath the forest floor for years, awaiting a sunlit opening in which to sprout and produce quantities of seeds that may disperse over hundreds of kilometers and quickly germinate in other open sites. Fireweed spread profusely in the first summer after the fires and appeared to peak in 1991, when in many areas it grew in thick patches of waist-high flowers. Then as competition with other growing plants increased, fireweed declined.

As a way to assess the productivity in four previously forested sites, in July 1997 Turner's research team measured the cumulative new biomass for that year (referred to as "above-ground net primary production" or ANPP) of the lodgepole pine and herbaceous components.⁵⁸ All four of the one-hectare sites had been "fully stocked with trees" before the 1988 fires, but they now represented four different types of early post-fire succession as measured in terms of lodgepole pine sapling density: an "infertile non-forest" (fewer than 100 stems per hectare); a "fertile non-forest" (1,000 stems per hectare); a low-density forest (20,100 stems per hectare); and a high-density forest (62,800 stems per hectare). As expected, the tree ANPP generally reflected sapling density, but the herbaceous ANPP was comparable in the infertile non-forest and the more intensely competitive environment of the high-density pine stands. Herbaceous ANPP was also comparable in the fertile non-forest and the low-density pine stand, suggesting that during the early stages of succession, areas dominated by herbaceous vegetation can be as productive as areas returning as forest.

Forest Herbs



Arnica cordifolia
Heartleaf arnica, 1991.

Benjamin Tracy, a doctoral student at Syracuse University working under Sam McNaughton, found that herbaceous plants growing in burned forest in the Grant Village area produced almost three times more biomass than those in nearby unburned forest.⁵⁹ But this striking disparity, evident even five years after the fires, was mainly due to one grass species, blue wild-rye (*Elymus glaucus*) that grew in the newly sunlit forest understory. He found no difference in biomass when comparing burned and unburned meadows in the same area.

Grasslands and Meadows

Most of Yellowstone continues to be considered “forested,” even though some of the post-fire forests are comprised mostly of seedlings and saplings. About 6% of the park is still sagebrush grasslands, found primarily on the northern range, which has a warmer, drier climate than the rest of the park, and 7% is higher elevation meadows.⁶⁰ Although they accounted for an even smaller portion of the total area that burned in 1988, these grasslands and meadows were important to assess for fire effects because they are an essential source of forage for elk, bison and other large herbivores.

Although damper areas are primarily vegetated by bearded wheatgrass, sedges, and introduced species such as Kentucky bluegrass, the low-elevation grasslands are often dominated by big sagebrush (*Artemisia tridentata*), one of four species of sagebrush that are present in the park, appearing with an understory of native bunchgrasses and forbs. Sagebrush is especially important in parts of the northern range that remain relatively free of snow, where it provides forage for mule deer and pronghorn as well as elk throughout the winter. Sagebrush communities also provide security and thermal cover for ungulates and other animals. Big sagebrush is not tolerant of fire, as the volatile oils in its leaves cause it to burn intensely. Unable to resprout from the root crown as do many other shrubs, sagebrush is greatly reduced after a fire, and the reduction concentrates animal browsing on the surviving or newly reestablishing plants. Any sagebrush that survives the fire produces abundant seeds that germinate readily, but sprouting grasses and forbs dominate in burned areas until the new sagebrush seedlings become established and grow to maturity, which may take up to 30 years.⁶¹

Many studies have shown that by removing plant litter, fires can increase the productivity of grasslands and alter the foraging behavior of large grazers like elk and bison.⁶² In the absence of both fire and significant grazing activity, the accumulation of litter may reduce plant productivity by insulating the soil from sunlight and precipitation, and slowing the decomposition of organic material that provides nutrients needed by the plants. But as with other aspects of post-fire ecological response in Yellowstone, researchers found that “recovery” means different things on different grassland sites.

Using a combination of visual estimations and clipping samples, Evelyn Merrill and Ronald Marrs of the University of Wyoming measured the biomass at 61 burned and unburned sites in grassland habitats during two-week periods for three summers starting in 1989. Vegetation was classified as “green graminoids, green forbs, and standing dead herbaceous material.”⁶³ Although the green forb biomass was significantly higher on burned sites in 1990, they found no significant differences in total green biomass between the unburned sites and those of different burn intensities, and the total herbaceous biomass at all sites was within the range of variation that Merrill had documented for the same area in 1987.

During the 1993 growing season, Ben Tracy compared four sagebrush grassland areas near Hellroaring Creek with different fire histories: one area had burned in 1988, one in 1992 (a deliberately set experimental burn of about 500 hectares), one in both 1988 and 1992, and one not at all in recent history.⁶⁴ He found that grasses and sedges produced more above-ground biomass on the burned sites than on the unburned sites. Tracy suggested that the rate at which primary production in sagebrush grasslands recovers from fire may be affected by the patchiness of burned sagebrush, ungulate inputs (nutrients in urine and



Artemisia tridentata
Big sagebrush

feces that stimulate more production on burned than unburned soils), and the fire-induced sprouting of lupine, which is unpalatable to elk and may deter them from using burned areas. (See “Elk and Bison,” page 70.)

Where moisture conditions were favorable, the regrowth of grasses after the fires frequently brought significant increases in plant vigor and standing crop, especially for perennial bunchgrasses. However, Meagher and Houston found that although species composition roughly mirrored pre-burn conditions, in some burned subalpine meadows and herblands that have relatively short growing seasons and cool temperatures, the standing crop was lower than in unburned areas two to four years post-fire.⁶⁵ Sampling biomass in 1992 and 1993, Tracy found no significant difference in biomass between burned and unburned meadows in the Grant Village area that are interspersed with conifer forest.⁶⁶

Speaking of Wide Open Spaces

Botanists use a variety of terms to describe Yellowstone's northern range: sagebrush grassland, sagebrush steppe, shrub steppe, or bunchgrass steppe—all of which refer to similar plant communities. Sagebrush (*Artemisia*) is the fragrant, grayish-green shrub that is commonly one or two feet tall (though it may reach five feet); its tiny yellow flowers do not appear until August or September. “Bunchgrass” refers to a number of grasses (family Gramineae) that grow in tight clumps and regenerate each year from deep roots.

But as you head up into higher, moister areas of the park, the distinctions get more complicated. “Meadow” generally refers to an area that may have many of the same species as a sagebrush grassland, but is usually smaller in extent and, because of factors such as soil and precipitation, produces more plant biomass. Compared to a “sedge bog,” which usually has water at the surface or may even float on a lake, a “sedge meadow” is drier, with water below the surface during a large part of the growing season, and therefore contains different plant species. (Unlike grasses, which usually have a round stem, sedges belong to a plant family with stems that are triangular in cross-section.)

“Subalpine meadow” refers to an elevation zone just below the timberline, while “montane meadow” is a more general term encompassing any relatively high-elevation meadows. “Herblands” are also areas that contain non-woody plants that die back at the end of the growing season, but they are dominated by taller broad-leafed plants instead of grasses and sedges. Although it may have the same plant species, a “forest park” generally refers to an opening in a forested area that is smaller than an herbland.



Bull elk near Lava Creek, November 1990.

Willows

Long they may wane.

After the 1988 fires.



Enticing to elk and moose.

The distribution of willow in the park is largely defined by elevation and precipitation. Although many individual willow plants may be found scattered along stream banks at lower elevations, nearly all of the park's willow communities are located in areas that are above 7,000 feet or receive more than 20 inches of precipitation a year.⁶⁷

Willow have persisted in deep-snow areas of the park such as the upper Yellowstone River delta, and colonized active floodplains and some localized wet sites. But evidence from pollen pond sediments⁶⁸ and photographic comparisons suggests that they have declined about 60% during the last century at both high and low elevations throughout the park, and been replaced by coniferous forest, sedge meadows, and other herbaceous vegetation. Declines were especially pronounced during the prolonged drought of the 1930s and on ungulate ranges where they have been heavily browsed. As with aspen, similar changes can be seen in photographs taken outside the park, and the decline in willow has been attributed to elk herbivory, beaver declines, a warmer and drier climate, and fire suppression.⁶⁹

Willow are highly palatable to elk, and are browsed on by Yellowstone's far smaller moose population. Frank Singer, now with the U.S. Geological Survey at Colorado State University, found that about half of the willow stands on the northern range were "browsing suppressed," being only half as tall as "unsuppressed" willows, which averaged 80 cm in height.⁷⁰ And because they produce fewer of the compounds that serve as defense mechanisms (through offensive odor or taste, or by disrupting herbivore digestion), suppressed willow become even more vulnerable to browsing. Meagher and Houston have noted that some changes were to be expected with the first appearance of wintering moose on the northern range early in the 20th century; willow communities in Jackson Hole underwent similar changes when colonized by moose.⁷¹

It has also been suggested that the park's previous policy of fire suppression increased the abundance of conifers and big sagebrush on the northern range at the expense of willow.⁷² Fire has been known to increase willow production, vigor, and recruitment by stimulating sprouting and eliminating other vegetation that reduces soil moisture. Prescribed burns are considered an appropriate tool for land managers to use in promoting willow production. Although the riparian areas where most of Yellowstone's willows grow are generally too wet to burn and the fires of 1988 often skipped over them, even where they did not, evidence of better days ahead for Yellowstone's willow are hard to come by.

In connection with his study of moose on the northern range (see page 76), in the spring of 1988 Dan Tyers of the U.S. Forest Service set up 265 plots to monitor eight willow communities.⁷³ Of the 46 plots that burned that summer, 18 had willow reestablished by 1997. However, in 1992 a mudflow from a burned hillside buried all 35 plots on a site that had partially burned in 1988, and no willow had reestablished there by 1997. The reduction in willow available for browsing because of the fires and drought stress increased the browsing pressure on the surviving stands, which may have further increased their mortality. On plots where willow were still present at the end of his study period, Tyers determined that the average number of twigs produced per plot declined in 1989 and slowly returned to pre-fire levels within about seven years, but overall, more willow had died from one cause or another than were reestablished, and fewer twigs were available for browsing.

Comparing willows at burned and unburned sites on the northern range sites and at Black-tail Creek, Jack Norland of North Dakota State University observed "no positive stature response" after the fires of 1988.⁷⁴ Willow protein and digestibility, leaf size, and shoot length increased dramatically, but the effect of burning on willow production varied considerably, with more above-ground biomass in some places and less at others. The difference may have been due to fire intensity, for Norland observed that willow recovery was minimal at other northern range sites where the soil had been extensively heated in 1988.

At the Blacktail Deer Creek site, where the organic matter had been somewhat moist or was not as deep, the shoots from burned willows were significantly longer, the leaf surface areas about twice as large, and shoot weights were more than twice those of unburned willows. Yet apparently because of the higher protein levels and generally higher digestibility of willow at burned sites, ungulate herbivory increased so much that by three years post-fire, all of the willows at burned sites were shorter than those at unburned sites.

To assist the long-term study of elk impacts on willow, the National Park Service constructed several exclosures around willow on the northern range in 1957 and 1962. Based on data collected in and outside the exclosures in August 1988, Steve Chadde and Charles Kay found no indications that burning would cause resprouting willows to “grow so fast or become so chemically defended that they could grow beyond the reach of elk and reform tall-willow communities.”⁷⁵

Frank Singer also found that even after protection from ungulates for more than 30 years, previously suppressed willows produced far less above-ground growth than tall-willow communities and showed no community expansion.⁷⁶ But he believed that the suppressed willows were located on sites with inherently lower growth potential. In a subsequent study with several other USGS scientists, he compared willow communities in Yellowstone and Rocky Mountain national parks, which have had similar elk densities (11-16 elk/km²), rates of herbivory (26% to 28% of the willows’ annual growth), beaver declines since the 1930s, and a long-term trend toward warmer, drier weather on elk winter ranges.⁷⁷ They found that annual growth was 250% greater and that the willow shoots were 100% heavier and 41% longer in Rocky Mountain National Park than in Yellowstone. To assess the impact of browsing, willows in both parks that had been protected by an exclosure for at least 30 years were clipped from 1993 through 1995. During this period, the Rocky Mountain willows maintained their rate of annual growth, but the Yellowstone willows did not. Singer believes that the Rocky Mountain willows compensated better for elk herbivory and mechanical clipping because of better growing conditions for elk, i.e., more precipitation, more beaver dams in drainages, and probably higher water tables near streams.

Singer concluded that although high elk density was a major factor, and perhaps the most important factor, ungulate herbivory alone does not explain willow declines on the northern range. He speculated that in addition to the drier climate, the relatively larger beaver decline in Yellowstone may have exceeded a threshold value needed for willow persistence and recruitment. Active beaver ponds enhance conditions for willow growth by raising water tables, flooding willow stands, and increasing the input of nitrogen and phosphorous into the system, and abandoned beaver ponds can provide excellent establishment sites for willow. Common on the northern range until at least the 1920s, beaver are rare there today. Their decline has been also been attributed to climate change and to reduction in habitat and food sources because of elk browsing.

Regardless of the elk population, Singer believes that some willow and aspen declines were to be expected in Yellowstone and Rocky Mountain national parks because of the long-term trend toward aridity, and if this trend hastened beaver declines, then the effect of aridity on willows and aspen would have been exacerbated.

When protected from elk.



Moose in Willow Park, 1986.

Exotic Plants

Early in the 20th century, when less was understood about the potential impact of introducing non-native species, hay meadows were cultivated in the Lamar Valley and along Slough Creek for park horses. Some willows were removed, and non-native grasses such as common timothy (*Phleum pratense*), smooth brome (*Bromus inermis*) and crested wheatgrass (*Agropyron cristatum*) were seeded. Common timothy, which can be dispersed by the presence of even minimal wildlife, is now found widely throughout the park on sites where it mixes with and can eventually displace the native alpine timothy (*Phleum alpinum*). Such misguided introductions of non-native species have been augmented by the growing number of uninvited invaders such as cheatgrass (*Bromus tectorum*) and spotted knapweed (*Centaurea maculosa*).

Although the presence of non-native plants in the park had been limited primarily to areas adjacent to roads, park structures, and other human activities, the 1988 fires created corridors into backcountry areas which they might quickly invade. Firefighting activities also scarified the soil, which could increase its receptivity to alien plants, especially if off-road vehicle use inadvertently transported the seeds of species such as leafy spurge and spotted knapweed, which are a problem in many parts of greater Yellowstone. Non-native plants have continued to increase their presence in the park's landscape since 1988, but with the possible exception of Canada thistle (*Cirsium arvense*), there has been little evidence that either the fires or the corridors created by fire lines have made much difference.

Although often seen along park roads and trails, the Canada thistle had not yet invaded most of the area that burned in 1988. But it soon appeared in places that had been used for fire suppression activities and was expected to spread to newly burned patches through seed dispersal. When their study ended in 1993, Monica Turner's group found that Canada thistle was still increasing in all nine sites of varying burn severities.⁷⁸ The density of Canada thistle and prickly lettuce (*Lactuca serriola*), an exotic biennial that had not been conspicuous in unburned forest, was greatest in severely burned areas. But prickly lettuce had a negligible presence in light surface burns and peaked in the stand-replacing burns in 1991. Over the short-term, Turner concluded that areas of crown fire provided the best colonization sites for opportunistic species (both native and exotic species that were absent or only incidental before the fires), "but we do not yet know how long they will persist."



Phleum pratense
Common timothy
(non-native)



Phleum alpinum
Alpine timothy
(native)



Cirsium arvense
Canada thistle
(non-native)

The fittest survive

From the study of fossils, we know that Yellowstone has been home to very nearly the same assemblage of mammals for at least the past 2,000 years, during which several major fire events similar to those of 1988 occurred. This continuity suggests that the park's wildlife has not been significantly affected by fires over the long run, although conditions that favor one species during one year may change the next. Twelve years after the fires of 1988, the only animals for which there is evidence of a population decline as a result of the fires are moose and snails, but only a small number of species has been studied for possible impacts. For example, although annual survey counts suggest that the fires had little or no effect on the Yellowstone bison herd, much less is known about the number and distribution of black bears, whose population is far more difficult to estimate.

Foraging While Yellowstone Burns

Extensive fires cause habitat alterations and may displace animals from their customary ranges, but they do not kill significant numbers of wildlife. Except under the most extreme conditions of fast-moving fire fronts, most appeared indifferent to the flames and, like human grazers at a 1950s cocktail party, many continued their foraging activities even in thick smoke. Yet although Yellowstone's wildlife has had thousands of years to adapt to fire, helicopters are still an alien presence. When a noisy chopper came near ferrying a water bucket or fire crew, elk visibly tensed and sometimes bolted.

One radio-collared grizzly bear ushered her two cubs around the edge of an approaching fire storm and left the area, traveling more than 20 km during the next 12 hours. But some animals appeared curious, approaching a fire and watching trees burn; a black bear was seen sticking his paw into the flames of a burning log. Another female grizzly remained in the path of the fire storm and foraged in the burned area for several days.



Bull elk, August 1989.



Why did the bison cross the road?
One of the many questions not answered
by researchers in Yellowstone.

As soon as the fires began to subside, extensive surveys by foot, horseback, and helicopter located 261 carcasses: 246 elk, 9 bison, 4 mule deer and 2 moose.¹ Although this count probably included all of the large groups of carcasses, which were conspicuous because of the scavengers they attracted, isolated carcasses may have been missed. Even assuming a large undercount, the number of mortalities would be insignificant relative to the size of these animal populations and the thousands that die during a typical winter.

All of the carcasses were found in sites where the fire fronts were estimated to have exceeded 2 km in width and 4 km/hr in rate of advance. Most of the elk fatalities occurred on the Blacktail Plateau when part of the herd was trapped by a flank of the North Fork fire. Based on the presence of soot below the vocal cords, the cause of death in 26 of the 31 examined carcasses was assumed to be smoke inhalation.² Only two of these animals, one elk and one bison, showed clear evidence of hav-

ing died as a result of burns. Examinations of the other three carcasses were inconclusive because the tracheal lining was completely burned, which could have happened after the animal had died from some other cause. One elk was euthanized because it had been severely burned and was unlikely to survive.

Most ungulate species in Yellowstone were more affected by the drought and the relatively severe winter that followed than by the fires. Although none of their winter range burned, mule deer counts declined 19% and pronghorn antelope 29% during the winter of 1988–89.³ Park ornithologist Terry McEneaney recorded an unprecedented 80 bald eagle sightings that winter in Yellowstone, as they took advantage of the scavenging opportunities.

Elk and Bison

After studying the population dynamics of elk and bison in Yellowstone over a 15-year period, Mark Boyce of the University of Wisconsin and Evelyn Merrill of the University of Wyoming had found that three factors accounted for most of the year-to-year variation in growth rates: summer forage quality, winter severity, and population density.⁴ They expected that the greatest impact of the fires on ungulates would therefore be on the quantity and quality of forage available to them in subsequent years.

Although elk mortality rose to about 40% in the winter of 1988–89, the multiple confounding factors make it difficult to determine how much of this was due to reduced forage because of the fires. An estimated 21,000 elk began the winter on the northern range, about 20% of which had burned; another 1,000 elk were on the more heavily forested range in the Madison-Firehole area, of which 40% burned. But even without the fires, several factors would probably have led to high elk mortality that winter.

- **Summer drought.** Forage production was 60–80% below long-term averages on the summer range of the northern elk herd and 22% below on their winter range.⁵
- **Herd density.** When the winter of 1988–89 began, the elk and bison herds were relatively large because of the two preceding mild winters, when elk mortality was estimated to be less than 5%. Because of the large herd size and small forage production, elk and bison migrated to winter ranges in larger numbers and earlier than usual. More than half the northern elk herd left the park for only the third time since 1916.⁶ A disproportionate number of the elk mortalities during the fires and the following winter were adult bulls, apparently because they preferred heavily timbered slopes where they were more likely to get caught in a fire front, and because the older bulls were less likely than the cows to migrate from their established ranges in the winter.

Mortality after the fires.

- **Hunting harvest.** The large migration resulted in a large elk harvest by hunters: 2,400 elk were taken in 1988 (about 14-16% of the population), compared to a 1975–90 average of about 1,000 elk.⁷ A special hunt sponsored by the state of Montana also removed 569 bison that had migrated north of the park.
- **Winter severity.** Based on their differing physiologies and forage needs, Phil Farnes has developed indices of winter severity for elk, bison, mule deer, and pronghorn that combine measurements of air temperature, snow accumulation, and forage production during the previous growing season.⁸ On this scale, the winter of 1988–89 was the most severe for all ungulates since at least 1982. Older animals that had been able to survive the preceding mild winters finally succumbed.

Park managers considered but ultimately turned down appeals from concerned citizens to feed the elk and other wildlife during the winter after the fires. The use of artificial feeding sites causes animals to congregate at them, increasing the spread of disease, and promotes the survival of animals that do well on the supplied food, which are not necessarily the fittest animals for Yellowstone.

Frank Singer of the park staff worked with Glenn DelGiudice of the Minnesota Department of Natural Resources to assess the physiological status of the northern range and Madison-Firehole elk herds for three winters starting in 1987.⁹ A chemical analysis of urine in snow indicated that nutritional stress among elk was relatively mild the winter before the fires and severe during the first post-fire winter; by the second post-fire winter, nutritional restriction was milder and similar to that observed before the fires.

Nutritional stress.

A group of researchers led by Monica Turner and Yegang Wu, then both at the Oak Ridge National Laboratory in Tennessee, developed a simulation model to study the effects of winter severity and fire size and pattern on ungulate survival on the northern winter range.¹⁰

Using this model, they found that fire size and pattern would have no appreciable affect during mild winters. However, when the first post-fire winter snow conditions were moderate to severe (as measured by snow depth and water equivalent), the larger the fire, the greater the ungulate mortality, with calf mortality approaching 100% in a scenario that replicated the most severe winter conditions in the last 50 years.¹¹ A comparison of mortality rates in the winter of 1988–89 using actual elk numbers and winter conditions indicated that elk calf mortality was about a third higher because of the fires, but overall elk mortality increased only 7%.

Coughenour and Singer developed a model that simulates ecosystem influences on plant-ungulate interactions in order to assess ecological carrying capacity (ECC). According to this model, the northern range could support a mean of 21,800 elk during the period 1968–87.¹² The amount of winter forage per area varies with summer precipitation, and the area available for winter foraging varies with snow cover. Using these measures, the ECC declined 80% in the winter of 1988–89, dropping to 4,350 elk, but less than 5% of the decline was due to the fires, which had even less effect in subsequent years.

In a study of radio-collared elk calves from 1987–90, Singer found that the number lost to predation doubled during the first summers after the fires.¹³ Bears, coyotes, eagles, and mountain lions may have been searching harder for calves because other foods were less available, and the calves may have been less well hidden because about a third of their tall shrub and conifer cover had burned in the fires.



Elk near Madison River during the fires.

Elk as nutrient recyclers.

Although the loss of forage caused by late summer fires can result in high ungulate mortality the following winter, studies elsewhere in the western United States have generally shown that forage quantity and quality may be enhanced in subsequent years, making larger herds possible as a result of fires.¹⁴ But like fire, grazing animals are themselves agents of nutrient cycling. Whereas fire removes accumulated plant litter, the removal of the standing crop by ungulates before it can die slows the accumulation of litter. Whereas fire releases the nutrients in organic material by turning them to ash, ungulates achieve a similar effect by converting plants to dung and urine, improving forage growth and quality. Fire, elk, and habitat become interrelated in a way that can make it difficult to determine which came first, the elk dung or the nutritious forage. Ben Tracy found that ungulate urine had a greater impact in stimulating above-ground production on burned soil than on unburned soil.¹⁵

Based on patterns of plant succession in lodgepole pine, sagebrush grasslands, and sedge meadows after clearcutting or burning that had been documented in other studies, Boyce and Merrill predicted in 1989 that two fire benefits for ungulates—the increased nutrients in forage on burned sites and better foraging efficiency because the dead standing biomass and litter had been removed—would be short-lived, lasting less than three years as the fire-added nutrients were reabsorbed and dead plant litter built up again.¹⁶ They believed the major impact of the fires on ungulates would be in the availability of various forage species, including an increase in forb diversity and production in lodgepole pine communities. The reduction in big sagebrush (*Artemisia tridentata*), which can only reestablish through seedling production, was also likely to increase the presence of more nutritious forbs on the northern range (see page 64). Boyce and Merrill expected that fire-induced improvements in forage quality would peak in 1994, but acknowledged that “we cannot know the extent to which ungulates will use the burned areas and how much better their diets will be compared to pre-fire diets.”

Do elk prefer burns?

How did the fires affect forage in Yellowstone after the fires, and did these changes affect the ungulate populations? Although several studies were done during the first few years after the fires, the results were highly variable, with some researchers finding changes in forage as a result of burning and others not. While such disparities may indicate shortcomings in research methodology, they could just as well reflect the variation of ecological responses across a heterogeneous landscape. Depending on factors that may not have even been thought of yet, the forage quality at one site may improve the first year after burning, in the second year after burning at another site, and not at all at a third site of similar elevation and plant community. About the only certainty is that the removal of forest canopy in many places has resulted in more foraging areas for ungulates to choose from.

In October 1990, a group of researchers from academia and the Oak Ridge National Laboratory compared the quantity and quality of forage at 38 locations that included burned and unburned examples of four plant communities on the northern range (wet, moist, and mesic grasslands, and canopy understory). Within each community type, they found a larger quantity of biomass on the burned than the unburned site, but no differences in forage quality as measured by crude protein and digestible fiber.¹⁷

During two 14-week periods beginning in January 1991 and 1992, the researchers monitored grazing at 15 locations on the northern range that included burned and unburned sites.¹⁸ They observed that from the beginning of February to mid-March 1991, elk and bison used burned areas more often than was expected based on their availability, but in 1992, they showed a preference for burned areas only during March. During the rest of the study period, elk either showed no preference or used unburned sites slightly more relative to their availability. Any nutritional advantage of feeding in burned areas where fire had reduced the standing dead and litter appeared to be gone after greenup began in the spring.



Poa sandbergii
Sandberg's bluegrass

In a two-year forage study that began in the fall of 1989 on the northern range, Frank Singer assisted Jack Norland of North Dakota State University and Lauryl Mack of the park staff in examining three grasses, two of them common in sagebrush habitat (*Agropyron spicatum* and *Festuca idahoensis*) and the other in Douglas-fir habitat (*Poa* spp).¹⁹ Using a similar measure of forage quality to that of the previous study, they arrived at somewhat the opposite results: better forage quality at burned than unburned sites, but no increase in biomass, which actually decreased where soil heating to a depth of 5 cm was extensive. They found that the forage quality was significantly higher in the burned sites in both habitat types starting with the fall 1989 sampling; the difference was smaller a year later, but the spring forage quality was still significantly higher at the burned sites in 1991. However, other hypotheses they were testing were not borne out by their research: the diversity of elk diet did not increase; and elk did not show a preference for the burned sites, as measured by density of pellet groups.

Sometimes they don't.

Only 8 of the 20 elk that David Vales and James Peek had radio-collared in 1987 survived the winter of 1988–89, when their diets contained more indigestible fiber and lignin from trees and less grasses and forbs than in previous winters.²⁰ Mortality was significantly related to the animal's age and to the proportion of winter home range (as defined by each elk's movements) that had burned, which varied from 0 to 82%; 12 of the elk moved out of the home range they had used the preceding two winters. However, because there was no correlation between migration date and the extent of home range burned, Vales and Peek concluded that the early migrations in the fall of 1988 were probably due to the drought rather than the fires. The elk appeared to be using burned habitat in proportion to its availability during the summer after the fires.

A study of forages on the dry, relatively unproductive bunchgrass slopes of the Blacktail Plateau from 1986–90 by Frank Singer and Mary Harter, then on the park research staff, also found that the nutritional quality and digestibility of grasses were largely unaffected by burning.²¹ By 1990, however, the burned sites were producing 20% more biomass than unburned grassland sites. Based on elk counts obtained during flights from 1986–91, Singer and Harter also determined that after 25% of the Blacktail Plateau burned in 1988 the portion of the northern elk herd using it for winter range dropped, from about 15% of the herd pre-fire to 8% of the herd in January 1989. When the number of elk there rose to 14% of the estimated herd size during the second and third post-fire winters, elk use of burned grassland sites relative to their availability also increased, but the elk were still showing a preference for unburned grasslands on Blacktail Plateau.

Isn't forage in burned areas more nutritious?

Elk avoided the burned forest sites during all three winters of the study period; the snows were deeper than in the unburned forest, and the herbaceous biomass was still 61% less in the burned forest sites during the second post-fire winter. Conifers as a food source increased from 3% to 40% of elk diets the first post-fire winter, apparently because of the reduction of other types of forage. However, pre-fire observations had shown that elk obtain less than 10% of their forage from these forested areas even when unburned, and prior studies in other locations have found that herbaceous biomass in burned forests does not rebound until six to eight years after the fires. Singer and Harter therefore suggested that greater use of burned forests by elk was more likely to be seen in subsequent years, especially during winters with below-average snow depths.

Ben Tracy found that during the first year post-fire, elk on the northern range consumed more forage at a burned site than an unburned site in the winter, but they avoided grazing in burned forest sites near Grant Village and consumed little green forage on burned northern range sites during the summer, despite their higher concentrations of nutrients than the unburned sites.²²



Poa pratensis
Kentucky blue grass

Why Yellowstone elk may prefer unburned sites.

Based on an analysis of clippings taken at each of four sites, he determined that an elk consuming one gram of forage in early spring would ingest almost three times more minerals in a site that had burned the prior summer than in an unburned site. However, when the nutrient levels were expressed per square meter rather than per kilogram, the difference between the burned and unburned sites disappeared, causing Tracy to conclude that the nutrient concentration in burned forages was more a result of the removal of standing dead biomass than of increased nutrient uptake of soil. Tracy speculated that in both of his summer study plots, the elk may have been deterred from grazing by the presence of plants they find unpalatable: blue wild-rye (*Elymus glaucus*) in the forested sites, and a large bloom of lupine (*Lupinus sericeus*) in the sagebrush grasslands.

Singer and Harter proposed that the relatively small impact of the fires on elk forage on the northern range could be attributed to the relatively cool fire front that had quickly crossed the sites with little residual burning because of the low accumulation of litter in bunchgrass communities.²³ Nearly all of the burning on the northern range occurred during a 24-hour period beginning the afternoon of September 9, when the North Fork fire made a 34-km run. Most other post-fire studies have been done on prescribed burns, which are typically hot, slow backfires in tall-grass prairies with more litter.

Three biologists from Northwestern College in Iowa documented the changes in forage and elk use in sagebrush-dominated sites that were subjected to prescribed burning in the Custer National Forest from 1984 to 1993.²⁴ They found that by removing the sagebrush, the fire increased production of more preferred elk foods (grasses, sedges and forbs) and plant protein levels, rather than overall biomass. Forage quality peaked during the first year after burning, but remained above that of non-burned sites up to nine years later. The study area is part of the winter range for the northern Yellowstone elk herd, and the researchers found that elk use of the burned sites increased from 144–680%, peaking from one to four years after burning and remaining above non-burned sites for up to nine years.

Let them eat bark.

To study the foraging habits of the Madison-Firehole elk herd, P.J. White, a doctoral student at the University of Wisconsin working under Robert Garrott, radio-collared 27 mature female elk and monitored them several times a week during the third and fourth post-fire winters.²⁵ The elk used the burned forests extensively for both feeding and bedding, but favored unburned areas relative to their availability, presumably because deeper snow accumulated in burned areas.

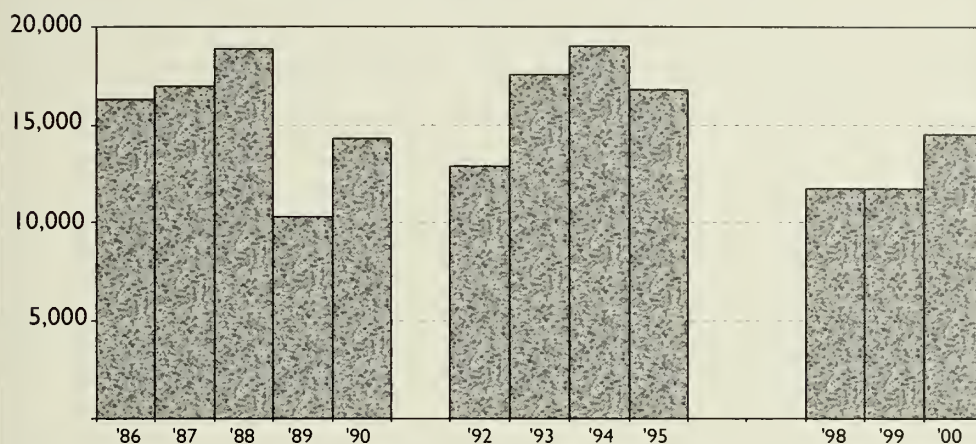
When little else is available, elk may eat lodgepole pine needles and twig tips, but live lodgepole is generally considered unpalatable because it contains large amounts of terpenes and other plant chemicals. It is generally assumed that plants produce these compounds to deter browsing. However, White and Garrott found that burned lodgepole pine bark was the third most utilized food of their radio-collared elk during the third and fourth post-fire winters, despite an apparent abundance of alternative forage, including sedges, grasses, and aquatic plants. Vales and Peek also often observed elk feeding on charred lodgepole bark.²⁶



Ben Tracy collecting elk dung.

In comparing burned to unburned dead bark, a group of researchers at the University of Wisconsin found no differences in chemical composition or digestibility, but the burned bark had lower levels of the toxic compounds that serve plants as defense mechanisms against browsing.²⁷ The bark is lower in nutritional value than most winter forage, but the elk probably ate it because it was readily available and required little exertion to obtain. Despite their change in diet, however, no substantial declines were observed in the physiological condition of White's radio-collared elk cows; they all survived both winters, and most became pregnant and calved.

Northern Range Elk — Winter Count



The elk population on the northern range is counted by the interagency Northern Yellowstone Cooperative Wildlife Working Group using aerial surveys.²⁸ Although there was evidence of a significant decline during the winter ending in 1989, that year's count (10,265) is relatively inaccurate because of poor survey conditions. In some years, no reliable counts could be made.

Pronghorn

Yellowstone's pronghorn (often called antelope) are one of the few herds that has been able to largely maintain its historic migration pattern. It was believed to number up to 2,000 in the early part of the 20th century, but was subject to culling in the 1940s and 1950s, and after dropping below 200 was estimated to be nearly 500 in the spring of 1988, and close to 600 in 1991. Since then, the herd size has declined precipitously, to a count of only 205 animals in April 2000. The reason is not known, but predation by coyotes and other carnivores, inbreeding, and loss of winter range are possible factors.

The range that is occupied year-round by about 80% of the herd, generally along the park's northern boundary, did not burn in 1988. However, from about mid-March to mid-November, the rest of the herd migrates to a higher summer range, further east in an area along the Yellowstone and Lamar rivers, much of which did burn. Based on pre-fire location data, M. Douglas Scott and Hannes Geisser concluded that the pronghorn almost always preferred non-forested range or mountain meadow habitats.²⁹ The most common shrub on the summer range was mountain big sagebrush, while Wyoming big sagebrush and rubber rabbit-brush dominated the year-round range.

To determine if the 1988 fires affected the pronghorn's seasonal movements, Scott and Geisser compared migration patterns derived from historic and recent pre-fire sightings to visual observations they made along roadways and telemetry data from 73 radio-collared animals. Pronghorns were seen in at least nine unusual places in the spring and summer of 1989, eight of them entirely outside the typical pronghorn year-round or summer range, all of them in areas that had burned. These temporary shifts may have been prompted by the opening up of the forest by fire, permitting new migration routes. But such sightings had declined to one by 1993. The pronghorn did not appear to avoid using burned grasslands, probably because their preferred summer foods, forbs and grasses, quickly regrew on burned sites.



Antilocapra americana

The Shiras moose, one of four subspecies recognized in North America, is a relatively new arrival in Yellowstone, having emigrated into the area sometime in the 19th century. Although apparently common in the southern part of the park by the 1880s, moose were still rare on the northern range in the first years of the 20th century.³⁰

Moose habitat is often associated with forest edge and early successional stages of forest that provide conditions favorable for the growth of deciduous shrubs. Studies done in northern Canada and on the Kenai Peninsula in Alaska found that the habitat appeared to be optimal for moose within the first 30 years post-fire.³¹ However, in the Yellowstone area, which has few browse species that grow tall enough to extend above the snowpack, moose must survive the winter on subalpine fir. This tree is mostly likely to establish itself under a mature forest canopy, where it faces less competition from sun-loving species and is sheltered from winter snow.

Population increase after 1900.

The increase in moose population that occurred in Yellowstone after 1900 may therefore have been a result of a closing forest canopy as well as greater protection from hunting. Based on historical records, George Gruell of the U.S. Forest Service found that the number of moose in Jackson Hole, south of the park, did not rise significantly until 60 years or more after large fires and he attributed the increase to improved winter forage.³²

Compared to other ungulates, moose populations are difficult to estimate because moose are often solitary and occupy habitats where they are difficult to see from the ground or in the air. However, declines in hunting success outside the park led to a belief that the moose population on the northern range had dwindled since earlier in the century, and this view was corroborated by a low count in a 1985 horseback survey.

To find out more, in 1986 Dan Tyers of the U.S. Forest Service began a study of four areas of the upper Yellowstone River drainage that were known to include scattered areas of winter habitat used by moose.³³ At the time, these areas were mostly covered by lodgepole pine and subalpine fir and had varying abundance of willow stands; timber on some of the national forest land north of the park had been harvested. This research project, which continued to collect data on moose and their habitat through October 1999, was sponsored by the Northern Yellowstone Cooperative Wildlife Working Group, which includes the four agencies with management responsibilities for the northern range: the Montana Department of Fish, Wildlife and Parks, Yellowstone National Park, the Gallatin National Forest, and the Biological Resources Division of the U.S. Geological Survey.

Forage decline after the fires.

Tyers found that moose cope with winter on the northern range by seeking concentrations of food that require a minimum of energy expenditure to obtain. When the snow depth reaches about 80 cm, moose movement is restricted, and at 120–140 cm, it is nearly curtailed. Foraging efficiency, as expressed by the number of twigs browsed per meter traveled, was highest in areas with willow, but these become less accessible as winter progresses. Moose browsed most frequently on subalpine fir less than 5 m in height, which they found most abundantly in older lodgepole pine forests. Only two moose in the entire Yellowstone area appear to have died during and as a direct result of the 1988 fires,³⁴ but with such forests and willow stands reduced, moose have starved during subsequent winters.

One of Tyers' four study areas was not affected by the fires; each of the other three was partially or mostly burned. After the 1988 fires, the 14 moose he had radio-collared continued to be located most often in the oldest lodgepole, the oldest spruce-subalpine fir, and willow cover habitats. But the moose whose home ranges included burned areas had to increase the size of their ranges and the energy expended in foraging. Three of the moose died of starvation during the first post-fire winter, five were legally killed by hunters, and the remaining six were still alive when their monitoring ended in February 1991.

Data collected on habitat use showed that during the first post-fire winter, moose in extensively burned areas browsed on burned vegetation as well as on live lodgepole pine, which had not previously been an important food source. But overall in post-fire winters, moose depended on the remaining subalpine fir and willow, traveling less and browsing more twigs per plant compared to pre-fire. The average annual utilization of willow, as measured by the percent of twigs browsed, peaked at nearly 50% in 1989; it remained high in subsequent years but gradually declined, reaching 18% in 1997, which was close to the pre-fire average. Along with the fires and drought, this heavy browsing pressure could have contributed to willow mortality. Unlike other research on post-fire moose habitat, Tyers' study did not find an increase in shrub biomass along forest edges created by fire or logging.

Heavy pressure on willow.

To collect data on the northern range moose population, Tyers used five methods: a 177-km trail surveyed annually by horseback from 1985–99; flights conducted twice monthly from 1987–90 to locate the radio-collared moose and survey two large willow communities; daily ground observations of one willow community from April 1996 through June 1997; a survey along the 89-km road from Mammoth Hot Springs to Cooke City at least four times a month during six years from 1987–97; and eight aerial surveys conducted from 1988–92 over the general study area, concentrating on those locations where moose were most likely to be found. Although these indices of population abundance could not provide the basis for estimating the total population, Tyers believed that in combination they offered a reasonably reliable mechanism for assessing the population trend since 1985. Each method provided some evidence of a post-fire decline, with more substantial declines in areas where fire effects were more severe. For example, on the annual fall horseback survey along the Hellroaring, Buffalo Fork, and Slough creeks in an area of the Absaroka-Beartooth Wilderness where much of the moose habitat burned, the number of moose seen was 49 in 1988 and 40 in 1989, and never exceeded 20 in subsequent years.

Tyers concluded that “the loss of late successional subalpine fir patches was likely the most important reason for the decline in moose numbers” after the fires, although competition with elk for the limited availability of willow may also have been a factor. The willow on his study plots had shown some signs of recovery from the fires and drought by 1997 (see page 66), but the reappearance of forest canopies that can effectively intercept snow on winter ranges may take several hundred years. In the mean time, the moose that are surviving the post-fire winters appear to be those that can avoid excessive movement by concentrating on small islands of unburned and lightly burned habitat, or by shifting their home ranges to unburned mature conifer stands where the snow is sufficiently deep to discourage elk use.

Survival strategies.

The moose quota for the five hunting districts in Tyers' study area, which was 55 of either sex in 1986, had been reduced to 13 antlered bulls by 1998. In the first five years after wolf reintroduction began in 1995, 13 moose kills by wolves were documented in the greater Yellowstone area, 7 of them in 1999.



Alces alces shirasi

Grizzly Bears

During the fires.

Although relatively little is known about the number and distribution of Yellowstone's black bears, grizzly bears have been monitored since 1975 using radio telemetry because they are a threatened species under the Endangered Species Act. Most of the data presented here were collected by the Interagency Grizzly Bear Study Team (IGBST), whose representatives from seven state and federal agencies conduct research on the bear's population, food sources, and habitat in greater Yellowstone.

Of the 38 bears wearing radio transmitters when the 1988 fire season began, 21 had home ranges that were hit by one or more of the fires; 13 of these bears moved into burned areas after the fire front had passed, three bears (adult females without young) stayed within active burns as the fire progressed, three bears remained outside the burn lines at all time, and two adult females could not be located.³⁵ The bears in burned areas were observed feeding on the carcasses of ungulates killed in the fires, grazing on newly emerged sedges and bluegrass, digging in logs and anthills for insects, and excavating tubers and corms in surface burns. Examination of the carcasses suggested that when many were available, the bears ate only small portions of each, moved often from one carcass to another, and seldom buried anything for later consumption, as is done in times of scarcer food. In the 65 grizzly bear scats collected for analysis in October 1988, ungulates accounted for 28.6% of the volume, compared to an average of 7.7% in the fall samplings for 1979-87.

Extensive searches failed to locate the two missing radio-collared bears after fire storms passed rapidly through drainages they had been using during that summer, but one of the bears showed up in Hayden Valley in the summer of 1990, looking none the worse for wherever it was she had been. The fires had no apparent effect on the size of grizzly bear ranges, their mean rate of movement, or their choice of den sites in 1988, five of which were located in burned areas.³⁶ Based on 867 locations of 44 grizzly bears obtained from 1989-92, it appeared that the bears used burned habitats in proportion to their availability within their ranges. Although their annual ranges during this period were similar in size to 1975-87 averages, their seasonal rates of movement were consistently lower, indicating the adequacy of nearby food. Overall during the springs and summers of this four-year period, the bears grazed more frequently at burned than unburned forest sites, primarily on forbs, especially clover (*Trifolium* spp.) and fireweed (*Epilobium angustifolium*). But unburned forested sites were favored for feeding on ungulate carcasses in spring, insects during the summer, and whitebark pine seeds during the fall.

Post-fire grizzly diets.

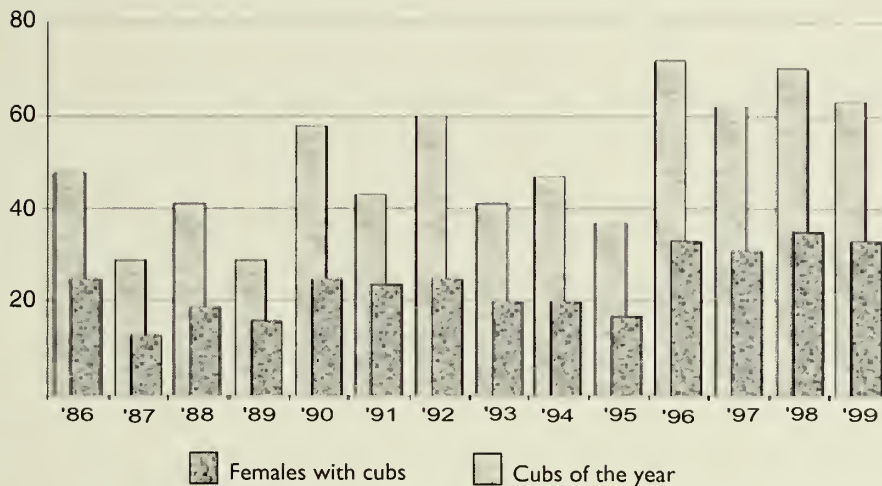


Ursus arctos horribilis

The IGBST monitors the availability of ungulate carcasses, cutthroat trout, and whitebark pine seeds as three of the most important grizzly bear foods. Although there has been some evidence of a decline in the number of cutthroat spawners in certain streams since 1988, the trend cannot be clearly linked to fire impacts (see page 98). The burning of about 28% of the park's whitebark pine forest in 1988 (see page 57) could be more significant for grizzly bears. The whitebark pine may not begin producing cones until the tree is at least 100 years old, and all of the stands used by Yellowstone grizzlies to obtain the high-fat seeds were mature before the fires. Raiding cone middens buried by red squirrels, the grizzly may forage exclusively on whitebark pine seeds to the extent they are available. But because cone production varies greatly from year to year, from stand to stand, and among trees within a stand, determining its long-term effect on the grizzly bear population is difficult. Annual IGBST monitoring of whitebark pine estimates the number of cones per tree in its study transects, not the total crop size in greater Yellowstone.

However, an IGBST research project collected data from 1984-86 on the density of red squirrel middens and grizzly bear use of whitebark pine seeds in 57 line transects on Mount Washburn, a study area that encompassed the elevational range of mature whitebark pine,

Count of Female Grizzlies with Cubs in Greater Yellowstone



(Data from the Interagency Grizzly Bear Study Team)

from 2,360 m to 2,870 m. Half of the total length of the transects burned in 1988, and the study was repeated from 1995–97, a period which had a similar pattern in average cones per tree, with a large crop preceded and followed by a small crop. Shannon Podrutzny and Dave Mattson of the U.S. Geological Survey, working with Dan Reinhart of Yellowstone National Park, found no middens in transect areas that had burned. The number of active middens per kilometer had declined 27% overall compared to the pre-fire density, and the mean size of the middens had decreased 51%.³⁷ As a previous study had shown that bears are less likely to dig up small middens, the researchers were not surprised to find that bear feeding activity in the study area (as measured by the number of excavated middens) had decreased disproportionately, by 63%.

Since the IGBST began keeping records in 1980, years with a low cone count per tree have often been associated with more frequent grizzly bear management problems. When the bears move closer to humans in search of food, they are more likely get into trouble and have to be relocated or removed from the population entirely. However, in both 1997 and 1998, when the average cone count for all greater Yellowstone transects was fewer than 9 per tree, there were also fewer than 9 captures of “problem” grizzlies, compared to the 1980–98 annual average of 15. In 1999, when the average cone count in the park was 43, only 2 grizzly bears were captured because of conflicts with human activities.

Fewer cones can mean more bear problems.

Regardless of the fires’ possible impact on the number of whitebark pine seeds, cutthroat trout, or bear captures, they have had no discernible impact on the number of grizzly bears in greater Yellowstone since 1988. The population met all three of the targets for delisting as an endangered species for the first time in 1994, and again in 1998 and 1999. As shown in the graph above, one of the targets pertains to the summer count of females who have new cubs with them. Because adult females generally have cubs every three years, the total adult female population can be estimated from this count, which is based on ground and aerial surveys. Although the species has met the recovery criteria for two consecutive years, the grizzly bear cannot be removed from the endangered species list until a strategy to secure habitat and monitor the population has been agreed upon by the various federal and state agencies involved.

Coyotes



Canis latrans

As wolves were exterminated from Yellowstone in the first decades of the 20th century, their ecological niche was partially filled by coyotes, which became the major elk predator and consumed a large portion of the available small mammal prey. Partly in anticipation of changes in the coyote population as a result of possible wolf reintroduction, Bob Crabtree and Jennifer Sheldon of Yellowstone Ecosystem Studies radio-tagged 129 coyotes on the northern range during a nearly four-year study period that began in 1989.³⁸ Comparing their own findings to those reported by Adolph Murie's pioneering research in 1940, they concluded that coyote territories are "traditional" and had not shifted since then, nor had the coyote's diet. Based on scat analysis, Murie estimated that 20.3% of the coyote diet was elk; Crabtree and Sheldon found 21.2%. Five of seven den areas documented by Adolph Murie in the 1940s were still being used, and the boundaries of 8 of the 12 territories located by Crabtree and Sheldon did not shift during their study period.

The proportion of each territory (averaging 15 km² in size) that burned in 1988 ranged from 0 to 52%, which could affect prey abundance. Ground squirrels and shrews were far more abundant in the burned than unburned sagebrush-grassland portions of the study area in 1992 and 1993, yet demographic measures such as pack and litter size appeared unaffected by burn level. However, since wolves returned to Yellowstone in 1995 (see page 85) and began killing coyotes in the battle for turf, the northern range coyote population has been substantially reduced and traditional territories abandoned. By 1998, according to Crabtree and Sheldon, "Coyote packs in this core area of wolf territories either disappeared or were in a constant state of social and spatial chaos."

Small Mammals

Small mammals are more likely to die as a direct result of wildland fires than are large mammals. The numbers involved is unknown, but rodents probably had the highest fire-related mortality of any mammal species. Although many small mammals may have escaped the fire in burrows, others probably died of suffocation as fire came through an area. Coyotes, foxes, and weasels benefitted from the loss of cover available to their prey and from scavenging on fire-killed carrion; some appeared to be attracted to fires, presumably looking for animals driven from their homes. With few islands of grass in which to hide, mice, voles, chipmunks, and squirrels became easy targets in areas of ground fire. But if the number of small mammals did temporarily decline while their predators multiplied, the increased number of predators would soon face a food shortage themselves, continuing the ongoing adjustment in the predator-prey ratio.

Roy Renkin, a biologist on the park staff, trapped small mammals for 63 days at eight burned sites beginning in September 1988 to assess immediate shifts in post-fire abundance.³⁹ He found that small mammal communities were not eliminated by fire, but did change in structure and habitat use. The redback vole, which is common in dense forests, was the most abundant species at the four lodgepole pine sites that had canopy burns. Renkin noted that this finding differed from post-fire studies in clear-cut areas, and attributed the difference to the density of downed trees present after fire in coniferous forests, which the redback vole appeared to favor as habitat. Fire suppression activities that use mechanized equipment and timber harvesting activities such as slash piling and burning, by contrast, alter some optimum downed log density and cause soil compaction or scarification that more adversely affects the vole than does burning. As the study period continued, the frequency with which animals were caught increased, suggesting that they were returning to forage in the burned areas.

The marten, which is considered common in Yellowstone, is known to prefer mature forests, especially during the winter. The coarse woody debris that has accumulated in such forests intercepts snowfall and creates "subnivean tunnels, interstitial spaces, and access

holes” that marten use to obtain prey, escape from predators, and as thermal insulation.⁴⁰ Where trees have been removed by clearcutting, marten populations have declined, as marten seldom cross large open areas that do not have some form of overhead cover, and debris left by logging tends to disintegrate within a few years.

With some of his students, John Bissonette of the Utah Cooperative Fish and Wildlife Research Unit at Utah State University examined marten use of a 10,000-hectare site that after 1988 had a mosaic of burned, partially burned and unburned cover types, mostly lodgepole pine.⁴¹ Based on trapping results, the area appeared to support from 25 to 57 marten. By studying marten tracks and monitoring 10 radio-collared animals in the winters of 1990 and 1991, Bissonette observed that the marten preferred areas of unburned lodgepole pine and appeared to avoid crossing open areas that were more than 100 meters wide, especially stands of canopy-burned lodgepole pine. Marten used areas of surface burn where standing trees remained as travel corridors, moving through them in a relatively straight line, without hunting or foraging, but did not prefer them over unforested areas. The critical factor in marten habitat selection appeared to be not the age of the trees, but the sub-canopy typical of old growth forests in which coarse woody debris offers access through the snowpack during the winter.

Given the variety of habitats and food sources used by different bird species, some find their options are improved after a fire, and others find they are worse. Whether Yellowstone may be considered “better” bird habitat overall as a result of the 1988 fires therefore becomes a question of whether the park can now support greater bird numbers and diversity of species, especially those species that are threatened by diminishing habitat elsewhere. Although some birds such as the boreal owl need extensive tracts of mature forest, others like the mountain bluebird require open habitats with dead trees for nesting. Burned trees may look desolate, but they are often swarming with insects that attract certain birds.

After studying seven areas in the 1960s that had burned in Yellowstone at various times in the past, Dale Taylor determined that loss of suitable habitat that resulted from the closure of the forest canopy had led to a decline in nesting birds—from 72 breeding pairs per 100 acres 29 years post-fire to no pairs 57 years post-fire.⁴² Continuing his research until 1973, Taylor found that in three lodgepole pine forests on the Yellowstone plateau which had had stand replacing fires in the past, two hole-nesting species (the mountain bluebird and the tree swallow) comprised at least 30% of the breeding avifauna until the canopy closed again. Boring beetles and other insects attack the dead snags; woodpeckers concentrate in the burned area to feed on the insects and make nest holes in the snags, and abandon them each year to make new ones. Their old holes are used by other insectivorous birds that cannot make their own nesting holes, such as mountain bluebirds and tree swallows. But in Taylor’s study sites, both of those species were found in much higher densities than the were the available nesting places, resulting in harassment of birds that had found nests and their occasional displacement.

In 1977, Steve Gniadek, a seasonal employee at the park, set up three 300-m² plots near Yellowstone Lake to study fire impacts on bird species composition.⁴³ Two of the sites had been partially or largely burned during the preceding three years; the third site contained largely mature lodgepole pine with a dense understory of spruce fir. During 96 hours of censusing over two summer months, Gniadek found that each site was occupied by 21 species and had similar densities of breeding pairs. Of six categories of foraging birds, the largest percentage at all sites were birds that eat seeds or insects off the ground (such as dark-eyed juncos), but each site had a slightly different group of species. Only the burned sites had woodpeckers and flycatchers, while the unburned site had more species that glean seeds or insects from foliage, such as the mountain chickadee.

Birds



Colaptes auratus
Red-shafted flicker

A comparison of breeding pairs at the burned and unburned sites suggested to Gniadek that the fires had made the habitat more favorable for 10 species and less favorable for 11 species. However, he noted that many of the species that benefitted from the fires were considered more rare or limited in range, such as the three-toed woodpecker (*Picoides arcticus* and *P. tridactylus*). His conclusion in 1977 was that “early successional forest represents an extremely small percentage of total forest in Yellowstone Park, and thus natural fires can be viewed as highly important in recreating a broader mosaic of vegetation types and successional stages.”

Mortality during the fires.

By the time fires were on their way to creating such a mosaic in July of 1988, most of the year's new fledglings had left their nests and could escape the flames. Five bald eagle nests were destroyed in the fire, but no eagles were known to have died, and an aerial survey conducted in October and November 1988 found that territory occupancy by adult bald eagle pairs was high, indicating little if any displacement. But osprey are among the last birds to fledge in Yellowstone, and Terry McEneaney, the park ornithologist, reported that at least 17 chicks had died.⁴⁴

Many birds received at least short-term benefits from the fires, including some osprey and other raptors. McEneaney believes they may have been alerted by the columns of smoke that signaled places where rodents were fleeing to escape the heat and flames, only to find themselves swept off the ground by some large bird. Osprey are primarily fish-eaters, but McEneaney saw one carrying a red squirrel in its talons. Although ferruginous hawks are rarely seen in the park, McEneaney saw more than 40 between Cascade Meadows and Hayden Valley on September 7, feeding on displaced voles and pocket gophers.

After the fires.

Over the longer term, the different intensities and types of burn have increased the diversity of bird habitats, with more open areas for ground nesters and dead stands of trees for cavity dwellers, and abundant insects to be found in decaying trees and litter. But it's difficult to separate the effects of these changes on birds from those of weather, which has a major impact on food availability and nesting success.

McEneaney found the greatest diversity of birds in areas where the fires were of moderate intensity, leaving a patchy mosaic of burned and unburned forest. The burgeoning crop of wildflowers increased hummingbird numbers, but in severely burned forest areas, the bark drops off trees, depriving insects of their hiding places. In these areas, even most woodpecker species were uncommon, but Lewis' woodpeckers were observed in new areas, and the hairy woodpecker can drill into a bare trunk for insects. Since plants generally take longer to reestablish in more severely burned areas, northern flickers gathering ants and American robins seeking worms find their prey more accessible.

Where fire intensities were lower, bark-chipping woodpeckers have had easy pickings, and where the trees were only swept by surface fire, the food supply for birds that forage in the canopy was not much affected. There also appeared to be an increase in cavity-nesting waterfowl such as Barrow's goldeneyes and buffleheads, and some other cavity-nesting species, including bluebirds, swallows, kestrels, and flickers.

During the first two annual breeding seasons after the 1988 fires, Richard Hutto, an ornithologist at the University of Montana, Missoula, censused 34 sites in western Montana and northern Wyoming, including four sites in the park and several early successional clearcuts outside the park.⁴⁵ Like Gniadek, Hutto found that the bird species composition in recently burned forests was different from that of other Rocky Mountain cover types. Members of three guilds (woodpeckers, flycatchers, and seedeaters) were especially abundant in the burned sites. Of the 15 bird species that were generally more numerous in early post-fire communities, Hutto found five that appeared to be relatively restricted to early post-fire conditions, and one (the black-backed three-toed woodpecker) was nearly limited to the dead forests created by stand-replacement fires.



Nucifraga columbiana
Clark's nutcracker collecting
whitebark pine seeds.

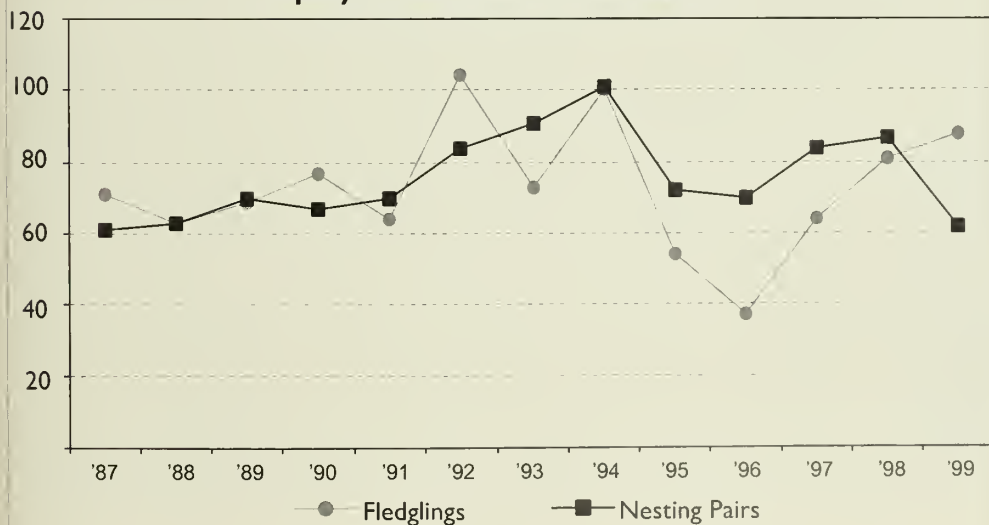
Most of the birds in burned forests relied heavily on the dead trees as food sources. Some species feed on conifer seeds (especially Clark's nutcracker, Cassin's finch, red crossbill, and pine siskin), which become more available after fire opens the lodgepole pine cones; these species peaked in abundance in the first post-fire year of Hutto's study, after which the seeds would have become scarcer. But the most abundant species were insect-eaters such as woodpeckers, which eat primarily wood-boring beetles. Hutto noted that woodpeckers responded to the increased availability of cerambycid and buprestid beetle larvae, which in some cases were themselves responding to the increased availability of unburned wood beneath the bark of fire-killed trees. Large trees were significantly more likely to show evidence of bird feeding activity than were smaller trees, which is consistent with the pattern of use by beetle larvae.⁴⁶ Aerial insectivores such as flycatchers and swallows used standing dead trees as perches from which they sallied out for their prey.

Of the 31 bird species that Hutto found nesting in burned sites, nearly two-thirds, including both open-nesting and cavity-nesting species, used standing fire-killed trees. Broken-top snags and standing dead aspen were used by cavity-nesting species significantly more often than would be expected on the basis of their abundance. From these observations, Hutto concluded that stand-replacement fires may be necessary for the long-term maintenance of bird species that are relatively abundant in or relatively restricted to burned sites. Salvage cutting may reduce the suitability of burned forest as bird habitat by removing its most important component for species that use burned forests: standing dead trees.

But McEneaney has found the presence of so many dead trees to be a mixed blessing even for the birds that use them. Although his 1994 annual report credited the park's record high of 101 osprey fledglings partly to the "superabundance of dead snags," the drop to 54 fledglings in 1995 was "primarily due to tree instability" as a result of the fires and harsh spring weather. Similarly, he attributed the decline in bald eagle fledglings in the park from 12 in 1988 to 3 in 1989 to be "due to unstable nesting trees as a result of the wildfires," yet the fledgling count reached a record 17 in 1993 and has remained above pre-fire levels in subsequent years. McEneaney expected that falling trees during the next decade could result in egg failure, loss of nest sites, or sudden changes in nesting locations, but "these naturally occurring post-fire conditions are unlikely to cause a significant change in the bald eagle population as a whole." Two other important nesting species in the park, the trumpeter swan and the peregrine falcon, had not been affected by the fires.

When the bough breaks.

Osprey in Yellowstone National Park



(Data from McEneaney, 1999)

Invertebrates

A bug's eye view of litter.



Dorothy Beetle

Searching for snails.

In addition to providing a source of food for fish, birds, and other wildlife, invertebrates play an important role in many forest and grassland ecological processes, including nutrient cycling, decomposition, and seed dispersal. Tim Christiansen of West Virginia University and Robert Lavigne of the University of Wyoming found that changes in the abundance and distribution of insects and other terrestrial invertebrates as a result of the 1988 fires depended on burn intensity.⁴⁷ Some insect species benefit from the fires, especially those that could invade fire-damaged trees (see page 53). But unlike reptiles and amphibians, which typically burrow into the soil or find moist areas in which to protect themselves from fire, litter-dwelling invertebrates may decline significantly where the forest floor burned.

Nature's litter includes the dead leaves, twigs, logs, fungi, and bacteria that help provide nutrients to the soil and keep it from drying out. Starting a year after the fires, Christiansen and Lavigne compared insect communities in forest and sagebrush grassland sites, both burned and unburned.⁴⁸ Although most of the invertebrate species they found in forest stands were different from those found in sagebrush grasslands, most of the species overall were mites (Acari) and springtails (Collembola). Based on the Shannon-Wiener Diversity Index, a commonly used measure of biodiversity, they found higher invertebrate diversity in forest stands (a total of 134 species) than in sagebrush-grasslands (60 species), and greater litter diversity overall in Yellowstone than in similar habitats elsewhere in Wyoming. Consistent with Taylor's findings on the diversity of mammals and birds (see page 50), Christiansen and Lavigne recorded the highest insect diversity in middle-aged lodgepole pine stands (30 to 60 years old), and the density of insects decreased as the density of standing dead trees increased.

To compare burned and unburned forest stands, Christiansen and Lavigne collected litter and ashen material every 10 days from 12 sites from July until mid-September 1989, and from late May until mid-October 1990. Overall, the burned sites contained significantly lower litter weight, percent herbaceous cover, and density of seedlings, saplings, and log debris density than did the unburned sites, and consequently had lower densities, richness and diversity of invertebrate species. One year after the fires, invertebrate diversity was 63% lower in severely burned stands than in unburned stands, and it had increased only slightly by 1990. Density was 77% less, and the invertebrate predator:prey ratio fell from 1:24 to 1:8. However, the severely burned forested sites had significant higher seedling density and herbaceous cover than lightly disturbed sites, and higher insect density. In severely burned sagebrush grasslands, the invertebrate communities were almost completely wiped out by the fire, with diversity declining 90% and density declining 94%.

Their analysis suggested that certain minimum levels of herbaceous cover, tree seedling density, litter, and fallen trees were necessary to support high densities of mites and springtails. After measuring the litter at their study sites in grams per square meter (g/m^2), Christiansen and Lavigne concluded that it took at least $100 \text{ g}/\text{m}^2$ to accommodate abundant millipedes, which are important litter decomposers in coniferous forests, and $70 \text{ g}/\text{m}^2$ for high densities of ants, which help spread seeds and create pores in the soil which permit better water penetration. Post-fire reestablishment of an invertebrate community was detected with a minimum of 10% herbaceous cover, 10 pine seedlings per square meter, and 14 logs per square hectare, but many species that were abundant in unburned habitats were observed only occasionally in burned sites even two years after the fires.

Aspen groves provide habitat for snails that convert leaf litter and fallen logs into soil nutrients, and are themselves eaten by small mammals and birds. Dorothy Beetle, a retired planetarium director who undertook a five-year study of snails in aspen sites representing a range of burn intensities, identified 21 land snail and 2 freshwater species.⁴⁹ In 1989, all of

the species could be found in unburned sites, but burned groves held a only a few live species and fragments of others. From 1990 to 1991, snail populations had declined somewhat even where mature aspen had survived; no new species were present, nor was there any evidence of migration into burned groves.

The land snail glides over a mucus trail it secretes using the muscular contractions of its foot. Its small size allows for some passive dispersal by wind or heavy rains and, under favorable moisture conditions, small snails may climb into the hair of mammals or feathers of birds and move to a new habitat. But snails on their own are very slow, and unlikely to survive travel across a pine forest or grassland to another aspen grove. By 1994, after two dry years, many aspen had died without replacement and snails were no longer present in any of the burned sites.

For information about aquatic insects and other invertebrates in streams, see page 96.

Amphibians

The cause of the apparent decline of amphibian populations in many places throughout the world remains undetermined. Climate changes that have increased ultraviolet radiation, whether or not contributed to by human activity, are thought to be one possible explanation. But in Yellowstone, as in most places, the lack of long-term data on amphibian populations has made it difficult to determine which species, if any, have declined, and what factors may be involved. Replication in the mid-1990s of a survey conducted in the mid-1950s in a 28-hectare area near Lake Lodge has provided Charles Peterson of Idaho State University with evidence that the spotted frog population may have declined 80%, from approximately 1,500 to 300 frogs.⁵⁰ However, comparisons of burned and unburned sites made from 1989 to 1993 suggest that the occurrence of some common species of frogs, toads, salamanders, and snakes was not significantly altered by the fires.⁵¹

Wolves

Now that the fires are finally going out, how about letting some wolves in?

Amidst complaints about park mismanagement and the \$120 million spent on fire suppression, on September 9, 1988, Congress approved a public lands spending bill containing \$200,000 for a study that would ignite another controversy about Yellowstone: the possibility of reintroducing wolves. What could have seemed less likely?

Yet less than seven years later, after extensive research into the possible consequences and dozens of public hearings, 14 wolves from Canada were released in Yellowstone. Like the reintroduction of a natural fire regime, the return of wolf packs more than 60 years after their extermination in the park was primarily motivated by the goal of maintaining as many of Yellowstone's original components and processes as possible.

Those wolves and their descendants, numbering more than 120 by the summer of 2000, have surely been affected by the changes in the landscape wrought by the fires. Although no one has studied the question, research on related topics suggests possible correlations. Wolves don't eat burned bark, aspen sprouts, or ash-enriched forage, but they do prey on elk and other animals whose abundance, distribution, and nutritional health depend partly on their consumption of such items. And a wolf pack's success in bringing down a winter-stressed elk could depend on the wolves' superior maneuvering skills in the deeper snow pack of a forested area that lost its canopy a decade before.



Canis lupus

Going with the flow

In addition to causing changes in forest structure, large crown fires may produce rapid alterations in the underlying landscape. In a vegetated watershed, trees and other plants help hold the soil in place, absorb rain, and reduce the snowpack that would otherwise accumulate on the ground. When a watershed burns, dramatic changes in streams may result from tree fall, loss of plant cover, the release of nutrients from vegetation into streams and lakes, debris and sediment flows, changes in water temperature, and shifts in the aquatic food web.

- The loss of vegetation reduces the amount of water absorbed by the soil and plants, which in turn increases the portion of precipitation leaving the watershed.
- The increased water flow can increase erosion and mobilize debris, transporting sediment and nutrients downstream, and affecting floodplain species like aspen, willow, and alder. Runoff events can also destroy bird nests and, at least over the short term, decrease biotic diversity and production.¹
- But debris flows and floods are a major source of spawning gravels, and the addition of sediments and nutrients to aquatic ecosystems and the higher summer water temperatures (because of loss of shading vegetation) may bring about pulses in aquatic productivity for up to six years after a large fire.²
- Like the young seedlings that sprout after the fires, the charred trees that tower over them are part of a long-term shift in nutrient cycling and soil processes. Although some of these snags may remain standing for decades, many have already toppled to the ground, creating a coarse woody debris that provides habitat for certain insects, fungi, and nesting birds.



Gibbon River, July 2000.

The 1988 fires have led to ongoing changes in the park's streams, sending gravel and tree trunks into some sections and deepening others. The magnitude of these changes is affected by the geology, topography, and size of the stream; the amount and timing of subsequent precipitation; and the size and severity of the fire.

Runoff and Erosion

In human communities, erosion is generally regarded as a problem that can reduce topsoil and other property value. If the human species had been around at the time, someone would have wanted to do something about the excessive erosion that resulted in Arizona's Grand Canyon. In Yellowstone, fire-related erosion has been a major factor in the export of sediment from tributary basins and has had a substantial impact on the park's landscape. The sedimentation record shows that fire-related debris flows make up about 30% of the deposits in alluvial fans that have been accumulating during the late Holocene.³

G. Wayne Minshall and his colleagues at the Stream Ecology Center of Idaho State University have compared "burn streams," where at least 50% of the catchment burned in 1988, to "reference streams" where no more than 5% of the catchment burned. Comparison with an entirely unburned site was not feasible because nearly all of the park's large watersheds burned to some extent. They found that sheet erosion, rill and gully formation, and mass movement of material occurred on burned watersheds in Yellowstone during the summer of 1989, when heavy rains were followed by widespread "black water" conditions and debris torrents.⁴ Three major mudslides and a dozen smaller ones caused by a rain-storm in August 1989 carried large volumes of silt, sand, and stones into the Gibbon River a short distance above Gibbon Falls. Suspended sediment increased in streams in burned watersheds throughout the park following runoff from both snowmelt and rain from spring through summer in 1989 and 1990.

But the extent of channel alterations was substantially larger in 1991, when at least two large runoff events caused major physical changes and declines in the biotic components in all of the study streams located in burned watersheds with moderate to steep gradients. Most high-gradient burn streams underwent major changes in channel morphology. For example, high flows in the catchment of 3rd order Cache Creek caused the channel to shift laterally about 30 meters, while the channel in 1st order Cache Creek, despite significant regrowth of riparian vegetation, was cut down to bedrock in many areas.

When the water rises.

Since 1991, the input of fire-related sediment into Yellowstone streams has been greatly reduced by even sparse growth of herbaceous plant cover, and much of the sediment is now being deposited along the sides of valleys and on flood plains, where the organic and nutrient-rich material contribute to the productivity of these environments.⁵ Fire-related debris flows and floods have occurred only in limited areas, such as from dry, south-facing slopes that are slower to revegetate. However, some streams in burned watersheds changed more from 1995 to 1997 than in the first six post-fire years, demonstrating the importance of long-term research after a large-scale disturbance.⁶

Streams are commonly differentiated by "orders," where the smallest unbranched tributaries are designated 1st order streams, the joining of two or more 1st order streams forms a 2nd order stream, and so on. The park's largest streams are 6th order. The low-order stream watersheds in Yellowstone tended to burn either extensively or not at all, and when they did burn, they underwent more physical and chemical variations than did higher-order streams.⁷ For example, low-order streams in burned watersheds were more likely to experience light and temper-

Conclusions based on only a few years of data can be misleading, "as evidenced by the apparent 'devastation' of stream ecosystems immediately after the 1988 fires, their rapid progress toward 'recovery' in post-fire years 1 to 2, their equally abrupt downturn in post-fire years 3 to 4, and their massive reorganization in years 7 to 9." The initial "recovery trajectory" was much different—faster initially, with more time before major storm impacts were seen—than was expected.

— Minshall et al., 1998

ature increases because the loss of the shade provided by streamside vegetation would have a larger impact on them. The mean catchment burned at the Stream Ecology Center's study sites was 75% for 1st and 2nd order streams and 50% for 3rd and 4th order streams. However, during aerial and ground reconnaissance they observed that the catchments of many fire-affected 3rd and 4th order streams in the park and along its northern boundary were less than 50% burned, and larger streams even less.

When the snow melts.

Snowmelt accounts for 50% to 70% of the total annual runoff in lodgepole pine and spruce/fir stands of the northern Rockies.⁷ The forest openings created by fire can increase the amount of snow and rain that reaches the ground, and the loss of vegetation and increased hydrophobicity (water repellency) of soils may cause snowmelt to begin earlier. After the 1988 fires, water users downstream from the park and agencies responsible for disaster actions were concerned about possible changes in streamflow volumes, and the timing and amount of peak flows.

Data on streamflow has been collected at gauging stations maintained by the U.S. Geological Survey on the Yellowstone and Madison rivers since 1911, making it possible to assess the impact of the 1988 fires on runoff in subsequent years. Based on data through 1998 regarding annual fall soil moisture, spring precipitation, and the extent to which the loss of forest canopy had increased snow and rain "throughfall," three researchers from Montana State University in Bozeman estimated that the fires had increased annual runoff for the Yellowstone River at Corwin Springs 4% to 5%, and that the peak runoff was occurring two days earlier than before the fires.⁸ Runoff for the Madison River near Grayling Creek was estimated to have increased about 6% to 8% during the same period. They predicted that runoff levels will remain higher as a result of the fires until the forest canopy closes again toward the end of the 21st century.

However, these increases are relatively insignificant compared to the annual fluctuations that result from variations in precipitation amounts. For example, the lowest volume of runoff recorded for the Yellowstone River (59% of the long-term average) occurred in 1934, during an extended period of drought; the highest runoff (161% of average) was recorded in 1997, when the snowpack was 154% of average.

In comparing three burn and two reference 1st order streams that drain into the Lamar and Yellowstone rivers, Wayne Minshall of the Stream Ecology Center and Michael McIntyre of the Idaho Division of Environmental Quality found that during the first two years post-fire, the burn streams had significantly higher flows in summer and fall than did the reference streams, but not during the snowmelt period.⁸ This could be at least partly due to the loss of trees which had previously lowered the water table in summer and fall.



Cache Creek, August 1995.

Both Jones Creek and Crow Creek in the North Absaroka Wilderness in the Shoshone National Forest have primarily north and south-facing slopes of similar steepness and elevation zones dominated by subalpine fir. But while the Clover Mist fire burned only 2% percent of the Crow Creek watershed in 1988, leaving 60% forested; it severely burned 50% of the Jones Creek watershed, leaving 15% forested and newly hydrophobic soil 2.5 to 10 cm deep. Because of the comparative data on fire effects that these adjacent watersheds could provide, a post-fire monitoring study was established as an interagency effort (Shoshone National Forest, Rocky Mountain Forest and Range Experiment Station, U.S. Geological Survey, and the Wyoming Department of Environmental

Quality). During the 1989–92 period, which was not particularly wet, the flow from Jones Creek averaged 540 mm per km² of watershed area (66.8 km² total area) and Crow Creek, 402 mm per km² (in a 49.5 km² watershed area). The data collected at these sites suggested that the Clover Mist fire had increased both streamflow quantity and sediment export during this period, but had little effect on peak discharge or summer storm response.⁹

The U.S. Fish and Wildlife Service (USFWS), which previously maintained a field station in Yellowstone, selected study sites on six 4th to 6th order streams in watersheds ranging from 9% burn (Soda Butte Creek) to 50% burn (Lamar River). Their data on streamflow also showed no significant post-fire change in peak discharge. The trends in discharge generally paralleled annual precipitation levels from 1985–91; the peak discharge was highest in 1986, the year of greatest precipitation at all sites except the Gibbon River.¹⁰

Changes in runoff as a result of fire may alter the interacting influences of erosion, stream channel morphology, sediment composition and concentration, and the recruitment and distribution of large woody debris. However, in places where the forest canopy is only scorched, fallen needles may create a mat that checks erosion, and toppled snags can serve as dams on hillsides. Erosion and channel alteration usually peak during the snowmelt period. But when the very cool extended spring resulted in an unusually slow snowmelt in 1989, runoff peaks were much reduced, and erosion and channel alterations were largely determined by summer rainstorms. The drought of 1988 may also have affected runoff; much of the melting snowpack remained stored in the unusually dry soils.

Richard Marston and David Haire measured runoff and soil loss in the summer of 1989 through a series of rainfall simulation experiments at 30 sites in the Shoshone National Forest and the John D. Rockefeller Memorial Parkway representing a range of geologic substrates, logging history, and burn intensities.¹¹ Soil loss was greatest at sites that had been logged, a finding that was attributed to the reduction in litter on the forest floor. Litter density was the key variable controlling both runoff and soil loss. When the timber is harvested, lodgepole forests are typically clear-cut, leaving no source of post-fire needles to replenish litter cover, but even in forests that had not been logged, lodgepole pine needles burned easily in the 1988 fires. Douglas-fir forests that had been selectively logged provided post-fire needles because they are more fire-resistant.

Marston and Haire found that the correlation between runoff and soil loss was poor. For example, silty soils had lower runoff but higher soil loss. Most soil was mobilized by rainsplash, not runoff, as was evident in the greater soil loss in 1989 from summer storms than from snowmelt runoff. Nor was slope gradient a significant factor; its effect was confounded by the high micro-roughness of the soil surface as a result of litter, grass, and downed timber. For this reason, both logging and fire history had a larger impact on soil loss and than on runoff. But erosion effects generally peak within 10 years after a fire event, while road building, log yarding, tree clearing, and slash burning may produce sources of erosion that persist for decades, and the sediment stored behind fallen logs may be remobilized if salvage logging is done.

Most of Yellowstone's trees are evergreen, but the deciduous trees and bushes it does have tend to be concentrated in the damper areas along streams. The leaves from these plants, such as aspen, willow, and alder, provide organic matter that is much

Forest litter prevents soil loss.



Lamar River, September 1998.

more favorable for aquatic life than are pine and spruce needles.¹² In the absence of fire, stands of evergreens eventually replace the deciduous vegetation along streams, further reducing the transfer of nutrients from the land to streams to lakes. Post-fire regrowth in riparian areas depends on the species that were present before the fire and the intensity of burning. Over both the short and long term, changes in riparian vegetation can affect soil stabilization and the insect community.

Riparian vegetation.

During and after the 1988 fires, Deron Lawrence and Wayne Minshall of the Stream Ecology Center photographed vegetation at five locations along each of 18 burn and 4 reference streams in the park.¹³ At the burned sites immediately after the fires, the topsoils were charred and most of the organic matter was vaporized, leaving only mineralized products, yet many stems and tree boles were still intact. After one year, the grasses and forbs were still of low stature and did not cover the soil. These plants intercept rainfall and protect soil from minor erosion but not from intense rainstorms or snowmelt, which can move large amounts of sediment to the stream channel.

During the second year post-fire, the grasses and forbs increased in height and coverage, further stabilizing the soil. But a heavy snowpack combined with spring rains the following year to increase peak flows and sediment loading, which led to widespread channel cutting and vegetation suppression. These high flows returned the successional process to a state in which new plants colonize areas of sediment deposition.

The role of woody debris.

Crown fires can create large amounts of coarse woody debris (CWD), some of which may be combusted or converted to charcoal in subsequent fires. Over the short term, the presence of CWD in streams affects channel morphology, retains organic matter and sediment, and provides habitat heterogeneity and stability for fish and insects. To study the effects of various disturbances on soil quantity and quality, in 1995 Daniel Tinker and Dennis Knight began comparing the amount of CWD in burned and unburned Yellowstone forests to that in clear-cut and uncut sites in the Medicine Bow National Forest.¹⁴ Their research has shown that clear-cut stands of lodgepole pine generally contain 50% less CWD than stands of similar pre-disturbance density and age. But the fire-related changes that result from CWD recruitment can last for decades in forested drainages. In extreme cases where fire has consumed much of the vegetation or water yield is substantially increased, debris loading may decline until revegetation can provide new sources of wood.¹⁵

Compared to their unburned study sites, McIntyre and Minshall found fewer naturally occurring dams in burned watersheds during the first two years post-fire in 1st to 3rd order study streams, perhaps partly because they had been washed out by higher discharge resulting from the fire. The burn streams were still experiencing a net loss of wood through 1991.¹⁶ Although CWD may increase immediately after a fire, it generally bridges the stream, and in the Yellowstone climate it may take at least 10 years for the effects of wind, decay, and channel repositioning to incorporate it into the stream debris.¹⁷

Debris in the Fast Lane

Michael Young and Michael Bozek from the University of Wyoming used the heavily burned Jones Creek watershed and the nearly unburned Crow Creek watershed to compare the movement of CWD by attaching aluminium tags to 160 pieces of debris that were at least two meters long.¹⁸ In 1990 and 1991, debris in Jones Creek was three times more likely to move, and moved more than four times as far as debris in Crow Creek. The greater duration of high spring flows after snowmelt or occasional high summer flows after thunderstorms apparently displaced much of the debris in the burned watershed. But in subsequent years as more dead trees fell over, the debris in the Jones Creek watershed was expected to slow down.

Minshall noted that many of the conifer seedlings in the Stream Ecology Center's study areas that had germinated after the fires were six feet tall by 1997, and many of the charred tree trunks were still standing.¹⁹ The continuing growth of young trees and falling of dead trees will continue to alter the availability and movement of CWD.

Fires can increase sediment transport in burned watersheds because the loss of tree canopy increases the raindrop impact on the soil and the loss of ground cover increases surface flow. High

sediment loads were observed in some streams draining burned watersheds after the 1988 fires, but usually only during spring runoff or after heavy thunderstorms. The average annual precipitation was greater from 1989–92 than it had been from 1985–87, but the first two post-fire years had relatively cool springs and dry summers, resulting in slower snowmelt and lower streamflows than pre-fire.

With three years of data collected prior to the 1988 fires, Roy Ewing on the park staff continued his research to measure the effects of the fire on suspended sediment in two of the park's major rivers, the Yellowstone and its principal tributary, the Lamar.²⁰ Compared to the long-term average (1961–90) the largest annual snowmelt runoff (116%) and the largest April–September runoff (102%) on the Yellowstone River at Corwin Springs during the first four post-fire years occurred in 1991. However, these levels were lower than they had been in 1986, when snowmelt runoff was 126% and total April–September runoff was 116% of the long-term average.

Ewing also sought to isolate the changes in sediment levels that were due to the fires from those due to changes in precipitation by determining the relationship between streamflow and sediment for the pre-fire period and using it to project sediment loads for the post-fire period. If an actual post-fire load was greater than the predicted load for a given season, then the increase could be fire-related. In this way, Ewing determined that fire-related increases in suspended sediment had occurred on the Yellowstone and Lamar rivers after the 1988 fires, but not consistently throughout the year or throughout the watershed.

The portion of the total sediment load that the river carries as bed load (the coarser sediment) is often larger in the mountainous headwaters. During field trips in the Lamar River basin, Ewing located many woody debris jams which were storing coarse bed-load sediment that would be released during the first high-streamflow storm. Summer transport of sediment in the severely burned steep drainages of the Lamar River basin more than tripled after the fires and yet the effects were not experienced downstream, where they were apparently diluted by clear runoff from unburned watersheds or those unaffected by storms.

Sediment heads downhill.

Delayed release of sediment.



Cache Creek, July 1998.

Ewing determined that the sediment load in the Yellowstone River was about 60% higher during snowmelt in 1989–1992 because of the fires; increases during the summer were less than half that. But on the Lamar River, sediment transport appeared to have diminished by 1992 to less than what would have been projected under pre-fire conditions.

Although the native soils are prone to erosion and the background sediment concentrations and load are quite high, Charles Troendle and Greg Bevenger of the U.S. Forest Service found that sediment export in the burned Jones Creek watershed was significantly greater in terms of both concentration and total suspended load than it was in the unburned Crow Creek watershed.²¹ During the 1989–92 period, Jones Creek yielded an average load of 59 metric tons/km², compared to only 13 metric tons/km² from Crow Creek. On at least one occasion, after an intense rainstorm in August 1990, the suspended sediment apparently caused some trout to suffocate.²²

However, “the data do not indicate the hill slopes have unraveled and delivered greater amounts of material to the riparian/channel environment.” Troendle and Bevenger hypothesized that because the fire removed riparian vegetation in the Jones Creek watershed, including woody debris and root systems, the material already in the stream bed and banks may have become destabilized and more readily available. “The storm response appears to be from near or within channel sources, minimizing the opportunity for off-site delivery.” In the absence of extreme rainfall events or severely wet antecedent conditions, “the opportunity for increased erosion and introduction of new sediment to the channel system appears to have been minimal.”

Sediment deposits.

Dan Mahony and Robert Gresswell, continuing the USFWS research, monitored annual variations in streamflow, substrate composition, water chemistry, macroinvertebrate communities, fish populations, and recreational fishing at six sites in the park.²³ Annual precipitation after the fires was similar at all sites, and the peak streamflow occurred about two to four weeks earlier than in the three years previous to the fires. Yet despite large variation in substrate, Mahony and Gresswell found that the amount of fine sediment at different sites was not related to either the size or the burned percentage of the watershed. The most prevalent effect of the fires appeared to be that low-gradient 4th to 6th order streams were functioning as depositional areas for sediment and nutrients transported from higher-gradient upstream burned areas. Data collected by Minshall and Robinson also suggested the presence of “a pulse of fine sediments moving from the burned watersheds into the headwater streams and then gradually into larger burn streams over time.”²⁴

Organic matter.

The detritus that collects in streams from decaying vegetation, fecal matter, and dead algae is a major source of carbon and nutrients in aquatic food webs. Boulders, rocks, debris dams, and riparian vegetation impede the transport of organic detritus, allowing time for it to be transformed into particles through physical and biological processing before moving downstream. When fire converts upland and riparian vegetation to charcoal and ash (which are not food sources), the amount of light and organic matter that enter streams is immediately affected.

Organic matter in streams can be described as either “benthic” (remaining in place on the bottom) or “transported” (in transit), and measured in two size categories: fine particulate organic matter (FPOM) and coarse (larger than 1 mm) particulate organic matter (CPOM). As a result of major runoff events in 1991, both FPOM and CPOM and the percent charcoal increased at all 18 of the Stream Ecology Center’s burned study sites that year.²⁵ Benthic organic matter increased initially in the 1st to 3rd order burn streams (with the largest increase at the 1st order sites); data since 1989 indicate that although reduced in amount, charcoal was still being added to burn streams, which could decrease the quality of organic matter as food for aquatic insects (see page 96).

In their comparison of 1st order streams during the first two years post-fire, McIntyre and Minshall found that the burn streams transported more organic matter in all seasons and that burn stream CPOM was mostly charcoal, where as CPOM in reference streams consisted of dead leaves, needles, and twigs.²⁶ They suggested that fire reduces the capacity of burn streams to store organic matter by increasing runoff, by altering the types and magnitudes of riparian vegetation and debris dams that serve as retention barriers, and by transforming the CPOM itself.

Aquatic Habitats

Four large lake watersheds and about a third of the park's streams were in drainages that burned to some extent in 1988. Fire-related changes in riparian vegetation, water quantity and quality, the timing and intensity of peak discharges, and the physical characteristics of a stream can affect aquatic biology. In the Yellowstone fires, the degree of alteration of stream habitat was highly correlated with stream size and the percent of catchment burned.²⁷ The area burned within the affected watersheds ranged from less than 10% to more than 90%. Because of differences in landscape morphology and in the nature of the fires, streams in the Madison, upper Yellowstone River, and Snake River drainages were less likely to be affected by the fires than the other main river systems in greater Yellowstone. As the size of the watershed increases, larger portions remain unburned and the larger volumes of water that feed the watershed's streams and lakes serve to diffuse the fire effects.²⁸

Although fire may cause immediate and temporary changes in water chemistry and food resources, the major potential impact on aquatic ecosystems is the physical disturbances resulting from increased runoff; changes in runoff timing and magnitude may diminish species that lack the genetic or reproductive capacity to adjust. There may also be longer-term shifts associated with the removal and eventual replacement of vegetation and the resulting changes in the stream's food resources and retention capacity.²⁹

Most of the effects of fire and fire suppression activities observed in Yellowstone's aquatic habitats have been short-term. Although the 10 million gallons of water drawn from ponds and streams and the 1.4 million gallons of fire retardant dropped by aircraft in or near the park may have had little effect on the fires, they also caused little disturbance to aquatic life. About 100 dead fish were seen in Fan Creek and in Little Firehole River after accidental drops of fire retardant, but the ammonium phosphate was quickly diluted and the effects temporary. Changes in some aquatic organisms, such as diatoms and benthic invertebrates, were observed in small streams, but no obvious effects on the organisms of the larger rivers or on fish populations have been detected.

The proximity of fires themselves did not raise water temperatures above the tolerance levels of fish and aquatic invertebrates, nor did the loss of overhead canopy generally result in greater extremes in water temperatures even in smaller streams. Although the minimum temperature increased 3°C from 1988 to 1991 at two of the Stream Ecology Center's Iron Springs Creek sites and the main Blacktail Deer Creek site, it remained "essentially unchanged" at the other 15 burn sites and the four reference sites.³⁰

The pulse of minerals that is released from plant matter by fire eventually reaches the park's waters. By mobilizing nutrients in upstream biomass or soils and moving downstream, fires may serve to link the terrestrial and aquatic biogeochemical cycles.³¹ The level of post-fire nutrient input to aquatic systems depends on factors such as fire severity and size, weather, and the physical, chemical, and biological characteristics of the watershed.



Water relocation, 1988.

Changes in water chemistry.

Analysis of water samples from six 4th to 6th order streams in the USFWS study showed slight increases in chemical concentrations during the first or second year post-fire, but they remained within the range of pre-fire records, and the similarity between Soda Butte Creek (9% of watershed burned) and heavily burned watersheds suggested that some increases were not fire-related.³² The only change in water chemistry that the USFWS attributed to the fires was an increase in silica in the Gibbon and Madison rivers in 1989 and 1990. Elevated silica concentrations are not unusual in rhyolitic watersheds such as these, and apparently resulted from post-fire debris torrents that occurred in the drainage. Silica concentrations in the Madison River, which increased nearly eightfold after the fires and were the highest of any found in the park, may have been related to upstream landslides in the Gibbon River during the summer of 1989.

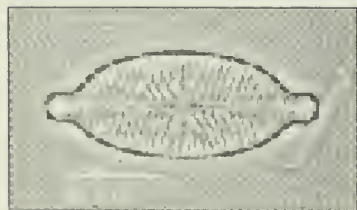
Minshall found that changes in water chemistry varied considerably among streams, but usually occurred in smaller streams during the first few post-fire years, while ash was available to provide the chemicals and before regrowth of streambank vegetation.³³ At the Stream Ecology Center burn stream sites, the concentration of most dissolved constituents increased between October 1988 and August 1989, apparently in response to recent rainstorms. Nitrate levels were as much as 3 to 4 times higher in catchments with moderate to extensive physical change after the fires (e.g., channel morphology), and they remained elevated in most burn streams, suggesting a loss of nitrogen from the catchment even five years post-fire.³⁴ However, nitrate levels subsequently declined in burned areas as the growing plants sequestered nutrients and delayed or prevented their runoff into streams.

In a project sponsored by the U.S. Forest Service, four scientists from NASA-Ames found that both nitrate and phosphate levels increased significantly in five streams in burned watersheds and were still high five years later.³⁵ While the levels stayed constant in an unburned reference stream (Amphitheater Creek), nitrate was 2.6 to 33 times higher and phosphate 2 to 29 times higher in burn streams, with concentrations correlated to fire intensity in the watershed and subsequent periods of snowmelt and summer storms.

Effects on groundwater.

To investigate the possibility that the leaching of minerals by ash might affect groundwater, for two years after the fires Donald Runnels and Mary Siders of the University of Colorado tested samples at four groundwater wells in watersheds of varying burn intensities for which pre-fire data were available.³⁶ They found that the changes were minimal and within the known range of pre-fire variation. They suggested that the "assimilative capacities" of the soil and rock substrate were sufficient to attenuate the impact that large quantities of ash-derived solubles could have on the ground water chemistry.

Diatoms



Navicula constans
(greatly magnified)

In streams draining montane areas that are low in plant nutrients, diatoms (Bacillariophyta) are often the predominant algae. The Cache Creek catchment, which was 80% burned, underwent substantial shifts in stream morphology after the fires, providing an opportunity to document changes in diatom assemblages along the length of a stream system relative to temporal changes in the physical environment. Researchers from the Stream Ecology Center collected samples at five sites in 1st through 4th order streams in the Cache Creek catchment in September 1988 and August 1989–1992, and compared changes in diatom assemblage structure and stream morphology with those in Rose Creek, a 2nd order stream in an unburned catchment.³⁷ Both streams drain areas that were primarily vegetated by coniferous forests of lodgepole pine and Engelmann spruce; riparian vegetation consisted of willow, rose, and alder.

Species richness and diversity were reduced in Cache Creek during the study period, especially in 1st and 2nd order streams, but substantial increases were observed in the relative abundance of *Navicula permitus*, *Cymbella sinuata*, and *Nischia inconspicua* compared to

Rose Creek. The researchers noted that both *N. perinitus* and *N. inconspicua* are extremely small diatoms that are probably highly resistant to physical disturbance. They found more pronounced changes in diatom assemblages in 1991, especially in burn streams hit by high flows in late spring and July. As a result of the increase in disturbance magnitude and frequency at the burned sites, disturbance-favored taxa remained dominant there, even after four years.

Lakes

Depending on the amount and timing of precipitation, some of the sediment, debris, and nutrients that move down through the park's watersheds ultimately end up in a lake as their final resting place. As in streams, the increased erosion that may occur after a fire can increase the sediment load in lakes, and the documented decline in the productivity of Yellowstone Lake during the last century has been attributed to the lack of fire.³⁸ About a quarter of the Yellowstone Lake and Lewis Lake watersheds and half of the Heart Lake watershed burned to some extent in 1988, but no significant changes have been observed in nutrient enrichment, plankton production, or fish growth as a result. However, these lakes may be large enough in comparison to their watersheds to dilute the effect of any increased runoff. (Yellowstone Lake covers 354 km² in an approximately 2,600 km² watershed.) Jackson Lake in Grand Teton National Park, which is smaller in relation to its basin and has a different bedrock and more noticeable sediment load, was less able to absorb post-fire sediments without loss of clarity after 26% of its watershed burned in 1988.

Data collected from 1976–91 for Yellowstone's four largest lakes (Yellowstone, Lewis, Heart, and Shoshone) revealed minimal post-fire changes in water quality; Robert Lathrop of Rutgers University believed that the major factor in annual fluctuations of chemical constituents to be precipitation.³⁹ All of the lakes except Shoshone showed post-fire decreases in sulfate, chlorine, and calcium, and increases in pH, sodium, and potassium, but because of changes in atmospheric chemistry, geothermal influences, and fisheries management, the impact of the fires cannot be isolated. An analysis of Landsat Thematic Mapper (TM) data and Advanced Very High Resolution Radiometer (AVHRR) imagery for Yellowstone Lake from 1987–90 also indicated no changes in water quality. However, because of its large volume and long renewal time (it takes 10 years for the entire lake to be replaced by new water), Lathrop believed the peak effect on Yellowstone Lake may have lagged behind the maximum yield from stream inputs by several years.

A similar analysis by Edward Theriot of the Academy of Natural Sciences in Philadelphia, who looked at data on the same four lakes through 1993, found an increase in total dissolved solids and silica after the fires.⁴⁰ Although this could be attributed to increased post-fire erosion from the catchment, Theriot suggested it could also be the result of increased diatom production or a drought-caused productivity decline, which would reduce the biological demand for silica. Other indications of biological activity that he measured, such as underwater visibility, conductivity, and sodium concentration, did not change significantly after 1988.



Beach Lake, September 1994.

Aquatic Insects

Macroinvertebrates, which include all invertebrates large enough to be seen without magnification, are an essential part of the aquatic food chain. Yellowstone's trout fisheries consume aquatic insects such as mayflies, caddis flies, and stone flies that feed on plant matter or by scraping algae off rocks. After riparian vegetation burns, the amount of plant litter falling into streams may decline dramatically, and in once-shaded reaches that are exposed to the sun, algae growth may increase. These shifts can be advantageous to insects that eat food produced in the stream—collectors and scrapers, such as mayflies and riffle beetles—rather than the normally dominant shredders that feed on detritus that falls into streams.

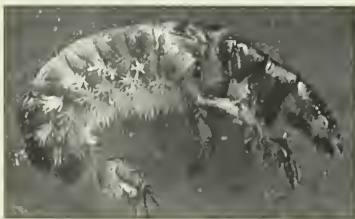
Because little data had been collected on pre-fire macroinvertebrate communities, changes that have been observed in them cannot be definitively attributed to the fires. However, comparisons with sampling done at unburned streams have suggested that the insect communities in burn streams changed dramatically as water conditions and food resources changed, and in some cases, have not returned to their pre-fire composition.

From October 1988 to March 1989, macroinvertebrate abundance and richness decreased in six out of eight burn sites at Cache Creek (while increasing or remaining the same in reference streams), but began to show substantial recovery before the first post-fire year had ended.⁴¹ Changes in species composition, however, were apparent even nine years later, reflecting alterations in food resources and a shift to “trophic generalists”—organisms that can survive in a range of habitats. The Stream Ecology Center researchers attributed these changes at burn sites to high levels of charcoal (more than 40%) in the stream bottom that decreased the palatability and quality of organic matter as food sources. In laboratory experiments to determine the response of benthic macroinvertebrates to different foods, only one of the 11 taxa examined, *Paraleptophlebia heteronea* (a mayfly) could grow on burned detritus, but it didn't increase in post-fire streams because it requires a stable flow and substrate conditions.⁴² The only species that increased in abundance at burned sites during the first post-fire year were chironomids (midges) that are believed to have a competitive advantage in streams with heavy sediment deposition because they are sediment burrowers that can produce multiple generations in a single year.

But the abundance and biomass of chironomids dropped steadily after the second year post-fire, and within a decade about half the invertebrates in Cache Creek were feeding on both litter and food produced in the stream; charcoal was still being added to the streams at the burn sites, but at a lower rate. After 1990, most fire-related effects appeared to be the result of higher peaks in runoff that caused physical disturbances in the stream bed, rather than changes in food resources.⁴³ The real survival test for a species, therefore, appeared to be not its food preferences, but whether it could endure the harsher physical environment of the post-fire stream.

A study from 1988 to 1992 at six burned sites in Cache Creek and four unburned reference sites indicated a correlation between taxa recovery and stream size, probably because of the higher slope and larger burned catchment area of smaller streams.⁴⁴ Species that require habitat with stable riffles or slower current velocities declined in abundance and biomass at burned sites during the study period, while generalists such as *Baetis bicaudatus* (a mayfly) and *Zapada columbiana* (a stonefly) were common. They feed on both detritus that falls into the stream and periphyton (attached algae) that grows in it.

Returning in July 1993, the researchers found that the channel morphology at Cache Creek still appeared unstable, and the burned sites there still had different diatom assemblages than the unburned sites at Rose Creek.⁴⁵ Periphyton biomass was lower in Cache Creek, suggesting a lack of recovery by primary producers. Chironomids were the most common



Caddisflies: larva (above)
and adult (below)

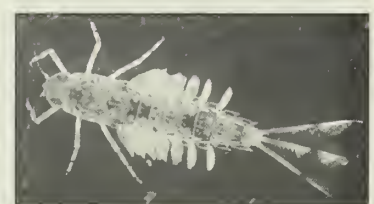
taxon in both burned and unburned sites, but macroinvertebrate richness, density, and biomass were still greater in the unburned sites. Opportunistic species such as chironomids and *B. bicaudatus*, which are well-suited for dispersal through drift (voluntary or accidental dislodgment from the stream bottom into the water column where they move or float with the current) and have relatively short generation times, seemed especially well adapted to post-fire conditions regardless of their trophic niche. The abundance of other species, especially Ephemeroptera (mayflies) such as *Cinygmula*, *Epeorus*, and *Rhithrogena* decreased soon after the fires and had showed little or no recovery.

While the research done at Cache Creek indicated that post-fire increases in streamflow and the resulting alterations in channel configuration or substrate composition could have reduced macroinvertebrate productivity at low-order streams, the USFWS found that macroinvertebrate abundance and species richness increased between the fall of 1988 and the summer of 1991 in most of its higher-order study streams.⁴⁶ Estimated biomass was highly variable among the streams and often highest in the first year post-fire, but no general patterns could be detected. At the three sites that exhibited a substantial decline in macroinvertebrate abundance and a substantial increase in streambank erosion during the first post-fire year (Lamar River, Slough Creek, and Firehole River), the USFWS researchers found no significant correlation between the estimated proportion of silt in the stream substrate and the macroinvertebrate abundance; the estimated erosion was similar at the unburned Soda Butte Creek sites, where macroinvertebrate abundance increased between 1988 and 1989.

The 5th order Gibbon River also showed declining macroinvertebrate abundance, species richness, and biomass during the first three post-fire years, which could have been affected by large fire-related debris flows in 1989 and 1990. The Gibbon River had the lowest post-fire chironomid abundance of any USFWS study site, and it declined as the proportion of post-landslide sand in the stream bottom increased. Sand is an unsuitable substrate for many benthic invertebrates, but the USFWS researchers suggested that the main effect of large sediment inputs from the landslide could be channel scouring, which would reduce the instream vegetation that provides suitable attachment sites for certain taxa.

Many of the invertebrate taxa that USFWS collected from the study streams were classified as moderately to highly tolerant of sediment inputs, suggesting that these streams are adapted to periodic sedimentation episodes. But the most common change in macroinvertebrate communities was in the relative proportion of the various trophic groups. Similar to the trends commonly observed in lower-order streams, macroinvertebrates at the USFWS study sites began to shift from a detritus-based to an autotrophic community (able to produce its own food from inorganic constituents) by the third year post-fire. This was particularly true in the Gibbon River, where a riparian-dependent community (shredders and collectors) was replaced by a community dominated by scrapers. Since scrapers are primarily dependent on food grown within the stream, the increasing abundance in this trophic group indicated an increase in primary production in the study streams.

George Roemhild, an entomologist at Montana State University who began collecting aquatic insects in Yellowstone in 1979, had sampled all of the park's major streams and many small backcountry streams prior to the fires of 1988, and returned to the same sites in 1991 and 1992.⁴⁷ Comparing three groups (stoneflies, mayflies, and caddisflies) before and after the fires, he found no large changes in the number or diversity of insect populations over the park as a whole. Noting that samples taken after the fires contained large amounts of charcoal, Roemhild speculated that it may have absorbed noxious gases and chemicals created by the fires, protecting the insects.



Mayflies: nymph (above)
and adult (below)

Fish

Fire-related mortality.

As with many other kinds of wildlife in the park, fires can have both negative (usually short-term) and positive (generally longer term) effects on fish. An increase in suspended sediment, depending on its concentration and duration, could cause physiological stress, reduced growth, or mortality in fish. But fisheries may benefit from the pulse of nutrients that flows into streams after fires, and fire-killed trees that fall into small to medium size streams can provide cover for fish and slow the current, allowing stressed fish to rest.

In addition to the fish that died as a result of an accidental drop of fire retardant in Fan Creek and the Little Firehole River, some mortality was observed during and shortly after the 1988 fires in the streams of a few extensively burned narrow drainages such as Blacktail Deer, Cache, and Hellroaring creeks. Although water temperatures were unlikely to have reached lethal levels in streams of that size, the Stream Ecology Center researchers conjectured that smoke may have caused fatally high ammonia levels in the water.⁴⁸ Monitoring by the USFWS indicated that trout populations had reestablished themselves at these locations within one year.

Outside the park, major fish kills occurred in Jones Creek, the North Fork of the Shoshone River, and portions of the Lodgepole and Crandall creeks in the Shoshone National Forest. At Jones Creek in August 1990, suspended sediment concentrations of 9,680 mg/L were recorded after a rainstorm-induced debris torrent, and dead trout displaying symptoms of suffocation were found the next day.⁴⁹ Suspended sediment is known to be lethal to salmonids, but usually at higher concentrations or for longer exposures than were found at Jones Creek.

Fish since the fires.

No discernible fire-related effects have been observed in the fish populations or the angling experience in the six rivers that have been monitored regularly since before 1988 (the Firehole, Gardner, Gibbon, Lamar, Madison, and Yellowstone), all of which are 5th or 6th order and therefore less susceptible to substantial alterations in hydrological regime, water chemistry, and vegetation than are smaller streams. Even in the Gibbon River, where landslides in August 1989 brought the most extensive sediment inputs, the spawning and recruitment of young fish appeared unaffected.⁵⁰



Whether the short-term increases in aquatic vegetation and macroinvertebrates in low-gradient 4th to 6th order streams that have functioned as depositional areas for sediment and nutrients from upstream burned areas will ultimately result in greater abundance or biomass of resident fish has not been determined. Post-fire data through 1992 on one to three-year old cutthroat trout showed some of the highest growth rates ever recorded in those streams, but longer-term studies are required to determine if there have been any significant changes across the entire population.⁵¹ Other research priorities have meant that this particular monitoring project has not been continued.

Using a 44-year database, Robert Gresswell's analysis of the Yellowstone cutthroat trout population structure in 1993 did not detect changes that could be attributed to the fires.⁵² By the time the fires reached Yellowstone Lake in 1988, the cutthroat trout spawning runs were completed and post-spawners had returned to the lake, where they were unlikely to be affected by any short-term changes in water chemistry.

But because the Yellowstone cutthroat trout is an important grizzly bear food, concern about the possible effect of changes in stream habitat prompted the Interagency Grizzly Bear Study Team to monitor 1989 spawning and related bear activity.⁵³ Of the 124 tributaries of Yellowstone Lake, 58 had evidence of a spawning run before the fires, of which 34 were located partially or wholly within burned areas. Most of the latter were characterized by open riparian corridors that were not burned intensely and acted as a buffer between the forest crown fire and the stream channel; there was no apparent increase in streambank erosion or change in substrate composition or channel morphology that would affect spawning habitat, nor does there appear to have been a decline in the number of spawning streams. Although the difference in spawner numbers between burned and unburned sites for 1989 in comparison to those recorded for 1985–87 was “marginally significant,” the apparent level of bear activity at spawning streams that year did not change.

Compared to that same pre-fire period, five of the streams in the West Thumb area showed a substantial decline in the average peak number of spawners counted in 1997 and 1998.⁵⁴ The watershed surrounding the West Thumb of Yellowstone Lake area did burn in 1988, and changes in the timing and magnitude of snowmelt runoff from the loss of vegetation could have affected stream temperatures and flow characteristics. However, other spawning streams in burned watersheds have not shown a similar decline. The more likely cause is the non-native lake trout, which preys upon the Yellowstone cutthroat trout and competes with it for other food sources. The lake trout population is believed to have grown steadily since it was illegally introduced sometime before 1988, and is known to be abundant in the West Thumb area.



“Extensive increases in the rate or amount of fine sediment that enters a stream could affect aquatic macroinvertebrate abundance and diversity or eliminate some spawning areas for fish. Over the long term, however, aquatic organisms in Yellowstone must be able to adapt to fire-related disturbances or they would not have survived to the present.”

—Minshall and Brock, 1991



No Turning Back

As shown by the human experiences and ecological changes described in this book, the Yellowstone fires of 1988 were both an event that occurred at a specific time in social and natural history, and part of an ongoing process. Areas that burned are sometimes referred to as having returned to a “biological starting point,” but it is not the same point from which they started after the last fire, any more than we can go back to looking at fire in Yellowstone as we did before 1988.

Although large fires have occurred in the area for millennia, Yellowstone’s history is not simply one of repeated cycles. Instead of returning the park to some past primeval state, the 1988 fires used the materials at hand to shape the park’s future. The ecological processes that have formed the Yellowstone landscape in the past will continue to do so, but in different proportions, on different scales, and at different rates than in the past. What patterns emerge will depend on the pre-fire patterns in the landscape, the patterns left in 1988 by variations in fire type and severity, and post-fire conditions such as climate. Wildland areas are not destined to achieve some particular ideal state if we could remove the human influences. We can look back, but never turn back. If the trend toward a warmer, drier climate in Yellowstone continues, the abundance and distribution of plant and animal species will shift, and large fires may occur more frequently.

Just as the human presence in and around wildlands is inescapable, so is human intervention necessary to preserve wildlands. But interventions that diminish wilderness values should be pursued only when human communities are clearly threatened. It is disturbing when nature shows its muscle with more zeal than we would like: it seems that we want nature, but don’t want it to be completely natural; we want it to behave in a civilized manner. The question is whether Yellowstone, a public trust, should be a stage where nature is allowed to perform, making up the script as it goes along. But if this is not possible in Yellowstone, then where? ❁



Chapter 1: The Role of Fire in Yellowstone

1. Despain, D. 1990. Yellowstone vegetation, consequences of environment and history in a natural setting. Roberts Rinehart, Boulder, Colorado. 238 pages.
2. Barrett, S.W. 1994. Fire regimes on andesitic mountain terrain in northeastern Yellowstone National Park. *International Journal of Wildland Fire* 4(2):65-76.
3. Houston, D.B. 1982. The northern Yellowstone elk. MacMillan, New York. 474 pages.
4. Balling, R.C., Meyer, G.A., and S.G. Wells. 1992a. Climate change in Yellowstone National Park: is the drought-related risk of wildfires increasing? *Climatic Change* 22:35-45.
5. Romme, W. H., and D.G. Despain. 1989. Historical perspective on the Yellowstone fires of 1988. *Bioscience* 39(10): 695-699.
6. Meyer, G.A., and S.G. Wells. 1997. Fire-related sedimentation events on alluvial fans, Yellowstone National Park. *Journal of Sedimentary Research* A67(5): 776-791.
7. Millsbaugh, S.H., C. Whitlock, and P. Bartlein. 2000. Variations in fire frequency and climate over the past 17,000 yr in central Yellowstone National Park. *Geology* (28)3:211-214.
8. Balling et al., Climate change in Yellowstone.
9. Morrison, M. 1993. Fire in paradise: the Yellowstone fires and the politics of environmentalism. Harper Collins Publishers, Inc., New York. 253 pages.
10. Houston, D.B. 1983. Wildfires in Yellowstone National Park. *Ecology* 54(5):1111-1117.
11. Pyne, S.J. 1989. Letting wild fire loose: the fires of '88. Montana, *The Magazine of Western Living* 39(3): 76-79.
12. Renkin, R., and D. Despain. 1992. Fuel moisture, forest type and lightning-caused fire in Yellowstone National Park. *Canadian Journal of Forest Research* 22 (1):37-45.
13. Despain, Yellowstone vegetation.
14. Renkin and Despain, Fuel moisture.
15. Ibid.
16. Ibid.
17. Balling, R.C., Meyer, G.A., and S.G. Wells. 1992b.

Relation of surface climate and burned area in Yellowstone National Park. *Agricultural and Forest Meteorology* 60(3-4): 285-293.

18. Renkin and Despain, Fuel moisture.
19. Brown, J.K. 1991. Should management ignitions be used in Yellowstone National Park? Pages 137-148 in R.B. Keiter and M. Boyce, eds. *The Greater Yellowstone Ecosystem: redefining America's wilderness heritage*. Yale University Press, New Haven, Connecticut.
20. Brown, J.K. 1989. Could the 1988 fires in Yellowstone have been avoided through prescribed burning? *Fire Management Notes* 50(4): 7-13.
21. Schullery, P., and D.G. Despain. 1989. Prescribed burning in Yellowstone National Park: a doubtful proposition. *Western Wildlands* 15(2):30-34.
22. Chase, A. 1988. How Yellowstone got burned. *Outside*. 13 (12): 33, 35-36.
23. Christensen, N.L., J.K. Agee, P.F. Brussard, J. Hughes, D.H. Knight, G.W. Minshall, J.M. Peek, S.J. Pyne, F.J. Swanson, J.W. Thomas, S. Wells, S.E. Williams, and H.A. Wright. 1989. Ecological consequences of the 1988 fires in the Greater Yellowstone Area. *The Greater Yellowstone Postfire Ecological Assessment Workshop Final Report*. 58 pages.

Chapter 2: The Summer of 1988

1. Varley, J.D. and P. Schullery. 1991. Reality and opportunity in the Yellowstone fires of 1988. Pages 105-122 in R.B. Keiter and M. Boyce, eds. *The Greater Yellowstone Ecosystem: redefining America's wilderness heritage*. Yale University Press, New Haven, Connecticut.
2. Collins, Katharine. 1988. Experts predict park fires will slow down. *Casper Star Tribune*, Casper, Wyoming. August 5, 1988.
3. Neckels, J., B. Mutch, R. Wallace, B. Van Zee, and E. Waldapfel. 1988. Greater Yellowstone Area fire situation 1988. Greater Yellowstone Coordinating Committee. 207 pages.
4. Mills, S., ed. 1989. The Greater Yellowstone postfire assessment. Greater Yellowstone Coordinating Committee. 147 pages.
5. Neckels et al., Greater Yellowstone Area fire situation.
6. Rothermel, R.C., R.A. Hartford, and C.H. Chase. 1994. Fire growth maps for the 1988 Greater Yellow-

- stone Area fires. USFS General Technical Report INT-304. 64 pages. Rothermel et al., Fire growth maps.
7. Despain, D.G., A.R. Rodman, P. Schullery, and H.F. Shovic. 1989. Burned area survey of Yellowstone National Park. Geographic Information Systems Laboratory, Yellowstone National Park. 14 pages.
8. Ibid.
9. Varley and Schullery, Reality and opportunity.
10. Romme, W. H., and D.G. Despain. 1989. Historical perspective on the Yellowstone fires of 1988. *BioScience* 39(10): 695-699.
11. Schullery, P., and D.G. Despain. 1989. Prescribed burning in Yellowstone National Park: a doubtful proposition. *Western Wildlands* 15(2):30-34.
12. Romme and Despain, Historical perspective.
13. Morrison, M. 1993. Fire in paradise: the Yellowstone fires and the politics of environmentalism. Harper Collins Publishers, Inc., New York. 253 pages.
14. Ibid.
15. Neckels et al., Greater Yellowstone Area fire situation.
16. Morrison, Fire in paradise.
17. Mills, Yellowstone postfire assessment.
18. Brown, J.K. 1989. Could the 1988 fires in Yellowstone have been avoided through prescribed burning? *Fire Management Notes* 50(4): 7-13.
19. Mills, Yellowstone postfire assessment.
20. Greenberg, M.R., Sachsman, D.B. Sandman, P.M., and K.L. Salomone. 1989. Risk, drama and geography in coverage of environmental risk by network TV. *Journalism Quarterly* 66(2): 267-276.
21. Morrison, Fire in paradise.
22. Smith, C. 1996. Media coverage of fire ecology in Yellowstone after 1988. Pages 25-34 in J. Greenlee, ed. The ecological implications of fire in Greater Yellowstone: proceedings of the second biennial conference on the Greater Yellowstone Ecosystem. International Association of Wildland Fire, Fairfield, Washington.
23. Smith, Media coverage of fire ecology.
1. mas, S. Wells, S.E. Williams, and H.A. Wright. 1989. Ecological consequences of the 1988 fires in the Greater Yellowstone Area. The Greater Yellowstone Postfire Ecological Assessment Workshop Final Rept. 58 pages.
2. Comstock, Theo. B. 1874. The Yellowstone National Park: its scientific value. *American Naturalist* 8:65-79.
3. Mills, Yellowstone postfire assessment.
4. Williams, E.D., and S.C. Smith. 1990. Rehabilitation of fire suppression impacts on the North Fork fire in Yellowstone National Park. Report to the U.S. Department of the Interior. YNP/LA 90-01.
5. Ibid.
6. Ibid.
7. Johnson, A.M., and K.A. Lippincott. 1989. Post-fire archeological assessment. Yellowstone National Park. Manuscript on file.
8. Ibid.
9. Connor, M.A., and K.P. Cannon. 1991. Forest fires as a site formation process in the Rocky Mountains of northwestern Wyoming. *Archaeology in Montana* 32(2): 1-14.
10. Cannon, K.P., and P. Phillips. 1993. Post-fire inventory and evaluation in Yellowstone National Park: the 1989 field season. Midwest Archeological Center Technical Report No. 24.
11. Connor, M.A., K.P. Cannon, and D. Carlevato. 1989. The mountain burnt: forest fires and site formation processes. *North American Archaeologist* 10: 293-310.
12. Johnson, A.M., S.W. Conner, and K.J. Feyl. 1991. Post-fire identification of nineteenth century wooden structures. *Archaeology in Montana* 32(2): 33-47.
13. Cannon and Phillips, Post-fire inventory.
14. Polzin, P.E., M.S. Yuan, and E.G. Schuster. 1993. Some economic impacts of the 1988 fires in the Yellowstone area. U.S. Department of Agriculture, Forest Service. Research Note INT-418.
15. Snepenger, D.J., J.D. Johnson, and N. Friede. 1996. Tourism in Montana after the 1988 fires in Yellowstone National Park. Pages 23-24 in J. Greenlee, ed. The ecological implications of fire in Greater Yellowstone: proceedings of the second biennial conference on the Greater Yellowstone Ecosystem. International Association of Wildland Fire, Fairfield, Washington.
16. Pyne, S.J. 1989. Burning questions and false alarms about wildfires at Yellowstone. *Forum for Applied Research and Public Policy* 4(2): 31-40.

Chapter 3: The Human Aftermath

1. Mills, S., ed. 1989. The Greater Yellowstone postfire assessment. Greater Yellowstone Coordinating Committee. 147 pages. See also: Christensen, N.L., J.K. Agee, P.F. Brussard, J. Hughes, D.H. Knight, G.W. Minshall, J.M. Peek, S.J. Pyne, F.J. Swanson, J.W. Tho-

17. Bath, A.J. 1993. Attitudes toward fire and fire management issues in Yellowstone National Park. Ph.D. diss., University of Calgary, Alberta, Canada.
18. Fire Management Policy Review Team. 1989. Final report on fire management policy. U.S. Department of Interior, Fish & Wildlife Service, Washington, D.C.
19. Bonnicksen, T.M. 1989. Fire gods and federal policy. *American Forests* 95(7/8): 14-16.
12. Runnells, D.D., and M.A. Siders. 1991. Pages 149 to 155 in University of Wyoming National Park Service Research Center Annual Report.
13. Montagne, C., and E. Skogley. 1992. Burned-unburned resin extractor soil nutrient comparison. Final report from the Plant and Soil Science Department and the Montana Agricultural Experiment Station, Montana State University, Bozeman.

Chapter 4: Changes in the Landscape

1. Despain, D. 1990. Yellowstone vegetation, consequences of environment and history in a natural setting. Roberts Rinehart, Boulder, Colorado. 239 pages.
2. Balling, R.C., Meyer, G.A., and S.G. Wells. 1992a. Climate change in Yellowstone National Park: is the drought-related risk of wildfires increasing? *Climatic Change* 22:35-45.
3. Romme, W.H., and D.H. Knight. 1982. Landscape diversity: the concept applied to Yellowstone Park. *BioScience* 32(8):664-669.
4. Houston, D.B. 1982. The northern Yellowstone elk. MacMillan, New York. 474 pages.
5. Romme and Knight, Landscape diversity.
6. Turner, M.G., W. Hargrove, R.H. Gardner, and W.H. Romme. 1994a. Effects of fire on landscape heterogeneity in Yellowstone National Park. *Journal of Vegetation Science* 5:731-742.
7. Ellis, M., C.D. von Dohlen, J.E. Anderson and W.H. Romme. 1994. Some important factors affecting density of lodgepole pine seedlings following the 1988 Yellowstone fires. Pages 139-150 in D. Despain, ed. Plants and their environments: proceedings of the first scientific conference on the Greater Yellowstone Ecosystem. NPS/NRYELL/NRTR. USDI, NPS, Denver.
8. Reed, R.A., M.E. Finley, W.H. Romme, and M.G. Turner. 1999. Aboveground net primary production and leaf-area index in early postfire vegetation in Yellowstone National Park. *Ecosystems* 2:88-94.
9. Taylor, D.L. 1973. Some ecological implications of forest fire control in Yellowstone National Park. *Ecology* 54(6):1394-1396.
10. Meagher, M.M. and D. Houston. 1998. Yellowstone and the biology of time. University of Oklahoma Press, Norman, Oklahoma. 287 pages.
11. Mills, S., ed. 1989. The Greater Yellowstone postfire assessment. Greater Yellowstone Coordinating Committee. 147 pages.
14. Ryan, K.C., and G.D. Amman. 1996. Bark beetle activity and delayed tree mortality in the Greater Yellowstone Area following the 1988 fires. Pages 151-158 in J. Greenlee, ed. The ecological implications of fire in Greater Yellowstone: proceedings of the second biennial conference on the Greater Yellowstone Ecosystem. International Association of Wildland Fire, Fairfield, Washington.
15. Knight, D.H. 1994. Mountains and plains: the ecology of Wyoming landscapes. Yale University Press, New Haven, Connecticut. 338 pages.
16. Turner, M.G., W.H. Romme, R.H. Gardner, and W.W. Hargrove. 1997. Effects of fire size and pattern on early succession in Yellowstone National Park. *Ecological Monographs* 76(4):411-433.
17. Amman, G.D. and K.C. Ryan, K. C. 1991. Insect infestation of fire-injured trees in the Greater Yellowstone Area. USDA Forest Service, Intermountain Research Station, Ogden, Utah. Research Note INT-398.
18. Parker, D.L., and L.E. Stipe. 1993. A sequence of destruction: mountain pine beetle and wildfire. Technical Report, USDA Forest Service, Southwest Region.
19. Ryan and Amman, Bark beetle activity.
20. Ibid.
21. USDA Forest Service, Northern Region. 1998. Montana: forest insect and disease conditions and program highlights 1997. Report 98-2.
22. Despain, Yellowstone vegetation.
23. Johnson, E.A., and G.I. Fryer. 1989. Population dynamics in lodgepole pine-Engelmann spruce forests. *Ecology* 70:1335-1345.
24. Despain, D., R. Clark and J. Reardon. 1996. Effects of crown fire on the crown seed bank of lodgepole pine in Yellowstone National Park. Pages 15-19 in J. Greenlee, ed. The ecological implications of fire in Greater Yellowstone: proceedings of the second biennial conference on the Greater Yellowstone Ecosystem. International Assoc. of Wildland Fire, Fairfield, Washington.
25. Anderson, J.E., and W.H. Romme. 1991. Initial

- floristics in lodgepole pine forests following the 1988 Yellowstone fires. *International Journal of Wildland Fire*. 1:119-124.
26. Ellis et al., Some important factors affecting density of lodgepole pine seedlings.
 27. Nyland, R.D. 1998. Patterns of lodgepole pine regeneration following the 1988 Yellowstone fires. *Forest Ecology and Management* 111(1):23-33.
 28. Romme, W.H. 1999. Causes and consequences of alternative successional trajectories following the 1988 Yellowstone fires. *Investigators' Annual Reports*. Yellowstone National Park.
 29. Personal communication, Burger, John, University of New Hampshire.
 30. Turner et al., Effects of fire size on landscape.
 31. Tomback, D.F. *In press*. Clark's nutcracker: agent of regeneration. In D.F. Tomback, ed. *Whitebark pine communities: ecology and restoration*. Island Press, Washington, D.C.
 32. Kendall, K.C. 1998. Whitebark pine. Pages 483 to 485 in Mac, M.J., P.A. Opler, C.E. Puckette Haecker, and P.D. Doran, eds. *Status and trends of the nation's biological resources*. Vol. 2. U.S. Department of the Interior, U.S. Geological Survey, Reston, Virginia.
 33. Ibid.
 34. Ibid.
 35. Tomback, D.F., A.J. Anderies, K.S. Carsey, and M.L. Powell. *In press*. Delayed seed germination in whitebark pine and regeneration patterns following the Yellowstone fires. *Ecology*.
 36. Renkin, R., and D. Despain 1996. Preburn root biomass/basal area influences on the response of aspen to fire and herbivory. Pages 95-106 in J. Greenlee, ed. *The ecological implications of fire in Greater Yellowstone: proceedings of the second biennial conference on the Greater Yellowstone Ecosystem*. International Association of Wildland Fire, Fairfield, Washington.
 37. Romme, W.H., M.G. Turner, L.L. Wallace, and J.S. Walker. 1995. Aspen, elk, and fire in northern Yellowstone National Park. *Ecology* 76(7):2097-2106.
 38. Barmore, W. *In press*. Ecology of ungulates and their winter range in Yellowstone National Park. Yellowstone Center for Resources, Yellowstone National Park, Mammoth, Wyoming.
 39. Despain, Yellowstone vegetation.
 40. Renkin and Despain, Response of aspen to fire.
 41. Meagher and Houston, The biology of time.
 42. Kay, C.E., and F.H. Wagner. 1996. Response of shrub-aspen to Yellowstone's 1988 wildfires; implications for "natural regulation" management. Pages 107-112 in J. Greenlee, ed. *The ecological implications of fire in Greater Yellowstone: proceedings of the second biennial conference on the Greater Yellowstone Ecosystem*. International Association of Wildland Fire, Fairfield, Washington.
 43. White, C.A., C.E. Olmsted, and C.E. Kay. 1998. Aspen, elk, and fire in the Rocky Mountain national parks of North America. *Wildlife Society Bulletin* 26(3): 449-462.
 44. Renkin and Despain, Response of aspen to fire.
 45. Ibid.
 46. Ibid.
 47. Romme et al., Aspen, elk, and fire.
 48. Renkin and Despain, Response of aspen to fire.
 49. Kay and Wagner, Response of shrub-aspen to Yellowstone's wildfires.
 50. Kay, C.E. 1997. Ungulate herbivory, willows, and political ecology in Yellowstone. *Journal of Range Management* 50(2):139-145.
 51. Romme, W.H., M.G. Turner, R.H. Gardner, W.W. Hargrove, G.A. Tuskan, D.G. Despain, and R.A. Renkin. 1997. A rare episode of sexual reproduction in aspen (*Populus tremuloides Michx.*) following the 1988 Yellowstone fires. *Natural Areas Journal* 17:17-25.
 52. Ibid.
 53. Renkin and Despain, Response of aspen to fire and herbivory.
 54. Romme et al., Sexual reproduction in aspen.
 55. Ripple, W.J., and E.J. Larsen. *In press*. The role of postfire coarse woody debris in aspen regeneration. *Western Journal of Applied Forestry* 16(2).
 56. Renkin and Despain, Response of aspen to herbivory.
 57. Turner et al., Effects of fire size.
 58. Turner, M.G., R.A. Reed, W.H. Romme, M.E. Finley, and D.H. Knight. 1997. Above-ground net primary production, leaf area index, and nitrogen dynamics in early post-fire vegetation, Yellowstone National Park. Pages 130 to 134 in *University of Wyoming National Park Service Research Center*.
 59. Tracy, B.F. 1997. Fire effects in Yellowstone's grasslands. *Yellowstone Science* 5(3): 2-5.

60. Meagher and Houston, The biology of time.
61. Knight, D.H., and L.L. Wallace. 1989. The Yellowstone fires: issues in landscape ecology. *BioScience* 39:707-715.
62. Tracy, B.F. and S.J. McNaughton. 1997. Elk grazing and vegetation responses following a late season fire in Yellowstone National Park. *Plant Ecology* 130 (2):111-119.
63. Merrill, E., and R. Marrs. 1997. Remote sensing of vegetation recovery in grasslands after the 1988 fires in Yellowstone National Park. Pages 130-133 in The University of Wyoming National Park Service Research Center Annual Report.
64. Tracy and McNaughton, Elk grazing and vegetation.
65. Meagher and Houston, The biology of time.
66. Tracy, Fire effects in Yellowstone's grasslands.
67. Yellowstone National Park. 1997. Yellowstone's northern range: complexity and change in a wildland ecosystem. National Park Service, Mammoth Hot Springs, Wyoming. 148 pages.
68. Engstrom, D.R., C. Whitlock, S.C. Fritz, and H.E. Wright, Jr. 1991. Recent environmental changes inferred from the sediments of small lakes in Yellowstone's northern range. *Journal of Paleolimnology* 5(2):139-174.
69. Meagher and Houston, The biology of time.
70. Singer, F.J., L.C. Mack, and R.C. Cates. 1994. Ungulate herbivory of willows on Yellowstone's northern winter range. *Journal of Range Management* 47:435-443.
71. Ibid. See also: Meagher and Houston, The biology of time.
72. Norland, J.E., F.J. Singer, and L. Mack. 1996. Effects of the Yellowstone fires of 1988 on elk habitats. Pages 223-232 in J. Greenlee, ed. The ecological implications of fire in Greater Yellowstone: proceedings of the second biennial conference on the Greater Yellowstone Ecosystem. International Association of Wildland Fire, Fairfield, Washington.
73. Tyers, D.B. *Submitted Ph.D. diss.* Winter ecology of moose on the northern Yellowstone range. Montana State University, Bozeman.
74. Norland et al., Effects of the Yellowstone fires on elk habitats.
75. Chadde, S. and C. Kay. 1991. Tall-willow communities on Yellowstone's northern range: a test of the "natural regulation" paradigm. Pages 231-262 in R.R. Keiter and M. Boyce, eds. The Greater Yellowstone Ecosystem: redefining America's wilderness heritage. Yale University Press, New Haven, Connecticut.
76. Singer et al., Ungulate herbivory.
77. Singer, F.J., Zeigenfuss, L.C., Cates, R.G., and D.T. Barnett, D.T. 1998. Elk, multiple factors, and persistence of willows in national parks. *Wildlife Society Bulletin* 26(3):419-428.
78. Turner et al., Effects of fire size on landscape.

Chapter 5: Wildlife

1. Singer, F.J., W. Schreier, J. Oppenheim, and E.O. Garton. 1989. Drought, fires, and large mammals. *BioScience* 39(10):716-722.
2. French, M.G., and S. French. 1996. Large mammal mortality in the 1988 Yellowstone fires. Pages 113-115 in J. Greenlee, ed. The ecological implications of fire in Greater Yellowstone: proceedings of the second biennial conference on the Greater Yellowstone Ecosystem. International Association of Wildland Fire, Fairfield, Washington.
3. Singer et al, Drought, fires, and large mammals.
4. Boyce, M. and E.H. Merrill. 1996. Predicting effects of 1988 fires on ungulates in Yellowstone National Park. Pages 361-68 in F.J. Singer, ed. Effects of grazing by wild ungulates in Yellowstone National Park. National Park Service, Natural Resource Information Division, Denver, Colorado.
5. Singer, F.J., and P. Schullery. 1989. Yellowstone wildlife: populations in process. *Western Wildlands* 15 (2): 18-22.
6. Singer et al, Drought, fires, and large mammals.
7. Ibid.
8. Farnes, P., C. Heydon, and K. Hansen. 1999. Snowpack distribution across Yellowstone National Park. Final Report to Yellowstone National Park.
9. DelGuidice, G.D., and F.J. Singer. 1996. Physiological responses of Yellowstone elk to winter nutritional restriction before and after the 1988 fires: a preliminary examination. Pages 133-135 in J. Greenlee, ed. The ecological implications of fire in Greater Yellowstone: proceedings of the second biennial conference on the Greater Yellowstone Ecosystem. International Association of Wildland Fire, Fairfield, Washington.
10. Turner, M.G., Y. Wu, L.L. Wallace, W.H. Romme, and A. Brenkert. 1994b. Simulating winter interactions among ungulates, vegetation, and fire in northern Yellowstone Park. *Ecological Applications* 4(3):472-496.

11. Wu, Y., M.G. Turner, L.L. Wallace, and W.H. Romme. 1996. Elk survival following the 1988 fires: a simulation experiment. *Natural Areas Journal* 16(3):198-207.
12. Coughenour, M.B. and F.J. Singer. 1996. Yellowstone elk population responses to fire—a comparison of landscape carrying capacity and spatial-dynamic ecosystem modeling approaches. Pages 169-179 in J. Greenlee, ed. *The ecological implications of fire in Greater Yellowstone: proceedings of the second biennial conference on the Greater Yellowstone Ecosystem*. International Assoc. of Wildland Fire, Fairfield, Washington.
13. Singer, F.J., A. Harting, K.K. Symonds, and M.B. Coughenour. 1997. Density dependence, compensation, and environmental effects on elk calf mortality in Yellowstone National Park. *Journal of Wildlife Management* 61(1):12-15.
14. Tracy, B.F., and S.J. McNaughton. 1997. Elk grazing and vegetation responses following a late season fire in Yellowstone National Park. *Plant Ecology* 130(2):111-119.
15. Tracy, B.F. 1998. Fire effects, elk, and ecosystem resilience in Yellowstone's sagebrush grasslands. Abstract in *Yellowstone Science supplement* 6(2):53.
16. Boyce and Merrill, Predicting effects of 1998 fires.
17. Wallace, L.L., M.G. Turner, W.H. Romme, R.V. O'Neill and Y. Wu. 1995. Scale of heterogeneity of forage production and winter foraging by elk and bison. *Landscape Ecology*. 10(2):75-83.
18. Pearson, S., M.G. Turner, L.L. Wallace, and W.H. Romme. 1995. Winter habitat use by large ungulates following fire in northern Yellowstone National Park. *Ecological Applications* 5(3):744-755.
19. Norland, J.E, F.J. Singer, and L. Mack. 1996. Effects of the Yellowstone fires of 1988 on elk habitats. Pages 223-232 in J. Greenlee, ed. *The ecological implications of fire in Greater Yellowstone: proceedings of the second biennial conference on the Greater Yellowstone Ecosystem*. International Association of Wildland Fire, Fairfield, Washington.
20. Vales, D.J., and J.M. Peek. 1996. Responses of elk to the 1988 Yellowstone fires and drought. Pages 159-167 in J. Greenlee, ed. *The ecological implications of fire in Greater Yellowstone: proceedings of the second biennial conference on the Greater Yellowstone Ecosystem*. International Association of Wildland Fire, Fairfield, Washington.
21. Singer, F.J. and M.K. Harter. 1996. Comparative effects of elk herbivory and 1988 fires on northern Yellowstone National Park grasslands. *Ecological Applications* 6(1):185-199.
22. Tracy and McNaughton, Elk grazing and vegetation responses.
23. Singer and Harter, Comparative effects of elk herbivory.
24. Van Dyke, F., M.J. Deboer, and G.M. Van Beek. 1996. Winter range plant production and elk use following prescribed burning. Pages 193-200 in J. Greenlee, ed. *The ecological implications of fire in Greater Yellowstone: proceedings of the second biennial conference on the Greater Yellowstone Ecosystem*. International Association of Wildland Fire, Fairfield, Washington.
25. White, P.J., and R.A. Garrott. 1993. Bark eating by Yellowstone elk. *Yellowstone Science* 1(4):2-5.
26. Vales and Peek, Responses of elk to the 1988 fires.
27. Jakubas, W.J., R.A. Garrott, P.J. White, and D.R. Mertens. 1994. Fire-induced changes in the nutritional quality of lodgepole pine bark. *Journal of Wildlife Management* 58:35-46.
28. Lemke, T.O., J.A. Mack, and D.B. Houston. Winter range expansion by the northern Yellowstone elk herd. *Intermountain Journal of Sciences* 4(1/2): 1-9.
29. Scott, M.D., and H. Geisser. 1996. Pronghorn migration and habitat use following the 1988 Yellowstone fires. Pages 123-132 in J. Greenlee, ed. *The ecological implications of fire in Greater Yellowstone: proceedings of the second biennial conference on the Greater Yellowstone Ecosystem*. International Association of Wildland Fire, Fairfield, Washington.
30. Houston, D.B. 1982. *The northern Yellowstone elk*. MacMillan, New York. See also: Schullery and Whitteley, 1992.
31. Kelsall, J.P., E.S. Telfer, and T.D. Wright. 1977. The effects of fire on the ecology of the boreal forest, with particular reference to the Canadian north. Occasional paper 323. Canadian Wildlife Service, Ottawa. 58 pages. See also: Schwartz, C.C., and A.W. Franzmann. 1989. Bears, wolves, moose, and forest succession; some management considerations on the Kenai peninsula, Alaska. *Alces* 25:1-10.
32. Gruell, G.E. 1980. Fire's influence on wildlife habitat on the Bridger-Teton National Forest, Wyoming. Intermountain Forest and Range Experiment Station, Ogden, Utah. USDA Research Paper INT-235.
33. Tyers, D.B. *Submitted Ph.D. diss.* Winter ecology of moose on the northern Yellowstone range. Montana State University, Bozeman.

34. Singer, F.J., W. Schreier, J. Oppenheim, and E.O. Garton. 1989. Drought, fires, and large mammals. *BioScience* 39(10):716-722
35. Blanchard, B.M., and R.R. Knight. 1990. Reactions of grizzly bears to wildfire in Yellowstone National Park. *Canadian Field-Naturalist* 104:592-594.
36. Blanchard, B.M., and R.R. Knight. 1996. Effects of wildfire on grizzly bear movements and food habits. Pages 117-122 in J. Greenlee, ed. *The ecological implications of fire in Greater Yellowstone: proceedings of the second biennial conference on the Greater Yellowstone Ecosystem*. International Association of Wildland Fire, Fairfield, Washington.
37. Podrutzny, S.R., D.P. Reinhart, and D.J. Mattson. *In press*. Fire, red squirrels, whitebark pine, and Yellowstone grizzly bears. *Ecology*.
38. Crabtree, R.L. and J.W. Sheldon. 1999. The ecological role of coyotes on Yellowstone's northern range. *Yellowstone Science* 7(2):15-23.
39. Renkin, R. 1989. Small mammal communities after the 1988 Yellowstone fires. Yellowstone National Park. Report on file.
40. Bissonette, J.A. and S.S. Sherburne. 1992. Habitat preferences of unexploited pine marten (*Martes americana*) populations in Yellowstone National Park. Final report. Utah Cooperative Fish and Wildlife Research Unit, Logan, Utah.
41. Ibid.
42. Taylor, D.L. 1982. Competition between mountain bluebirds and tree swallows in post-fire areas of Yellowstone National Park. *National Geographic Society Research Reports* 14: 655-667.
43. Gniadek, S. 1977. Some aspects of avian ecology following the 1974 Trail Creek and 1976 Divide fires in Yellowstone National Park. Final Research Report.
44. McEneaney, T. 1990. Yellowstone: not so black and white. *The Living Bird Quarterly*, Spring: 11-17.
45. Hutto, R.L. 1995. The composition of bird communities following stand-replacement fires in northern Rocky Mountain conifer forests. *Conservation Biology* 9:1041-1058.
46. Amman, G.D. and K.C. Ryan, K. C. 1991. Insect infestation of fire-injured trees in the Greater Yellowstone Area. USDA Forest Service, Intermountain Research Station, Ogden, Utah. Research Note INT-398.
47. Christiansen, T.A., and R.J. Lavigne. 1996. Habitat requirements for the reestablishment of litter invertebrates following the 1988 Yellowstone National Park fires. Pages 147-150 in J. Greenlee, ed. *The ecological implications of fire in Greater Yellowstone: proceedings of the second biennial conference on the Greater Yellowstone Ecosystem*. International Association of Wildland Fire, Fairfield, Washington.
48. Christiansen, T. 1996. Terrestrial litter invertebrate communities in Yellowstone Park. *Yellowstone Science* 4(2): 2-3.
49. Beetle, D.E. 1997. Recolonization of burned aspen groves by land snails. *Yellowstone Science* 5(3):6-8.
50. Patla, D.A., and C.R. Peterson. 1994. The effects of habitat modification on a spotted frog population in Yellowstone National Park. Pages 135 to 144 in *University of Wyoming National Park Service Research Center Annual Report*.
51. Koch, E.D., and C.R. Peterson. 1995. Amphibians and reptiles of Yellowstone and Grand Teton National Park. University of Utah Press, Salt Lake City. 188 pages.

Chapter 6: Watershed and Stream Dynamics

1. Minshall, G.W., and C.T. Robinson. 1993. Effects of the 1988 wildfires on stream systems of Yellowstone National Park: five-year comparison. University of Wyoming/National Park Service Research Center.
2. Minshall, G.W., J.T. Brock, and J.D. Varley. 1989. Wildfires and Yellowstone's stream ecosystems. *BioScience* 39:707-715.
3. Meyer, G.A., and S.G. Wells. 1997. Fire-related sedimentation events on alluvial fans, Yellowstone National Park. *Journal of Sedimentary Research* A67(5):776-791.
4. Minshall, G.W., J.T. Brock and T.V. Royer. 1998. Stream ecosystem responses to the 1988 wildfires. *Yellowstone Science* 6(3): 15-22.
5. Meyer and Wells, Fire-related sedimentation events.
6. Minshall et al., Stream ecosystem responses.
7. Farnes, P.E., W.W. McCaughey, and K.J. Hansen. *In press*. Role of fire in determining annual water yield in mountain watersheds. Chapter 11 in L. Wallace, ed. *After the fires: the ecology of change in Yellowstone National Park*. Yale University Press, New Haven, Connecticut.
8. McIntyre, M.J., and G.W. Minshall. 1996. Changes in transport and retention of coarse particulate organic matter in streams subject to fire. Pages 59-76 in J. Greenlee, ed. *The ecological implications of fire in Greater Yellowstone: proceedings of the second biennial conference on the Greater Yellowstone Ecosystem*. International Association of Wildland Fire, Fairfield, Washington.

- Greater Yellowstone: proceedings of the second biennial conference on the Greater Yellowstone Ecosystem. International Association of Wildland Fire, Fairfield, Washington.
9. Troendle, C.A., and G.S. Bevenger. 1996. Effect of fire on streamflow and sediment transport in Shoshone National Forest. Pages 43-52 in J. Greenlee, ed. The ecological implications of fire in Greater Yellowstone: proceedings of the second biennial conference on the Greater Yellowstone Ecosystem. International Association of Wildland Fire, Fairfield, Washington.
 10. U.S. Fish and Wildlife Service. 1993. Annual project technical report for 1992, fishery and aquatic management program, Yellowstone National Park.
 11. Marston, R.A., and D.H. Haire. 1990. Runoff and soil loss following the 1988 Yellowstone fires. *Great Plains-Rocky Mountain Geographical Journal*. 18:1-8.
 12. Varley, J.D., and P. Schullery. 2000. Yellowstone fishes: ecology, history, and angling in the park. Stackpole Books, Mechanicsburg, Pennsylvania.
 13. Lawrence, D.E., and G.W. Minshall. 1994. Short- and long-term postfire changes in riparian zone vegetation and stream macroinvertebrate community structure. Pages 171-184 in D. Despain, ed. *Plants and their environments: proceedings of the first scientific conference on the Greater Yellowstone Ecosystem*. Technical Report NPS/NRYELL/NRTR. USDI, NPS, Denver, Colorado.
 14. Tinker, D.B., and D.H. Knight. 1998. Fire and the dynamics of coarse woody debris in Yellowstone National Park. Conference abstract in *Yellowstone Science supplement* 6(2):53.
 15. McIntyre and Minshall, Changes in transport.
 16. Minshall and Robinson, Effects of the 1988 wildfires.
 17. Minshall et al., Wildfires and Yellowstone's streams.
 18. Young, M.K. and M.A. Bozek. 1996. Post-fire effects on coarse woody debris and adult trout in northwestern Wyoming streams. Pages 147-150 in J. Greenlee, ed. The ecological implications of fire in Greater Yellowstone: proceedings of the second biennial conference on the Greater Yellowstone Ecosystem. International Assoc. of Wildland Fire, Fairfield, Washington.
 19. Minshall et al., Stream ecosystem responses.
 20. Ewing, R. 1996. Postfire suspended sediment from Yellowstone National Park, Wyoming. *Journal of the American Water Resources Association* 32(3):605-627.
 21. Troendle and Bevenger, Effect of fire on streamflow.
 22. Young and Bozek, Post-fire effects on woody debris.
 23. Mahony, D.L., and R.E. Gresswell. 1998. Short-term postfire variation of physical habitat, fish populations, and associated aquatic communities in large streams of Yellowstone National Park. Conference abstract in *Yellowstone Science supplement* 6(2): 39.
 24. Minshall and Robinson, Effects of the 1988 wildfires.
 25. Ibid.
 26. McIntyre and Minshall, Changes in transport.
 27. Robinson, C.T., and G.W. Minshall. 1996. Physical and chemical responses of streams in Yellowstone National Park following the 1988 wildfires. Pages 217-222 in J. Greenlee, ed. The ecological implications of fire in Greater Yellowstone: proceedings of the second biennial conference on the Greater Yellowstone Ecosystem. International Association of Wildland Fire, Fairfield, Washington.
 28. Minshall, G.W., and J.T. Brock. 1991. Observed and anticipated effect of forest fire on Yellowstone stream ecosystems. Pages 146-157 in R.R. Keiter and M. Boyce, eds. *The Greater Yellowstone Ecosystem: redefining America's Wilderness Heritage*. Yale University Press, New Haven, Connecticut.
 29. Minshall et al., Wildfires and Yellowstone's streams.
 30. Minshall and Robinson, Effects of the 1988 wildfires.
 31. Lathrop, R.G. 1994. Impacts of the 1988 wildfires on the water quality of Yellowstone and Lewis Lakes, Wyoming. *International Journal of Wildland Fire*. 4(3):169-175.
 32. U.S. Fish and Wildlife Service, 1993 annual report.
 33. Minshall et al., Stream ecosystem responses.
 34. Robinson and Minshall, Responses of streams.
 35. Brass, J.A, V.G. Ambrosia, P.J. Riggan and P.D. Sebesta. 1996. Consequences of fire on aquatic nitrate and phosphate dynamics in Yellowstone National Park. Pages 53-58 in J. Greenlee, ed. The ecological implications of fire in Greater Yellowstone: proceedings of the second biennial conference on the Greater Yellowstone Ecosystem. International Association of Wildland Fire, Fairfield, Washington.
 36. Runnells, D.D., and M.A. Siders. 1991. Pages 149 to 155 in *University of Wyoming National Park Service Research Center Annual Report*.
 37. _____, S.W. Rushforth, and G.W. Minshall. 1996.

- Diatom assemblages in Cache Creek, Yellowstone National Park. Pages 77-81 *in* J. Greenlee, ed. The ecological implications of fire in Greater Yellowstone: proceedings of the second biennial conference on the Greater Yellowstone Ecosystem. International Association of Wildland Fire, Fairfield, Washington.
38. Romme, W.H., and D.H. Knight. 1982. Landscape diversity: the concept applied to Yellowstone Park. *BioScience* 32(8):664-669.
 39. Lathrop, Water quality of Yellowstone and Lewis Lakes.
 40. Theriot, E.C., S.C. Fritz, and R.W. Gresswell. 1997. Long-term limnological data from the larger lakes of Yellowstone National Park. *Arctic and Alpine Research* 29(3):304-314.
 41. Minshall et al., Stream ecosystem responses.
 42. Mihuc, T.B., G.W. Minshall, and C.T. Robinson. 1996. Response of benthic macroinvertebrate populations in Cache Creek, Yellowstone National Park to the 1988 wildfires. Pages 77-82 *in* J. Greenlee, ed. The ecological implications of fire in Greater Yellowstone: proceedings of the second biennial conference on the Greater Yellowstone Ecosystem. International Association of Wildland Fire, Fairfield, Washington.
 43. Minshall et al., Stream ecosystem responses.
 44. Mihuc, T.B. and G.W. Minshall. 1995. Trophic generalists vs. trophic specialists: implications for food web dynamics in post-fire streams. *Ecology* 76:2361-2372.
 45. Minshall, G.W., C.T. Robinson, T.V. Royer, and S.R. Rushforth. 1995. Benthic community structure in two adjacent streams in Yellowstone National Park. *Great Basin Naturalist* 55(3): 193-200.
 46. U.S. Fish and Wildlife Service, 1993 annual report.
 47. Roemhild, G. 1994. Aquatic insects and the fires of 1988. *Yellowstone Science* 2(2):2-4.
 48. Minshall et al., Stream ecosystem responses.
 49. Young and Bozek, Post-fire effects on woody debris.
 50. U.S. Fish and Wildlife Service, 1993 annual report.
 51. Ibid.
 52. Gresswell, R.E. 1996. Relative Effects of fire and anthropogenic perturbations on Yellowstone cutthroat trout in Yellowstone Lake. Page 17 *in* The ecological implications of fire in Greater Yellowstone, agenda & abstracts. Yellowstone National Park, Mammoth Hot Springs, Wyoming.
 53. Reinhart, D.P. 1989. Effects of fire on cutthroat trout spawning streams and associated bear use. Pages 19-27 *in* Yellowstone grizzly bear investigations: annual report of the Interagency Grizzly Bear Study Team. U.S. Geological Survey, Bozeman, Montana.
 54. Haroldson, M., D. Reinhart, K. Gunther, and L. Waits. 1998. Spawning cutthroat trout numbers on tributary streams to Yellowstone Lake. Pages 33-39 *in* Yellowstone grizzly bear investigations: Annual report of the Interagency Grizzly Bear Study Team. U.S. Geological Survey, Bozeman, Montana.



References



- Amman, G.D., and K. C. Ryan, K. C. 1991. Insect infestation of fire-injured trees in the Greater Yellowstone Area. USDA Forest Service, Intermountain Research Station, Ogden, Utah. Research Note INT-398.
- Anderson, J.E., and W.H. Romme. 1991. Initial floristics in lodgepole pine forests following the 1988 Yellowstone fires. *International Journal of Wildland Fire* 1:119-124.
- Balling, R.C., Meyer, G.A., and S.G. Wells. 1992a. Climate change in Yellowstone National Park: Is the drought-related risk of wildfires increasing? *Climatic change* 22:35-45.
- _____, _____, and _____. 1992b. Relation of surface climate and burned area in Yellowstone National Park. *Agricultural and Forest Meteorology* 60(3-4):285-293.
- Barmore, W. *In press*. Ecology of ungulates and their winter range in Yellowstone National Park. Yellowstone Center for Resources, Yellowstone National Park, Mammoth, Hot Springs, Wyoming.
- Barrett, S.W. 1994. Fire regimes on andesitic mountain terrain in northeastern Yellowstone National Park, Wyoming. *International Journal of Wildland Fire* 4(2):65-76.
- Bath, A.J. 1993. Attitudes toward fire and fire management issues in Yellowstone National Park. Dissertation, University of Calgary, Alberta, Canada.
- Beetle, D.E. 1997. Recolonization of burned aspen groves by land snails. *Yellowstone Science* 5(3):6-8.
- Bissonette, J.A. and S.S. Sherburne. 1992. Habitat preferences of unexploited pine marten (*Martes americana*) populations in Yellowstone National Park. Final report. Utah Cooperative Fish and Wildlife Research Unit, Logan, Utah.
- Blanchard, B.M., and R.R. Knight. 1990. Reactions of grizzly bears to wildfire in Yellowstone National Park. *Canadian Field-Naturalist* 104:592-594.
- Boltz, G., D.G. Carty, R.D. Jones, L.R. Kaeding, D.L. Mahony, and T. Olliff. 1993. Annual project technical report for 1992, fishery and aquatic management program, Yellowstone National Park. U.S. Fish and Wildlife Service, Yellowstone National Park. 171 pages.
- Bonnicksen, T.M. 1989. Fire gods and federal policy. *American Forests* 95(7/8): 14-16.
- Brown, J.K. 1989. Could the 1988 fires in Yellowstone have been avoided through prescribed burning? *Fire Management Notes* 50(4): 7-13.
- Cannon, K.P., and P. Phillips. 1993. Post-fire inventory and evaluation in Yellowstone National Park: the 1989 field season. Midwest Archeological Center Technical Report No. 24.
- Chase, A. 1988. How Yellowstone got burned. *Outside* 13(12): 33, 35-36.
- Christensen, N.L., J.K. Agee, P.F. Brussard, J. Hughes, D.H. Knight, G.W. Minshall, J.M. Peek, S.J. Pyne, F.J. Swanson, J.W. Thomas, S. Wells, S.E. Williams, and H.A. Wright. 1989. Ecological consequences of the 1988 fires in the Greater Yellowstone Area. The Greater Yellowstone Postfire Ecological Assessment Workshop Final Report. 58 pages.
- Christiansen, T. 1996. Terrestrial litter invertebrate communities in Yellowstone Park. *Yellowstone Science* 4(2): 2-3.
- Comstock, Theo. B. 1874. The Yellowstone National Park: its scientific value. *American Naturalist* 8: 65-79
- Connor, M.A., and K.P. Cannon. 1991. Forest fires as a site formation process in the Rocky Mountains of northwestern Wyoming. *Archaeology in Montana* 32(2) :1-14.
- _____, _____, and D. Carlevato. 1989. The mountain burnt: forest fires and site formation processes. *North American Archaeologist* 10: 293-310.
- Crabtree, R.L. and J.W. Sheldon. 1999. The ecological role of coyotes on Yellowstone's northern range. *Yellowstone Science* 7(2):15-23.
- _____, and _____. 1994. Effects of 1988 fires on ecology of coyotes in Yellowstone National Park. Pages 105-113 *in* The University of Wyoming National Park Service Research Center Annual Report
- Despain, D. 1990. Yellowstone vegetation, consequences of environment and history in a natural setting. Roberts Rinehart, Boulder, Colorado. 237 pages.
- _____, ed. 1994. Plants and their environments: proceed-

- ings of the first scientific conference on the Greater Yellowstone Ecosystem. Technical Report NPS/NRYELL/NRTR. USDI, NPS, Denver, Colorado.
- _____, A.R. Rodman, P. Schullery, and H.F. Shovic, H.F. 1989. Burned area survey of Yellowstone National Park: the fires of 1988. Division of Research and Geographic Information Systems Laboratory, Yellowstone National Park. 14 pages.
- Engstrom, D.R., C. Whitlock, S.C. Fritz, and H.E. Wright, Jr. 1991. Recent environmental changes inferred from the sediments of small lakes in Yellowstone's northern range. *Journal of Paleolimnology* 5(2):139-174.
- Ewing, R. 1996. Postfire suspended sediment from Yellowstone National Park, Wyoming. *Journal of the American Water Resources Association* 32(3):605-627.
- Farnes, P.E., W.W. McCaughey, and K.J. Hansen. *In press*. Role of fire in determining annual water yield in mountain watersheds. Chapter 11 in L. Wallace, ed. *After the fires: the ecology of change in Yellowstone National Park*. Yale University Press, New Haven, Connecticut.
- Fire Management Policy Review Team. 1989. Final report on fire management policy. U.S. Department of Interior, Fish and Wildlife Service, Washington, D.C.
- Gniadek, S. 1977. Some aspects of avian ecology following the 1974 Trail Creek and 1976 Divide fires in Yellowstone National Park. Final Research Report.
- Greenberg, M.R., D.B. Sachsman, P.M. Sandman, and K.L. Salomone. 1989. Risk, drama, and geography in coverage of environmental risk by network TV. *Journalism Quarterly* 66(2): 267-276.
- Greenlee, J. M. 1996. Ecological implications of fire in Greater Yellowstone. Proceedings of the second biennial conference on the Greater Yellowstone Ecosystem, Yellowstone National Park, September 19-21, 1993. International Association of Wildland Fire, Fairfield, Washington. 235 pages.
- Gruell, G.E. 1980. Fire's influence on wildlife habitat on the Bridger-Teton National Forest, Wyoming. Intermountain Forest and Range Experiment Station. USDA Forest Service Research Paper INT-235.
- Haroldson, M., D. Reinhart, K. Gunther, and L. Waits. 1998. Spawning cutthroat trout numbers on tributary streams to Yellowstone Lake. Pages 33-39 in *Yellowstone grizzly bear investigations: annual report of the Interagency Grizzly Bear Study Team*. U.S. Geological Survey, Bozeman, Montana. 72 pages.
- Houston, D.B. 1982. *The northern Yellowstone elk*. MacMillan, New York. 474 pages.
- _____. 1983. Wildfires in Yellowstone National Park. *Ecology* 54(5): 1111-1117.
- Hutto, R.L. 1995. The composition of bird communities following stand-replacement fires in northern Rocky Mountain conifer forests. *Conservation Biology*. 9:1041-1058.
- Jakubas, W.J., R.A. Garrott, P.J. White, and D.R. Mertens. 1994. Fire-induced changes in the nutritional quality of lodgepole pine bark. *Journal of Wildlife Management*. 58:35-46.
- Johnson, A.M., S.W. Conner, and K.J. Feyl. 1991. Post-fire identification of nineteenth century wooden structures. *Archaeology in Montana*. 32(2):33-47.
- Johnson, E.A., and G.I. Fryer. 1989. Population dynamics in lodgepole pine-Engelmann spruce forests. *Ecology* 70:1335-1345.
- Kay, C.E. 1993. Aspen seedlings in recently burned areas of Grand Teton and Yellowstone National Parks. *Northwest Science* 67(2):94-104.
- _____. 1997. Ungulate herbivory, willows, and political ecology in Yellowstone. *Journal of Range Management* 50(2):139-145.
- Keiter, R.B. and M. Boyce, eds. 1991. *The Greater Yellowstone Ecosystem: redefining America's wilderness heritage*. Yale University Press, New Haven, Connecticut.
- Kendall, K.C. 1998. Whitebark pine. Pages 483 to 485 in Mac, M.J., P.A. Opler, C.E. Puckette Haecker, and P.D. Doran, Status and trends of the nation's biological resources. Vol. 2. U.S. Department of the Interior, U.S. Geological Survey, Reston, Virginia.
- Knight, D.H. 1994. *Mountains and plains: the ecology of Wyoming landscapes*. Yale University Press, New Haven, Connecticut. 338 pages.
- _____, and L.L. Wallace. 1989. The Yellowstone fires: issues in landscape ecology. *BioScience* 39:707-715.
- Koch, E.D., and C.R. Peterson. 1995. *Amphibians and reptiles of Yellowstone and Grand Teton National Park*. University of Utah Press, Salt Lake City. 188 pages.

- Lathrop, R.G. 1994. Impacts of the 1988 wildfires on the water quality of Yellowstone and Lewis Lakes, Wyoming. *International Journal of Wildland Fire* 4(3):169-175.
- Lemke, T.O., J.A. Mack, and D.B. Houston. Winter range expansion by the northern Yellowstone elk herd. *Intermountain Journal of Sciences* 4(1/2): 1-9.
- Mahony, D.L., and R.E. Gresswell. 1998. Short-term postfire variation of physical habitat, fish populations, and associated aquatic communities in large streams of Yellowstone National Park. Conference abstract in *Yellowstone Science supplement* 6(2): 39.
- Marston, R.A., and D.H. Haire. 1990. Runoff and soil loss following the 1988 Yellowstone fires. *Great Plains-Rocky Mountain Geographical Journal*. 18:1-8.
- McEneaney, T. 1990. Yellowstone: not so black and white. *The Living Bird Quarterly*, Spring: 11-17.
- Meagher, M.M. and D. Houston. 1998. *Yellowstone and the biology of time*. University of Oklahoma Press, Norman, Oklahoma. 287 pages.
- Merrill, E., and R. Marrs. 1994. Remote sensing of vegetation recovery in grasslands after the 1988 fires in Yellowstone National Park. Pages 114-125 *in* The University of Wyoming National Park Service Research Center Annual Report.
- Meyer, G.A., and Wells, S.G. 1997. Fire-related sedimentation events on alluvial fans, Yellowstone National Park. *Journal of Sedimentary Research*. A67(5):776-791.
- Mihuc, T.B. and G.W. Minshall. 1995. Trophic generalists vs. trophic specialists: implications for food web dynamics in post-fire streams. *Ecology* 76:2361-2372.
- Mills, S., ed. 1989. *The Greater Yellowstone postfire assessment*. Greater Yellowstone Coordinating Committee. 147 pages.
- Millspaugh, S.H., C. Whitlock, and P. Bartlein. 2000. Variations in fire frequency and climate over the past 17,000 yr in central Yellowstone National Park. *Geology* (28)3:211-214.
- Minshall, G.W., J.T. Brock, and J.D. Varley. 1989. Wildfires and Yellowstone's stream ecosystems. *BioScience* 39:707-715.
- _____, _____, and T.V. Royer. 1998. Stream ecosystem responses to the 1988 wildfires. *Yellowstone Science* 6(3):15-22.
- _____, and C.T. Robinson. 1993. Effects of the 1988 wildfires on stream systems of Yellowstone National Park: five year comparison. Final report, University of Wyoming/National Park Service research center.
- _____, _____, T.V. Royer, and S.R. Rushforth. 1995. Benthic community structure in two adjacent streams in Yellowstone National Park five years after the 1988 wildfires. *Great Basin Naturalist* 55(3):193-200.
- Montagne, C., and E. Skogley. 1992. Burned-unburned resin extractor soil nutrient comparison. Final report from the Plant and Soil Science Department and the Montana Agricultural Experiment Station, Montana State University, Bozeman, Montana.
- Morrison, M. 1993. *Fire in paradise: the Yellowstone fires and the politics of environmentalism*, HarperCollins Publishers, Inc., New York.
- Neckels, J., B. Mutch, R. Wallace, B. Van Zee, and E. Waldapfel. 1988. Greater Yellowstone Area fire situation 1988. Greater Yellowstone Coordinating Committee. Billings, Montana.
- Nyland, R.D. 1998. Patterns of lodgepole pine regeneration following the 1988 Yellowstone fires. *Forest Ecology and Management* 111(1): 23-33.
- Parker, D.L. and L.E. Stipe. 1993. A sequence of destruction: mountain pine beetle and wildfire. Technical Report, USDA Forest Service, Southwestern Region.
- Pearson, S., M.G. Turner, L.L. Wallace, and W.H. Romme. 1995. Winter habitat use by large ungulates following fire in northern Yellowstone National Park. *Ecological Applications* 5(3):744-755.
- Podruzny, S.R., D.P. Reinhart, and D.J. Mattson. *In press*. Fire, red squirrels, whitebark pine and Yellowstone grizzly bears. *Ecology*.
- Polzin, P.E., M.S. Yuan, and E.G. Schuster. 1993. Some economic impacts of the 1988 fires in the Yellowstone area. U.S. Department of Agriculture, Forest Service. Research Note INT-418.
- Pyne, S.J. [1982] 1997. *Fire in America, a cultural history of wildland and rural fire*. Reprint by University of Washington Press.
- Pyne, S.J. 1989. Letting wild fire loose: the fires of '88. *Montana, The Magazine of Western Living* 39(3):76-79.
- Reed, R.A., M.E. Finley, W.H. Romme, and M.G. Turner.

1999. Aboveground net primary production and leaf-area index in early postfire vegetation in Yellowstone National Park. *Ecosystems* 2:88-94.
- Reinhart, D.P. 1989. Effects of fire on cutthroat trout spawning streams and associated bear use. Pages 19-27 in *Yellowstone grizzly bear investigations: annual report of the Interagency Grizzly Bear Study Team*. U.S. Geological Survey, Bozeman, Montana.
- Renkin, R., and D. Despain. 1992. Fuel moisture, forest type, and lightning-caused fire in Yellowstone National Park. *Canadian Journal of Forest Research* 22(1):37-45.
- Ripple, W.J., and E.J. Larsen. *In press*. The role of postfire coarse woody debris in aspen regeneration. *Western Journal of Applied Forestry* 16(2).
- Roemhild, G. 1994. Aquatic insects and the fires of 1988. *Yellowstone Science* 2(2):2-4.
- Rolston, H. 1989. Biology and philosophy in Yellowstone. *Biology and Philosophy* 5(2): 241-258.
- Romme, W.H. 1982. Fire and landscape diversity in subalpine forests of Yellowstone National Park. *Ecological Monographs* 52(2): 199-221.
- _____, and D.G. Despain. 1989. Historical perspective on the Yellowstone fires of 1988. *BioScience* 39(10):695-699.
- _____, and D.H. Knight. 1982. Landscape diversity: the concept applied to Yellowstone Park. *BioScience* 32(8): 664-669.
- _____, M.G. Turner, R.H. Gardner, W.W. Hargrove, G.A. Tuskan, D.G. Despain, and R.A. Renkin. 1997. A rare episode of sexual reproduction in aspen (*Populus tremuloides* Michx.) following the 1988 Yellowstone fires. *Natural Areas Journal* 17:17-25.
- _____, _____, L.L. Wallace, and J.S. Walker. 1995. Aspen, elk, and fire in northern Yellowstone National Park. *Ecology* 76(7):2097-2106.
- Rothermel, R.C., R.A. Hartford, and C.H. Chase. 1994. Fire growth maps for the 1988 Greater Yellowstone Area fires. USFS Technical Report INT-304. 64 pages.
- Runnells, D.D., and M.A. Siders. 1991. Impact of the 1988 forest fires on the chemistry of ground water in Yellowstone National Park. Pages 249-255 in *University of Wyoming National Park Service Research Center Annual Report*.
- Schullery, P., and D.G. Despain. 1989. Prescribed burning in Yellowstone National Park: a doubtful proposition. *West. Wildlands* 15(2):30-34.
- _____, and L. Whittlesey. 1992. The documentary record of wolves and related wildlife species in the Yellowstone National Park area prior to 1882. Pages 1-73 in J.D. Varley and W.G. Brewster, eds. *Wolves for Yellowstone? A report to the U.S. Congress, Vol. 4*. National Park Service, Yellowstone National Park, Wyoming.
- Sherburne, S.S. and Bissonette, J.A.. 1994. Marten subnivean access point use: response to subnivean prey levels. *Journal of Wildlife Management* 58(3): 400-405.
- Singer, F.J., ed. 1996. Effects of grazing by wild ungulates in Yellowstone National Park. National Park Service, Natural Resource Information Division, Denver, Colorado. 375 pages.
- _____, and M.K. Harter. 1996. Comparative effects of elk herbivory and 1988 fires on northern Yellowstone National Park grasslands. *Ecological Applications* 6(1): 185-199.
- _____, A. Harting, K.K. Symonds, and M.B. Coughenour. 1997. Density dependence, compensation, and environmental effects on elk calf mortality in Yellowstone National Park. *Journal of Wildlife Management* 61(1): 12-15.
- _____, L.C. Mack, and R.C. Cates. 1994. Ungulate herbivory of willows on Yellowstone's northern winter range. *Journal of Range Management* 47:435-443.
- _____, W. Schreier, J. Oppenheim, and E.O. Garton. 1989. Drought, fires, and large mammals. *BioScience* 39(10):716-722.
- _____, and P. Schullery. 1989. Yellowstone wildlife: populations in process. *Western Wildlands* 15(2):18-22.
- _____, Zeigenfuss, L.C., Cates, R.G., and D.T. Barnett, D.T. 1998. Elk, multiple factors, and persistence of willows in national parks. *Wildlife Society Bulletin* 26(3):419-428.
- Taylor, D.L. 1973. Some ecological implications of forest fire control in Yellowstone National Park. *Ecology* 54 (6):1394-1396.
- _____. 1982. Competition between mountain bluebirds and tree swallows in post-fire areas of Yellowstone National Park. *National Geographic Society Research Reports* 14: 655-667.

- Theriot, E.C., S.C. Fritz, and R.W. Gresswell. 1997. Long-term limnological data from the larger lakes of Yellowstone National Park. *Arctic and Alpine Research* 29(3): 304-314.
- Tinker, D.B., and D.H. Knight. 1998. Fire and the dynamics of coarse woody debris in Yellowstone National Park. Page 53 in *Yellowstone Science supplement, agenda & abstracts* 6(2):53.
- Tomback, D.F., ed. *In press*. Whitebark pine communities: ecology and restoration. Island Press, Washington, D.C.
- _____, D.F., A.J. Anderies, K.S. Carsey, and M.L. Powell. *In press*. Delayed seed germination in whitebark pine and regeneration patterns following the Yellowstone fires. *Ecology*.
- Tracy, B.F. 1997. Fire effects in Yellowstone's grasslands. *Yellowstone Science* 5(3): 2-5.
- _____. 1998. Fire effects, elk, and ecosystem resilience in Yellowstone's sagebrush grasslands. Conference abstract in *Yellowstone Science supplement* 6(2):53.
- _____, and S.J. McNaughton. 1997. Elk grazing and vegetation responses following a late season fire in Yellowstone National Park. *Plant Ecology* 130 (2):111-119.
- Turner, M.G., W. W. Hargrove, R.H. Gardner, and W. H. Romme. 1994a. Effects of fire on landscape heterogeneity in Yellowstone National Park. *Journal of Vegetation Science* 5:731-742.
- _____, R.A. Reed, W.H. Romme, M.E. Finley, and D.H. Knight. 1997. Above-ground net primary production, leaf area index, and nitrogen dynamics in early post-fire vegetation. Pages 130 to 134 in *University of Wyoming National Park Service Research Center*.
- _____, W.H. Romme, R.H. Gardner, and W.W. Hargrove. 1997. Effects of fire size and pattern on early succession in Yellowstone National Park. *Ecological Monographs* 76(4):411-433.
- _____, Y. Wu, L.L. Wallace, W.H. Romme, and A. Brenkert. 1994b. Simulating winter interactions among ungulates, vegetation, and fire in northern Yellowstone Park. *Ecological Applications* 4(3):472-496.
- Tyers, D.B. *Submitted Ph.D. diss.* Winter ecology of moose on the northern Yellowstone range. Montana State University, Bozeman.
- U.S. Fish and Wildlife Service. 1993. Annual project technical report for 1992, fishery and aquatic management program, Yellowstone National Park.
- Varley, J.D. and P. Schullery. 1991. Reality and opportunity in the Yellowstone fires of 1988. Pages 105-122 in R.B. Keiter and M. Boyce, eds. *The Greater Yellowstone Ecosystem: redefining America's wilderness heritage*. Yale University Press, New Haven, Connecticut.
- Varley, J.D. and P. Schullery. 2000. *Yellowstone fishes: ecology, history, and angling in the park*. Stackpole Books, Mechanicsburg, Pennsylvania.
- Wallace, L.L., M.G. Turner, W.H. Romme, R.V. O'Neill and Y. Wu. 1995. Scale of heterogeneity of forage production and winter foraging by elk and bison. *Landscape Ecology*. 10(2):75-83.
- White, C.A., C.E. Olmsted, and C.E. Kay. 1998. Aspen, elk, and fire in the Rocky Mountain national parks of North America. *Wildlife Society Bulletin* 26(3): 449-462.
- White, P.J., and R.A. Garrott. 1993. Bark eating by Yellowstone elk. *Yellowstone Science* 1(4):2-5.
- Williams, E.D., and S.C. Smith. 1990. Rehabilitation of fire suppression impacts on the North Fork fire in Yellowstone National Park. Report to the U.S. Department of the Interior. YNP/LA 90-01.
- Wu, Y., M.G. Turner, L.L. Wallace, and W.H. Romme. 1996. Elk survival following the 1988 fires: a simulation experiment. *Natural Areas Journal* 16(3):198-207.
- Yellowstone National Park. 1997. *Yellowstone's northern range: complexity and change in a wildland ecosystem*. National Park Service, Mammoth Hot Springs, Wyoming. 148 pages.



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