The Yellowstone Fires

A Primer on the 1988 Fire Season

National Park Service

Yellowstone National Park

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INTRODUCTION

The Greater Yellowstone Area fires of 1988 have received more national attention than any other event in the history of the parks, and are already being described as the cause of the largest fire suppression effort ever undertaken in this country. The fires have provided compelling evidence of the power of nature, and have generated renewed interest in the parks and their management. Fighting the fires has required all of the attention of the concerned agencies, so that no comprehensive overview of the whole fire story has been possible. This summary has been prepared for use until more complete reports are available.

This summary provides a brief overview of the Yellowstone fire situation as of October 1, 1988. Eventually complete fire histories will be assembled for all Yellowstone fires. In the meantime, the present narrative should serve to introduce the essential information. Statistics presented here should be regarded as preliminary and may have to be revised later as more complete information is received on various fires.

The bracketed numbers in the narrative refer to a variety of publications, information papers, and working reports produced during the fire that are appended to provide in-depth information.

Additional information will be available from the Superintendent, Yellowstone Park, Wyoming, 82190, 1-307-344-7381.

YELLOWSTONE'S FIRE PREHISTORY AND HISTORY

Naturally caused fires have occurred in the Yellowstone area as long as there has been vegetation to burn--at least since vegetation appeared following the retreat of glaciers about 12,000 years ago [1,2]. Fire, climate, erosion, and a vast assortment of life forms ranging from microbes to insects to mammals have all played roles in the creation of the vegetative landscape of Yellowstone.

The process was still going on when humans first arrived. During several thousand years of intermittent occupation of the Yellowstone area, native Americans may have influenced the vegetation in many ways, such as setting fires (accidental or intentional), moving seeds (in plant foods or horse's feed, for example), or influencing the numbers or movements of various plant-eating mammals.

The arrival of European man heightened human influence on vegetation, primarily through suppression of fires that would have burned unimpeded in earlier times. After the park was established, in 1872, park managers gradually improved their ability to monitor and control fires. Virtually no effective fire fighting was done until 1886, when the U.S. Cavalry was placed in charge of protecting the park. In fact, these soldiers marked the debut of federal involvement in fighting wildfires in the United States. The army, which did not leave Yellowstone until 1918, successfully extinguished some fires, though it is difficult to determine what effect their efforts had on overall fire frequency or extent.

In these early days, fire suppression was most effective on the grasslands, shrublands, and savannas of the park's northern range; fires were not allowed to burn freely on the grasslands and groves of the northern range for nearly a century [3]. Over the rest of the park, which is largely covered by forest, reliable and consistent fire suppression had to wait until modern airborn firefighting techniques became available, in the last thirty or forty years [4].

YELLOWSTONE'S FIRE MANAGEMENT PLAN

At the same time that we were learning more about putting fires out, a sense of the importance of natural processes was also increasing. Starting in the 1960s, managers in many national parks attempted to restore as much of the primitive setting as practical [5]. Step by step, Yellowstone's wildness has been given greater respect and freedom. Thus, in the 1930s, predators such as wolves, cougars, and coyotes were no longer controlled, in recognition of their possible role in the population dynamics of the park's herbivores; after the 1950s, hot springs were no longer channeled from their natural courses into swimming pools; in the 1960s black and grizzly bears were divorced from a variety of human food sources, and elk and bison population numbers, long pruned, were permitted to reach levels in keeping with available habitat; and in the 1970s the park's fisheries management program was redirected to restore high quality angling while restoring depleted fisheries populations. Many of these management actions were or continue to be controversial, and are the subject of ongoing research and evaluation.

Ecologists have known for many years that wildfire is essential to the evolution of a natural setting; when fires are suppressed, normal plant succession processes are stagnated, and biological diversity is reduced or altered Research into Yellowstone's prehistory has shown that on the park's northern range fires occurred one to four times a century, while over the vast extent of the park's subalpine forests the fire interval was more typically 200 to 400 years. Nature has lots of time, and at either interval fire was a premier force (along with climate and soils) in determining vegetative cover in what would become the park. The legislative mandate of the National Park Service is to maintain as near as possible a primitive ecological situation, and so it was that in the 1960s and early 1970s interest grew in restoring the influences of fire to the park [6].

On most public and private lands, of course, maintaining wild processes is not as high priority as other activities, such as grazing stock, harvesting timber, or providing recreation. On such lands, permitting wildfire to burn may be no more appropriate than trying to maintain a population of grizzly bears on a commercial sheep ranch. But in natural areas such as Yellowstone, preserving a state of wildness is a primary goal of management.

In 1972, Yellowstone was one of several national parks that initiated programs to allow some natural fires to run their courses. That year 340,000 acres, in two backcountry units, were designated as appropriate for naturally caused fires. The plan was developed and implemented after substantial communication with related agencies, and with the endorsement of the conservation and scientific communities. In 1974, after the initial successes of the program, plans were made to expand the acreage. In 1975, an Environmental Assessment was prepared on allowing fires to burn on about 1,700,000 acres in the park; the E.A. was approved early in 1976, and shortly thereafter Yellowstone Park and the Bridger-Teton National Forest entered into a cooperative program to involve the Teton Wilderness in the fire plan, so that naturally caused fires could burn across the boundary between the two federal units.

Over the years since 1976, Yellowstone's fire management plan has been gradually revised and updated in accordance with National Park Service guidelines. In 1986 a new revision of the plan--really just a refinement of earlier plan editions--was completed, and was in the final stages of approval as of the spring of 1988.

All park fires, whether man-caused or natural, are managed according to criteria in the fire management plan. Natural fires are continuously monitored, and tactics for monitoring and possible control are updated daily. Fires that threaten adjacent public or private lands and communities, park developments, or other significant resources, are suppressed with the same effort applied to fires on other public lands.

Yellowstone's fire management plan has four goals:

1. To permit as many lightning-caused fires as possible to burn under natural conditions.

2. To prevent wildfire from destroying human life, property, historic and cultural sites, special natural features, or threatened and endangered species.

3. To suppress all man-caused fires (and any natural fires whose suppression is deemed necessary) in as safe, cost-effective, and environmentally sensitive ways as possible.

4. To resort to prescribed burning when and where necessary and practical to reduce hazardous fuels, primarily dead and down trees.

Scientists have learned much about the occurrence and behavior of fire during the sixteen years since this plan has been put into effect. Tens of thousands of lightning strikes simply fizzle out with no acreage burned. Of those that have occurred in the past sixteen years, 140 produced fires. Most burned only a small area, but a few larger fires were started, so the average burn size was 250 acres. Eighty percent of the lightning starts in this period went out by themselves.

During this sixteen-year period, a total of 34,175 acres burned in the park due to natural fires [7]. The largest natural fire burned about 7,400 acres. During these years we lost no human lives and had no significant human injuries due to the fires. No park structures or special features were affected.

The largest natural fire in the park's written history prior to 1988 was a burn at Heart Lake in 1931. It was fought, but burned about 18,000 acres.

Fire was permitted to reassert its role in creating and maintaining the natural variety of habitats and vegetation types typical of a healthy wilderness, and millions of visitors had the opportunity to observe this fascinating natural process in operation.

THE FIRES OF 1988

Conditions

The summer of 1988 has been the driest on record in Yellowstone. April rainfall was 155 percent of normal, and May rainfall was 181 percent of normal, but practically no rain fell in June, July, or August, an event previously unrecorded in the park's 112-year written record of weather conditions. In early summer, about 20 lightning-caused fires had been allowed to burn [8]. According to the fire plan, fires were evaluated on a case-by-case basis, each on its own situation and merits, before being allowed to burn. Eleven of these burned themselves out, behaving as such fires did in previous years.

But those that survived into the extremely dry weeks of late June and July met dramatically changed conditions. By late July, moisture content of grasses and small branches in the park reached levels as low as two or three percent, and down trees was measured at seven percent (kiln-dried lumber is 12 percent). At 8 to 12 percent, lightning will start lots of fires, many of which will burn freely. At 12 to 16 percent, some fires will burn to 200 to 300 acres. At greater than 16 percent, there are still some starts, but few will burn any significant amount. Twenty-four percent is saturation. A series of unusually high winds, associated with dry fronts, fanned flames that even in the dry conditions would not have moved with great speed.

Yellowstone experienced an untypical weather pattern in recent years. Though there was below-average precipitation in winter, summers were abnormally wet, sometimes reaching 200 to 400 percent of normal rainfall in July. The recent statistics on rainfall in summer are striking enough to merit listing here:

Percent of normal rainfall

	April	May	June	July	August
1977	10	96	63	195	163
1978	91	126	42	99	46
1979	6	17	42	115	151
1980	33	152	55	143	199
1981	49	176	102	103	25
1982	169	74	89	118	163
1983	22	29	69	269	88
1984	44	84	66	297	121
1985	42	93	44	160	84
1986	145	47	64	212	75
1987	42	144	72	303	122
1988	155	181	20	79	10

Anticipating the continuation of this pattern, park managers and fire behavior specialists saw reason to expect that natural fires could be allowed to burn. Six consecutive years of significantly above-average July rainfall suggested that July of 1988 would be similarly wet.

Fighting the Fires

By July 15, however, it was clear that recent weather patterns were not of use in predicting this summer's weather. After that day, no new natural fires were allowed to burn. After July 21, all other fires were also subjected to full suppression efforts as manpower would allow. On July 27, during a visit to Yellowstone, the Secretary of the Interior reaffirmed that the natural fire program had been suspended and all fires fought. Man-caused fires had been vigorously suppressed all along.

An extensive interagency fire suppression effort was initiated in mid-July in the Greater Yellowstone Area, to attempt to control or contain an unprecedented series of wildfires. The extreme weather conditions and heavy, dry fuel accumulations presented even the most skilled professional firefighters with conditions rarely observed.

Accepted firefighting techniques, such as constructing fire lines along the edges of the advancing fires to create fuel breaks, and backfiring to reduce fuel accumulations in front of advancing fires, were frequently ineffective because fires spread long distances by "spotting," a phenomenon by which wind carries embers from the tops of the 200-foot flames far out across unburned forest to start spot fires well ahead of the main fire. Regular spotting up to a mile and a half away from the fires made the widest bulldozer lines useless and enabled the fires to cross such major topographic features as the Grand Canyon of the Yellowstone River. Fires routinely jumped such traditonally recognized barriers as rivers and roads.

Fires often moved two miles per hour, with common daily advances of five to ten miles, consuming even very light fules that would have been unburnable during an average season. The fast movement, coupled with spotting, made frontal attacks on the fires impossible dangerous, as fire crews could easily be overrun or trapped between a main fire and its outlying spot fires.

Even night time fires could not be fought. Normally, wildfires "lie down" at night, as increased humidity and decreased temperature quiet them; humidity remained low at night, and fire fighting was further complicated by extreme danger from falling trees.

Fire fighting efforts were directed at controlling the flanks of fires and protecting lives and property in the advancing paths of the fires, and the experts on site generally agreed that without help from the weather, in the form of rain or snow, there was no technology in existence that could stop the fires.

The frustration and wonder of the firefighters at these conditions were summed up by Denny Bungarz, a U.S. Forest Service fireboss from Mendocino National Forest in California. Bungarz was incident commander on the North Fork Fire, the one that threatened Old Faithful and West Yellowstone and eventually reached the northeast region of the park. Bungarz said, "We threw everything at that fire from Day One. We tried everything we knew of or could think of, and that fire kicked our ass from one end of the park to the other." Similar sentiments were expressed by other leading firefighters.

Some media attention has been given to restrictrions routinely placed on firefighting techniques in the park and in surrounding wilderness areas. In many situations, for example, the use of motorized equipment is limited or excluded in order to preserve primitive values to whatever extent practical. Such restrictions are a matter of established guidelines, and were rarely considered a hindrance by the firebosses who ran the operations (most comments on the restrictions seem to have originated from rank and file firefighters). Contrary to media reports, bulldozers were in fact used in the park when requested by the firebosses, and fire engines were used freely off roadways in fire suppression efforts. A complete review of these tactical matters will occur this winter.

By the last week in September, about 50 lightning-caused fires had occurred in the park, eight of which were still burning [9]. More than $100,000,000 had been spent in control efforts, and most major park developments--and a few surrounding communities--had been evacuated at least once as fires approached within a few miles of them. At the operation's peak, nine thousand firefighters (including army and marine units), more than 100 fire engines, and dozens of helicopters from many states participated in a huge, complex effort to control the fires and at least protect developments.

As there were also many fires burning in the Greater Yellowstone Area outside the park, and because of the magnitude of the firefighting effort within the park, many agencies and organizations were involved in the effort. The fire suppression effort in the Greater Yellowstone area is the largest such effort ever undertaken in the United States. This summary cannot do justice to the logistical challenges, spectacular natural power, human drama, and sheer size of this fire season. Chronicles of many forms will certainly be produced, both within and from outside of the various agencies that took part in the fires.

Extent of Fires

No topic has caused more confusion in the media and in the public mind than the actual extent of the fires. Confusion has resulted from all fires in the Greater Yellowstone Area, which includes more than ten million acres of public land, being called "Yellowstone Park fires," from all fires in the Yellowstone area being ascribed to the park's natural fire program, and from frequent and unfortunate oversimplification and exaggeration of burn acreages.

This was an extremely difficult fire year throughout the west, and the country surrounding Yellowstone Park was hit heavily. A number of major fires, most notably the North Fork Fire, the Hellroaring Fire, the Storm Creek Fire, the Huck Fire, and the Mink Fire, started outside the park and moved in. These fires accounted for more than half of the total burn in the Greater Yellowstone area, and include most of the ones that have received intensive media attention.

The North Fork Fire, which threatened Old Faithful, Madison, Norris, West Yellowstone, Mammoth Hot Springs, and Tower-Roosevelt Lodge, was probably started by a woodcutter's cigarette in Targhee National Forest and was the subject of immediate suppression efforts. The Storm Creek Fire started as a lightning strike in the Absaroka-Beartooth Wilderness of the Custer National Forest northeast of Yellowstone Park, and eventually threatened the Cooke City-Silver Gate area, where it received extended national television coverage and was usually reported as a result of Yellowstone Park's natural fire program.

Additional confusion results from continued media and public belief that managers in the Yellowstone area let park fires continue burning unchecked, out of devotion to the natural fire plan, long after such fires were in fact being fought. As pointed out earlier, no fires have been managed to burn since July 21. Public confusion was probably heightened by misunderstandings over just what the firefighting strategies were; if crews were observed letting a fire burn an area, it may have seemed to the casual observer that the burn was merely being monitored. In fact, in many instances firebosses recognized the hopelessness of stopping fires in certain situations, and concentrated their efforts on the protection of buildings and developed areas. The most unfortunate public and media misconception about the Yellowstone firefighting effort may have been that human beings can always control fire if they really want to; the raw, unbridled power of these fires cannot be overemphasized. Firefighters were compelled to choose their fights very carefully, and they deserve great acclaim for working so successfully to save all but a few of the buildings in the park. This was a heroic achievement.

Perhaps the worst source of confusion, however, has resulted from oversimplification of burn acreages. The daily reports issued cooperatively by the U.S. Forest Service and the National Park Service on fire status gave total acreages within the perimeters of each fire, pointing out that, "only about half of the vegetation has burned within many fire perimeters." Most reporting has focussed on the total acreage, and neglected the important statement about unburned vegetation. The park was regularly portrayed as a blackened moonscape.

The perimeter estimates are indeed shocking at first sight. Fires that started in Yellowstone Park totalled about 659,000 acres (preliminary estimate as of October 1) in and out of the park). Fires that started outside the park and moved in totalled about 969,000 acres in and out of the park. More detailed statistics will be available soon.

Because all available resources, including helicopters, were committed to fighting the fires, and because of dense smoke, it was not possible during the fires to make accurate estimates of unburned acreages within the fire perimeter. As of the last week of September, however, preliminary flights indicate that, though there is great variation from area to area, "about half" is probably not far off as a general estimate. As of October 1, the total fire perimeter (areas within which some burning occurred) within the park was about 1,100,000 acres (50 percent of the park). Approximately 440,000 acres (20 percent of the park) actually experienced some burning. Approximately 220,000 acres (10 percent of the park) experienced canopy fires only, and approximately 22,000 acres (one percent of the park) experienced high heat intensity fires.

Of the 1,100,000 acres within the burn perimeters in the park, roughly 520,000 acres were the result of man-caused fires.

There was substantial variation of burn acreage from fire to fire. For example, about 30 percent of the area within the perimeter of the Fan Fire burned, while as much as 70 percent of the Lava Creek, Firehole, and Madison River areas may have burned areas. Preliminary surveys suggest that about 90 percent of the burned areas received light to moderate soil heating, 10 percent received high heat, and none received extreme heat. Light to moderate heats do not customarily kill seeds and bulbs more than an inch below the surface, so Yellowstone's plant communities will be fully capable of regenerating.

Photographic mapping flights are currently underway, and more detailed surveys will be made later this fall. Resurveying the vegetation cover of more than 2,000,000 acres of national park is a time-consuming and expensive project. It may well be, when all the information is in, that only about half of the acreages now being reported as burned are actually burned. The significance of this characteristic of the burns, that they do not take everything, has as yet been unappreciated by both the media and the public; the ecological significance of the burn patterns is enormous.

Post-fire Response--Assessment and Rehabilitation

By late September, as the fires were diminishing, plans were underway in Yellowstone Park to develop comprehensive programs for all aspects of post-fire response. These will include replacement, rehabilitation, or repair of damaged buildings, power lines, fire lines, trails, campsites, and other facilities. An estimated 1,000 miles of fire lines, dozens of fire camps, tons of litter, 100 miles of roads, more than 600 miles of trails, and innumerable helispots and other local impacts will eventually require restoration. The restoration of Yellowstone's wilderness setting--that is, the healing of the necessary wounds of firefighting--will be of great importance to the National Park Service, to many members of the conservation community, and the public.

Similarly, programs are being developed to interpret the fires and their effects to visitors and to the general American public.

Yellowstone will cooperate with other agencies and state and local governments in promoting economic recovery of the communities near the park whose business was affected by the fires, including national and international contacts with the travel industry.

The scientific community, both private and public sector, has already shown great interest in monitoring the ecological processes following these major fires. The National Park Service is cooperating with other agencies and independent researchers and institutions in developing comprehensive research directions to take full advantage of this unparallelled scientific opportunity. It is probably safe to say that this research effort will be unparallelled in the history of the national parks, and its impact will be felt throughout the scientific community for many years to come.

The public has been expressing great interest in somehow helping with the Yellowstone fires and future programs involving the park's response to the fires. The National Park Service is determined to be responsive to these interests, and to find ways for all who may be interested to participate. A cooperative agreement has been entered into with the National Park Foundation, a Washington-based nonprofit institution, to serve as the main repository for contributions. For more information on contribution programs and how the public can help, contact the Superintendent, Yellowstone National Park, Wyoming, 82190.

Yellowstone Park's Post-Fire Recovery Plan is being developed at present, and will be available later this fall.

Ecological Consequences and the Esthetics of Fire

The fires of 1988 had an enormous effect on the Greater Yellowstone area. The face of the park and surrounding lands has been dramatically changed, on a scale not widely anticipated even among fire ecologists. But the change is not without precedent. The most recent research by Dr. William Romme, and independent Colorado fire history scientist, and his associates, still unpublished, suggests that the Yellowstone area has been visited by natural fires on this scale periodically in the past, including comprehensive burns in the early 1700s and in 1850.

The many effects of fires on wilderness processes were the subject of considerable scientific scrutiny even before 1988, as suggested earlier; this scrutiny will now expand. What is well known is that the vegetative setting of Yellowstone is in good part the product of fires that burned here freely before the arrival of European man. Each new burn initiates a sequence of events in the plant community that influences all other living forms in the area, especially in terms of the nutrient flow through the ecological systems. Fire suppression, as suggested earlier, halts or retards that flow [10].

Some plants, such as the lodgepole pine, are fire tolerant, and begin to seed in immediately following the fire, with seeds being released from both heat-sensitive cones and from mature cones-of-the-year. Park plant ecologist Don Despain has already documented seed densities in forests burned in 1988 ranging from 50,000 to 1,000,000 seeds per acre. Some of these seeds will survive the appetites of mice, squirrels, and birds, and will eventually produce a forest much like the one that burned on the site. Within five years, there may be 1,000 seedlings per acre, depending upon how much competition they face from grasses, wildflowers, and shrubs.

The growth of the new biotic community begins immediately following a burn. As mentioned earlier, temperatures high enough to kill seeds penetrate less than an inch into the soil in most places. Only under logs and deep litter accumulations, where the fire was able to burn for several hours, does the lethal heat pulse penetrate more deeply into the soil. Where water is available, new plant growth is immediate--within a few days. In dry soils the rhizomes, bulbs, root crown, seeds, and other reproductive tissues must wait until soil moisture is replenished the following spring.

Insects not associated with the pre-burn forest begin to use the new food sources (dead trees) immediately, while others lay their eggs in the bark. Squirrels and birds make use of a variety of seeds and cones, and root stalks of many plant species resprout within a few weeks. Within a few growing seasons, the forest floor is a mat of grasses, shrubs, and flowers, and seedlings of future forests of fir, spruce, and pine appear. Plant growth is unusally lush because of the mineral nutrients in the ash and because of increased light levels on the previously shaded forest floor.

The fires of Yellowstone did not simply annihilate all life forms in their paths. Burning at a variety of temperatures, sometimes as ground fires, sometimes as crown fires, they killed many lodgepole pines and other trees, but in fact did not kill most other plants; they merely burned the tops off of them, leaving roots to regenerate.

As the fires passed, they created a vegetative mosaic of burns, partial burns, and non-burns that will now become the new habitats of plants and animals in Yellowstone. One of the most frequent comments heard from recent visitors to Yellowstone Park has been, "I didn't expect to see so much green."

This is not to understate the large acreages that were indeed burned; it is instead to suggest that the Yellowstone fires of 1988 did not do any known harm to the natural systems for which the park is being protected. For all their other effects, including substantial economic ones for the region, and the expenditure of more than $100,000,000 in firefighting, the fires did nothing to Yellowstone that has not been done many times in the past. We may have preferred that only natural fires had burned, and it certainly would have been preferable if the process had not involved such expense and economic hardship, but the park's natural systems do not directly suffer from human economics. One of the greatest challenges offered by national parks is a conceptual one: they compel us to take the long view, and consider nature's directions rather than our own [11]. We are not protecting the parks merely for ourselves, but for many later generations, who will witness the revegetation of Yellowstone with an interest and excitement hard to appreciate through the smoke of 1988.

And the burns will affect future fires. Vegetation capable of sustaining another major fire is quite rare for decades, except in extraordinary situations (the 1988 fires actually reburned heavily burned areas in some locations). Lightning strikes and even firebrands from fires in neighboring forests can only ignite small spots. The mosaic of young and mature plant communities provides natural firebreaks, reducing the number of fire starts and limiting fire size over time while sustaining a greater variety of plant and animal species.

Smoke, quickly moving fires, and the demands of firefighting logistics made it impossible to monitor mortalities of large mammals during the fires. Preliminary surveys in late September reveal that surprisingly few large mammals were killed by fire or smoke. Park biologists anticipated a certain amount of mortality; the fires were both extensive and fast-moving. Firefighters reported few incidents of animals involved with fires. Local rumors of large numbers of animals killed by the fires are to date unsubstantiated; extensive radiotelemetry involving more than 100 animals--elk, cougars, moose, and grizzly bears--indicates that though animal movements were sometimes affected dramatically by the passage of fires, relatively few animals succumbed, considering the large size of park wildlife populations.

As of September 29, fewer than 50 dead elk had been located throughout the Greater Yellowstone Area, and 4 bison were known killed by the fire on the park's northern range. One black bear, reportedly burned on its feet, was destroyed by a Montana State Highway Patrolman near Cooke City, and a few mule deer had been reported killed. These are only the most preliminary of numbers, and will be updated later.

Of greater significance are the short- and long-term effects of the fires on wildlife. Portions of the park's northern range burned, which may have effects on winter survival of grazing animals when coupled with summer drought conditions that reduced production of forage. In this and many other ways, fires dramatically altered the habitat and food production of Yellowstone. There is general agreement among observers that in the long run the fires created much new habitat that will serve the large mammals well [12]. The fires of Yellowstone are not an isolated event, but part of an endless process.

Wildfire has been regarded as evil in America for centuries. Though ecologists have recognized the important role of natural fire in wilderness ecosystems for more than fifty years, the general public is still largely unaware of the implications of fire suppression in wilderness. On the fundamental level of esthetics, fires still evoke a negative emotional response. Appreciation of fire is an esthetic issue, one for which the Park Service's sixteen years of natural fire experience did little to prepare the public; most Americans were unaware of the policy until the media attention this summer. Introducing Americans to the esthetic values of wildfire after the fact, so to speak, is going to be difficult, at least partly because to some it will appear that the Park Service is merely trying to put a good face on a bad situation.

And in some respects the situation is indeed bad. The great expense of the fires, coupled with considerable economic difficulties caused by the fires, cannot be simply justified in terms of the ecological health of Yellowstone Park.

But in other respects the fires cannot be judged as bad. In a naturally functioning wilderness, natural fire is neither bad nor good; it is simply a part of the process. We judge the presence of fire in a wilderness as good or bad based on our personal views of man's place in the natural world. There will never be unanimity on such a touchy topic as fire. But at all costs we should maintain a distinction between our scientific understanding of fire as a wilderness process and our personal feelings over the appropriateness of letting fires burn in national parks.

CONCLUSION

Ultimately, the greatest impacts of the 1988 Yellowstone fire season will not be ecological. Yellowstone itself is already well on its way to responding to the massive stimuli provided by the fires: natural revegetation is underway, wildlife is adapting, and winter is about to settle the last of the fires for the winter.

Far greater concern is now being expressed in many circles over the future of park management. The course of the summer's fire management raised many questions, and some management actions and policies will be challenged. Already there are debates underway about the timing of first suppression of natural fires, uses of heavy equipment in park backcountry, and related procedural matters, as well as over the natural fire management plan itself. The entire firefighting effort will also be scrutinized as part of the necessary and routine review that must be gone through following any such huge expenditure of public funds.

The American public, management agencies, and many special interest groups now face a singular challenge: to come to grips with a newfound understanding of the power of the natural settings we are attempting to preserve and celebrate in the national parks. Beyond the operational questions of just how best to fight fires in wilderness, and beyond the policy questions of how an agency can be true to its mandate and yet anticipate an extraordinary one-in-300-year event of this sort, are deeper questions of just what we want from our parks, and just how far we are willing to let nature go in giving it to us.

Fire is one of the last great natural "public enemies." The same ecological community that decades ago taught us that predators are not bad in any intrinsic sense, and that natural diversity is as useful to human culture as a closely managed harvest, has more recently recognized that wildfire also has its values--scientific, esthetic, and even commercial. Fire is and has always been an essential part of the setting in our parks and natural areas; we cannot ignore its role, and to return to the total exclusion of it from those areas would be a folly for which our descendants would pay dearly.

Our goal in the national parks is the same as it has always been: to find some balance--some "reasonable illusion," as A. Starker Leopold so aptly put it in 1963--between the directions the natural setting might take on its own and our needs of it. We need a course of action that will permit us to appreciate fire's place and power without so wholly risking the financial and emotional disasters of the 1988 fire season. But even at that we would be well advised to retain enough humility to know that nature will not always be controlled despite our best, most carefully planned management.

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Landscape Diversity: The Concept Applied to Yellowstone Park

William H. Romme and Dennis H. Knight

Changes in landscape patterns may influence a variety of natural features including wildlife abundance, nutrient flow, and lake productivity. Data suggest that cyclic changes in landscape diversity occur on areas of 100 km² in Yellowstone National Park. When properly managed, large wilderness areas provide the best and probably the only locale for studying the kind of landscape changes that occurred for millenia in presettlement times. *(Accepted for publication 12 May 1982)*

Each successive level of biological organization has properties that cannot be predicted from those of less complex levels (Odum 1971). Thus, populations have certain attributes distinct from the characteristics of the individuals of which they are composed, and communities have unique properties beyond the attributes of their component populations. An important level of organization that is now receiving more attention is the landscape, or mosaic of communities that covers a large land unit such as a watershed or a physiographic region (Forman and Godron 1981).

The importance of large-scale landscape patterns has been widely recognized (e.g., Bormann and Likens 1979, Forman 1979, 1982, Forman and Boerner 1981, Forman and Godron 1981, Habeck 1976, Habeck and Mutch 1973, Hansson 1977, Heinselman 1973, Loucks 1970, Luder 1981, Pickett 1976, Reiners and Lang 1979, Rowe 1961, Shugart and West 1981, Sprugel 1976, Sprugel and Bormann 1981, Swain 1980, White 1979, Wright 1974, Zachrisson 1977, and others). A few studies have quantitatively treated changes in landscape patterns (e.g., Hett 1971, Johnson 1977, Johnson and Sharpe 1976, Shugart et al. 1973). We recently made a detailed analysis of landscape composition and diversity in a pristine watershed in Yellowstone National Park in relation to fire and forest regrowth following fire (Romme 1982). In this paper we describe the natural changes that have occurred in landscape pattern over a period of 240 years and the possible consequences of these changes for certain aspects of ecosystem structure and function. Although we focus on Yellowstone in this analysis, the concepts are applicable to other ecosystems as well.

The term *landscape diversity* refers to the diversity of plant communities making up the vegetational mosaic of a land unit. Landscape diversity results from two superimposed vegetation patterns: the distribution of species along gradients of limiting factors, and patterns of disturbance and recovery within the communities at each point along the environmental gradients (Forman and Godron 1981, Reiners and Lang 1979). Both of these patterns contribute to the vegetational diversity of the Yellowstone landscape.

Over the park's 9000 km², elevation ranges from about 1800 m along the Yellowstone River in the northern portion to over 3000 m on the high peaks of the east and northwest. As a result, there are pronounced gradients of temperature and moisture, with related patterns in species distribution. The areas at lower elevations in the north support open sagebrush (*Artemisia tridentata*) parks on drier sites and aspen (*Populus tremuloides*) woodlands and Douglas fir (*Pseudotsuga menziesii*) forests in more mesic locations (Despain 1973). On the cooler subalpine plateaus one finds extensive upland coniferous forests of lodgepole pine (*Pinus contorta* var. *latifolia*), subalpine fir (*Abies lasiocarpa*), Engelmann spruce (*Picea engelmannii*), and whitebark pine (*P. albicaulis*), broken by occasional meadows and sagebrush parks on alluvial and lacustrine soils. The high peaks are covered by forests of spruce, fir, and whitebark pine on sheltered slopes, with alpine or subalpine meadows and boulder fields on the more exposed sites. Pollen analysis of pond sediments indicates that these basic patterns of species distribution have been relatively stable during the last 5000 years (Baker 1970).

However, vegetational patterns related to the second source of landscape diversity—perturbation—have undergone changes during this time. Most of the changes have been natural, as described below, but some aspen and sagebrush communities in northern Yellowstone appear to have been altered somewhat by fire suppression during the last century. Comparisons of 100-year-old photographs with recent photographs of the same sites show that forests today are generally more dense, with an increase in conifers and a decrease in aspen, and that many sagebrush parks now contain more shrubs and fewer grasses and forbs. Streamside thickets of willow (*Salix* spp.) and alder (*Alnus* spp.) also appear less extensive and robust than formerly (Houston 1973).[1] Some have attributed these changes to excessive browsing by elk (*Cervus elaphus*) (Beetle 1974, Peek et al. 1967).

A more common explanation appears to be the virtual elimination of fire in this area from 1886 to 1975. Houston (1973) found that fires formerly recurred at average intervals of 20–25 years in northern Yellowstone, a disturbance frequency that probably was essential for the persistence of plant species and communities representing early stages of secondary succession (notably aspen and herbaceous plants). In the absence of fire, succession has proceeded unchecked and other species such as Douglas fir and sagebrush have become increasingly predominant. Thus fire

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[1] Houston, D. B. 1976. The Northern Yellowstone Elk. Parts III and IV. Vegetation and habitat relations. Unpublished report, Yellowstone National Park, Wyoming.

prevention appears to have modified the overall composition of the northern Yellowstone landscape, reducing landscape diversity by increasing the area covered by late successional plant communities at the expense of early successional communities. The magnitude of this change is relatively small in the context of the entire northern Yellowstone landscape, however, since aspen and herbaceous communities comprised a small fraction of the landscape even in presettlement times (Despain 1973). Similar changes have also been described in several other western parks and wilderness areas following effective fire control (Habeck 1976, Habeck and Mutch 1973, Kilgore and Taylor 1979, Loope and Gruell 1973, Lunan and Habeck 1973). Because a major management goal in the large national parks is to preserve ecosystems in their primeval state (Houston 1971), Yellowstone recently instituted a new fire management policy that allows lightning-caused fires to burn without interference if they do not threaten human life, property, or other values (US National Park Service 1975).

The situation seems to be different on the high subalpine plateaus that dominate most of the central, western, and southern areas of the park. Because of inaccessibility, effective fire control was not accomplished here until about 1950 when fire-fighting equipment and techniques were greatly improved (US National Park Service 1975). Moreover, our research indicated that fire occurs naturally at very long intervals because of very slow forest regrowth and fuel accumulation after fire (Romme 1982). On an average site, 200 years or more are required for a fuel complex to develop that is capable of supporting another destructive fire. On dry or infertile sites, 300–400 years may be necessary. Fires ignited prior to that time are likely to burn a very small area and have a minimal impact on the vegetation (Despain and Sellers 1977, Romme 1982). Recent uncontrolled fires in the park that burned intensely in 300-year-old forests have been observed to stop when they reached a 100-year-old stand, even though weather conditions remained favorable for fire (Despain[2], Despain and Sellers 1977). Thus, in an ecosystem where fire historically occurred at intervals of 200+ years on any particular site, suppression during the last 20–30 years probably has had very little effect on overall landscape pattern. Any major changes that have occurred are largely the result of natural processes that would have taken place even in man's absence.

Although the subalpine landscape apparently has not been substantially altered by man's activities (excluding, of course, those areas of intensive development for visitor use), it has by no means been static during the last 100 years. We found evidence that major fires occur cyclically, i.e., thousands of hectares may burn at intervals of 300–400 years with relatively few major fires in the same area during the intervening periods (Romme 1982). Such a fire cycle can occur because: geologic substrate, soils, and vegetation are very similar over much of the plateau region; forests over large contiguous areas grow and develop a fuel complex at approximately the same rates; and the plateau topography has low relief and few natural barriers to fire spread. Thus one extensive fire tends to be followed by another fire in the same area some 300–400 years later. In other parts of the Rocky Mountains where topographic barriers are more numerous, where succession occurs more rapidly, or where fuel characteristics are different, this particular type of fire cycle may not occur.

LITTLE FIREHOLE RIVER WATERSHED

We conducted our study in the Little Firehole River watershed, which covers 73 km^2 on the Madison Plateau, a large rhyolite lava flow in west-central Yellowstone. Coniferous forests predominate, with lodgepole pine occurring throughout and subalpine fir, Engelmann spruce, and whitebark pine being found on more mesic sites. Alluvial deposits in the central and northern parts of the watershed support subalpine meadows or open coniferous forests with rich shrub and herbaceous understories. The topography is generally flat or gently sloping, with an average elevation of about 2450 m.

Fire history during the last 350 years was determined using the fire-scar methods developed by Heinselman (1973) and Arno and Sneck (1977). Major fires occurred in 1739, 1755, and 1795 (± 5 years), collectively burning over half of the upland area. Of the forested areas that did not burn at that time, nearly all were located either on topographically protected sites (ravines, lower northeast-facing slopes) that burn rarely (Romme and Knight 1981, Zachrisson 1977), or in places that had been burned by a moderately large fire in 1630, [illegible] years earlier, and were covered by young forests. Since 1795 only three fires >4 ha have occurred, and all three were relatively small (<100 ha). The absence of recent large fires is almost certainly due to a lack of suitable fuel conditions over most of the watershed, not to fire suppression by man. In fact, park records show that only one fire has been controlled in this area, a 90-ha burn in 1949. The fire probably would not have covered a much larger area even without suppression, since it was surrounded by young forests and topographically sheltered sites. Today the areas burned in the 1700s support lodgepole pine forests that are all developing more-or-less synchronously; in another 100–150 years extensive portions of the watershed will again have fuel conditions suitable for a large destructive fire.

Three stages of forest regrowth following fire (early, middle, and late successional) can be recognized on upland sites. Early successional stages are usually present for about the first 40 years and are characterized by an abundant growth of herbs and small shrubs. The large dead stems of the former forest remain standing throughout most of this period, and an even-aged cohort of lodgepole pine becomes established. Middle successional stages are marked by the maturation and dominance of the even-aged pine cohort, beginning with canopy closure around 40 years and lasting until senescence around 250–300 years. Herbaceous biomass and species diversity are lowest during this period (Taylor 1973). During late successional stages (250–300+ years) the even-aged pine canopy deteriorates with heavy mortality and is replaced by trees from the developing understory to produce an all-aged, usually mixed-species stand, which then persists until the next destructive fire.

We used our data on fire history and on the rates and patterns of forest succession after fire to reconstruct the sequence of vegetation mosaics that must have existed in the Little Firehole River watershed during the last 240 years. Past landscape patterns were reproduced by first making a map showing the age (time since the last destructive fire) of all homogeneous forest units in 1978, based on extensive field sampling and aerial photography. Then, to reconstruct the landscape of 1738, for example, we subtracted 240 years from the age of each stand in 1978 and determined in which successional stage a stand of that age would

[2]D. G. Despain, personal communication.

have been. Where a fire had occurred more recently than the date of interest (e.g., areas that burned in 1739 in the reconstruction for 1738) we assumed that the stand was in a fire-susceptible late successional stage (Romme 1982).

Figure 1 shows the proportions of the Little Firehole River watershed covered by early, middle, and late successional stages at different times since 1738. In 1738 most of the area was covered by late successional forests, but fires in 1739, 1755, and 1795 greatly reduced the old-growth forests and replaced them with early successional stages. Middle successional stages became most abundant around 1800 and have dominated the watershed since. The early successional stages that were common in the late 1700s and early 1800s have been very uncommon since the mid-1800s. A decrease in middle successional stages after 1938 and an associated increase in late successional stages reflect forest maturation on areas burned in 1739.

To further describe historic patterns in landscape diversity, we calculated three diversity indices (similar to those used for measuring species diversity) and applied them to our landscape reconstructions for 1778–1978. We computed a richness index, based on the number of community types present; an evenness index, reflecting the relative amount of the landscape occupied by each community type; and a patchiness index, indicating the size and interspersion of individual community units as well as the structural contrast between adjacent communities (Romme 1982). Figure 2 shows the results of plotting a weighted average of all three indices, as a measure of overall landscape diversity, and the Shannon index (Pielou 1975), which we calculated by using the proportion of the watershed covered by a community type as a measure of abundance. Both indices reveal a similar pattern: Landscape diversity was high in the late 1700s and early 1800s following the extensive fires of 1739, 1755, and 1795; it fell to a low point in the late 1800s during a 70-year period with no major fires; and it increased again during this century as a result of two small fires plus some variation in the rate of forest maturation in areas burned in 1739 and 1795. This variation in rates of succession is attributable to several factors including localized high densities of the mountain pine beetle (*Dendroctonus ponderosae*) (Romme 1982).

The dramatic changes in landscape composition and diversity in the Little Firehole River watershed during the last 240 years (Figures 1 and 2) must have been associated with significant changes in ecosystem structure and function, including net primary productivity, nutrient cycling, total biomass, species diversity, and population dynamics of individual species. These relationships cannot be fully quantified at this time, but speculation based on existing knowledge is useful.

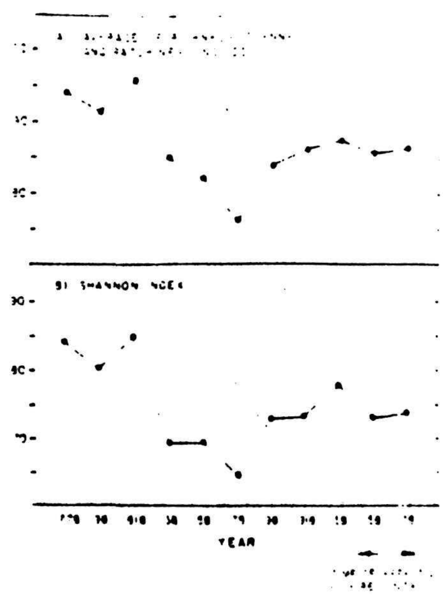

Figure 2. Changes in two measures of landscape diversity in the Little Firehole River watershed from 1778–1978.

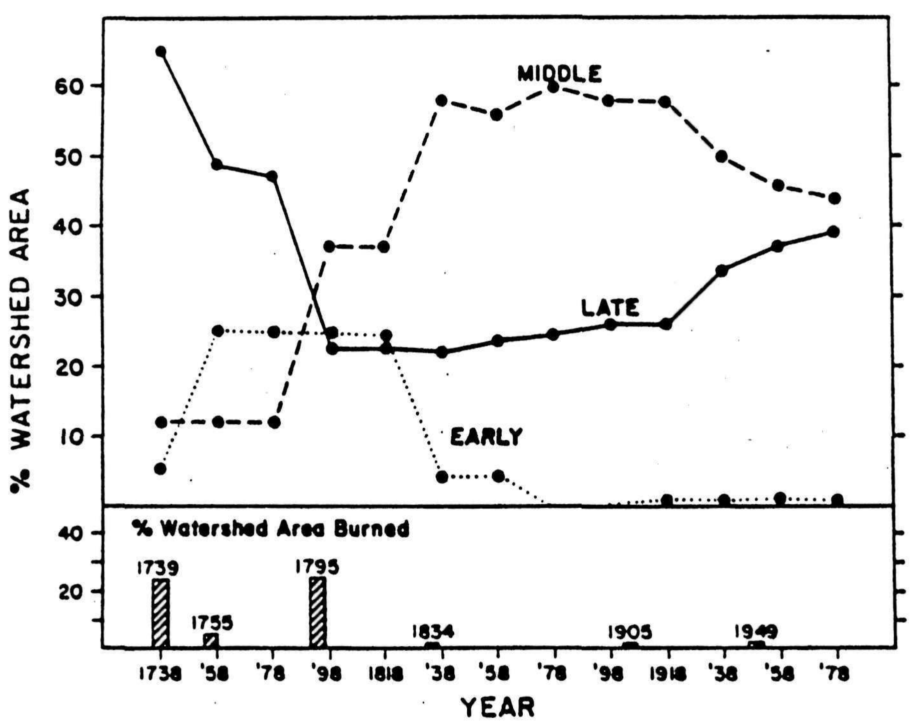

Figure 1. Percent of watershed area covered by early, middle, and late stages of forest succession from 1738–1978 in the 73-km² Little Firehole River watershed, Yellowstone National Park.

IMPLICATIONS FOR WILDLIFE

Taylor and Barmore (1980) censused breeding birds in a series of lodgepole pine stands representing a gradient from the earliest successional stages after fire through late successional stages in the park. Their data show the pattern of avifaunal succession in a single homogeneous stand. In attempting to answer the question of how breeding bird species and populations change with time in an entire subalpine watershed, we used Taylor and Barmore's (1980) census data to estimate the number of breeding pairs in each stand within our reconstructed vegetation mosaics, summing the estimates for all to arrive at an estimate of breeding pairs in the entire watershed.

Figure 3 shows the results for three representative species and for the total number of breeding pairs of all species. Mountain bluebirds (*Sialia currucoides*) require open habitats with dead trees for nesting. Such habitat was most abundant in the Little Firehole River watershed during the late 1700s and early 1800s when 25–50% of the area was covered by early forest successional stages following the large fires of the 1700s (Figure 1). Consequently, bluebirds may have been very numerous at that time. However, as forests matured bluebird populations probably dropped dramatically (Figure 3). Today bluebirds are uncommon in the watershed except in the 90-ha area that burned in 1949. Note that this probable population decline was a perfectly natural event, occurring at a time when European man had not yet entered the area.

In contrast to the bluebird, ruby-crowned kinglets (*Regulus calendula*) prefer mature forests. Thus, kinglets were less common when bluebirds were most abundant (Figure 3). The yellow-rumped warbler (*Dendroica auduboni*) breeds successfully in a variety of habitats and as a result the population of this species probably has fluctuated little during the last 240 years despite the major landscape changes that have occurred (Figure 3). Figure 3 also shows that the total number of breeding pairs of all species has probably fluctuated greatly in the last few centuries. The highest numbers apparently were in the late 1700s and early 1800s when landscape diversity was also greatest (Figure 2).

The population estimates shown in Figure 3 can be challenged easily on the basis that they were derived solely from habitat availability, i.e., the number of hectares of forest present in each age class. Of necessity we have ignored other critical determinants of population density. Nevertheless, the overall patterns are valid to the extent that they show the constraints of habitat on potential populations.

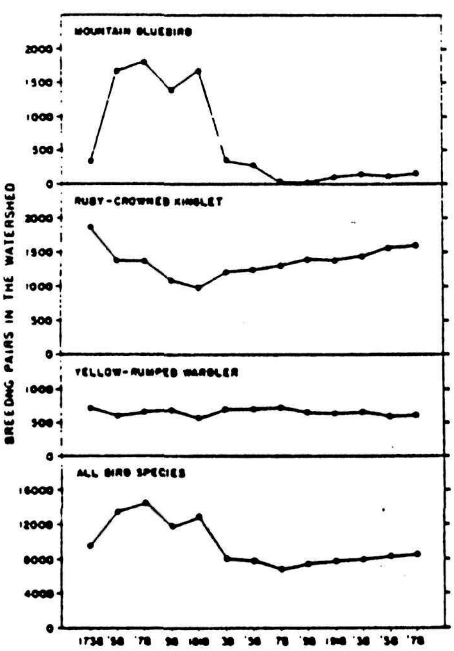

Figure 3. Estimated population sizes of breeding birds in upland forests of the Little Firehole River watershed, based on data from Taylor and Barmore (1980) and the trends shown in Figure 1. Populations in meadows and riparian forests, which cover approximately 16% of the watershed, are not included because appropriate population density data are not available for these habitats.

Table 1. Relative values of plant communities and successional stages for elk habitat in the Little Firehole River watershed.*

Plant community type	Potential forage value	DISTANCE COEFFICIENT — DISTANCE (m) TO COVER OR WATER 0–320	320–800	800–1500	1500+
Alluvial woodland adjacent to moist meadow	10	1.0	0.9	0.7	0.5
Meadow	9	1.0	0.9	0.7	0.5
Upland forest: early successional stages	7	1.0	0.9	0.7	0.5
Upland forest: late successional stages	3	1.0	0.9	0.7	0.5
Upland forest: middle successional stages	2	1.0	0.9	0.7	0.5

*Based on models and discussions by Asherin 1973, Basile and Jensen 1971, Black et al. 1976, Hershey and Leege 1976, Lonner 1976, Lyon 1971, Marcum 1975, 1976, Pengelly 1963, Reynolds 1966, Stelfox et al. 1976, Thomas et al. 1976, and Winn 1976.

We were also able to consider the effect of landscape change on elk. Using a model much like that developed by Thomas et al. (1976), we examined changes in three critical habitat features during the last 200 years, namely, forage quantity and palatability, shelter (or cover), and water. The forage and shelter provided by an individual forest stand change greatly during postfire succession. Early successional stages usually have the best forage whereas middle and late successional stages provide the best shelter. However, because elk use several different kinds of habitat, the distribution and interspersion of plant communities and successional stages is critical. Thus the center of a large meadow or recently burned area may receive little elk use, despite abundant forage, if it is too distant from shelter or water, and the potential shelter of very extensive tracts of mature forest may be largely ignored if little forage is available (Black et al. 1976, Hershey and Leege 1976, Marcum 1975, Reynolds 1966, Stelfox et al. 1976, Thomas et al. 1976, Winn 1976).

We developed a relative ranking system by which every type of plant community and successional stage in the Little Firehole River watershed was assigned a value from 0–10 to indicate potential forage value (Table 1). These values were subjective, based on published literature and our own observations in the study area. We then divided the watershed into 1429 units of 5 ha each, identified the dominant vegetation type within each unit, and assigned appropriate values to each. Every value was multipled by a distance coefficient reflecting the distance to the nearest shelter or water if those features were not present within the unit itself (Table 1), the product being our elk habitat index. In this manner we analyzed our reconstructed vegetation mosaics for 1778, 1878, and 1978.

Figure 4 (a, b, and c) shows the results for three 5-ha units having different histories of fire and forest regrowth. As a result of changes in stand structure, the quality of elk habitat has varied greatly. However, when we averaged the values for all 1429 individual 5-ha units to obtain an estimate of elk habitat quality for the watershed as a whole, we found much less difference among the landscapes of 1778, 1878, and 1978 (Figure 4d). There are probably two main reasons for this result. First, temporary increases in habitat quality in one part of the watershed (due primarily to the great improvement in forage after fire) have been balanced by decreases resulting from forest maturation on other areas burned earlier. Second, and probably more important, the best habitat is in and around moist meadows where forage, shelter, and water all occur in close proximity. In fact, our model may underestimate the habitat quality of subalpine meadows in the park, since we reduced our elk habitat index in the centers of large meadows to reflect the distance to shelter. However, the shelter requirement apparently is much less critical for elk populations that are not hunted by man, and elk in the park are frequently observed feeding in the centers of large meadows.[1] We were unable to determine whether the large fires in the surrounding uplands had burned the meadows and adjacent allu-

[1]L. Irwin, personal communication.

vial woodlands. We assumed that the fires in these areas were of low intensity and produced little change in community structure or elk habitat. Although our results suggest that fires may not greatly influence the overall quality of elk summer range on the high plateaus of Yellowstone, elk are attracted to recently burned areas (Davis 1977), and over much of the subalpine zone, moist meadows are less common than in the Little Firehole River watershed. Where meadows are less common, summer elk populations may fluctuate in response to changes in the upland landscape.

IMPLICATIONS FOR AQUATIC ECOSYSTEMS

One of the most interesting and attractive features of the park is Yellowstone Lake. This virtually unpolluted subalpine lake covers 354 km^2 and contains populations of the native cutthroat trout (*Salmo clarkii*). The trout support a complex food chain including pelicans, ospreys, otters, and bears. Some evidence indicates that the lake's net primary productivity has declined during the last century, as has its carrying capacity for trout and associated top predators (Shero 1977, US National Park Service 1975). Because the period of apparent decline coincides with attempts at fire control, some have suggested that the cause is reduced nutrient input to the lake due to biotic immobilization by forests. As noted earlier, however, our research indicates that the natural fire regime has not been greatly altered by man's activities in the Yellowstone subalpine zone, particularly in the very remote areas that drain into Yellowstone Lake.

Rather than attribute the cause to fire suppression, we favor the hypothesis that lake productivity is to some extent synchronized with the long-term fire cycle that seems to prevail in the watershed of Yellowstone Lake. A variety of evidence supports this hypothesis. For example, experiments in the Rocky Mountains have shown that removal of mature forest from 40% of a subalpine watershed results in an increase in total water discharge of 25% or more (Leaf 1975). The increase is due to several factors related to the distribution and melting of the winter snowpack. Albin (1979) compared two small tributary streams of Yellowstone Lake: about 20% of one watershed was burned by fires 36 and 45 years previously, whereas the other watershed was unburned. The burned watershed had greater seasonal variation in streamflow and greater total water discharge per hectare. If a large portion of a subalpine watershed burns at intervals of approximately 300 years, as seems to occur in the Little Firehole River watershed, then streamflow also may exhibit a long-term cycle over and above yearly and seasonal fluctuations. During the high-discharge portion of the cycle, especially in years of high snowfall, debris is washed out of stream channels, new channels are cut, and new alluvial deposits are created. Such events influence habitat for fish as well as for floodplain species like willow and alder, which in turn are important browse species for elk and other terrestrial animals (Houston 1973).

But more important to the question of Yellowstone Lake is the nutrient content of stream water. Immediately after deforestation by fire or cutting there often is an increase in dissolved minerals due to erosion, reduced plant uptake, increasd microbial activity, increased leaching, and the release of elements from organic matter by fire (Bormann and Likens 1979, McColl and Grigal 1975, Wright 1976). The increase is usually short-lived, lasting several years at most (Albin 1979, Bormann and Likens 1979), but it may be important as a periodic nutrient subsidy (Odum et al. 1979) to oligotrophic aquatic ecosystems. As young forests become established, biotic immobilization is so effective that nutrient concentrations in stream water fall to very low levels (Bormann and Likens 1979, Marks and Bormann 1972, Vitousek and Reiners 1975). Thus a watershed dominated by early and middle forest successional stages (e.g., the Little Firehole River watershed during the 1800s) would produce relatively nutrient-poor water. As forests reach late successional stages, tree growth and net primary productivity decrease, nutrient uptake is less, and consequently the leachate is richer in dissolved minerals (Bormann and Likens 1979, Vitousek and Reiners 1975).[4]

Thus, although the possible connection between fire suppression and reduced productivity in Yellowstone Lake is plausible, an equally attractive alternative hypothesis is that extensive fires in the watershed about 100 years ago replaced many late successional forests with early successional stages. As young forests over much of the watershed began utilizing soil nutrients more efficiently, the total amount leached into stream water feeding the lake was reduced accordingly. If this is true, any recent decline in lake productivity may be a natural phenomenon that has occurred many times in the past and will be alleviated as forests in the watershed mature. Of course, the Yellowstone Lake watershed is very large (ca. 2600 km^2), and landscape patterns over this large area may be in a state of dynamic equilibrium, or what Bormann and Likens (1979) have referred to as a shifting mosaic steady

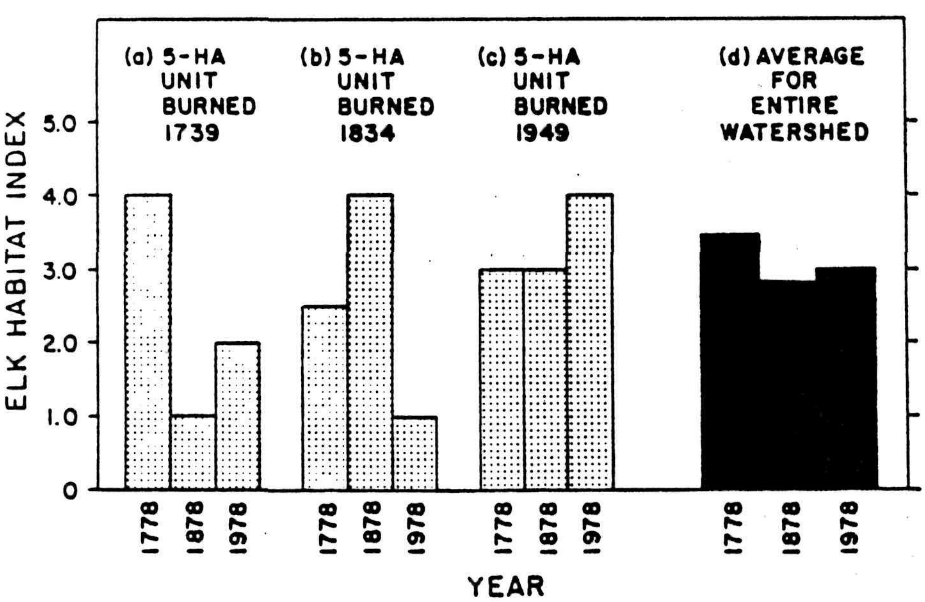

Figure 4. Elk habitat index (see text) for three representative 5-ha units and for the entire Little Firehole River watershed (d) in 1778, 1878, and 1978.

[4]Pearson, J. A., D. H. Knight, and T. J. Fahey. Unpublished ms. Net ecosystem production and nutrient accumulation during stand development in lodgepole pine forest, Wyoming.

state. If this is found to be true for the Yellowstone Lake watershed, then total nutrient input to the lake should be about the same from year to year (though the source would vary), and some other explanation for the decline in lake productivity will be required.

CONCLUSIONS

After a century of ecological research that focused largely on species or individual communities or ecosystems, there now is a growing interest in still higher levels of organization such as the landscape and biosphere. Changes in landscape patterns influence a variety of natural features including wildlife, water and nutrient flow, and the probability of different kinds of natural disturbances. Given a sufficiently large area and a natural disturbance regime, various measures of landscape pattern may remain fairly constant over time despite dramatic cyclic changes in localized areas such as a small watershed. Such "steady states" have been demonstrated or hypothesized for a Swedish boreal forest (Zachrisson 1977), high-elevation fir forests in New England and elsewhere (Sprugel 1976, Sprugel and Bormann 1981), primeval northern hardwood forests of North America (Bormann and Likens 1979), and mesic deciduous forests of the southern Appalachians (Shugart and West 1981). Our results suggest that strong cyclic changes occur on areas of at least 100 km^2 in Yellowstone National Park, but more research is needed to determine if the landscape patterns in the park as a whole are in a state of equilibrium. Large wilderness areas, when protected from pollutants and managed so that natural perturbations can continue, provide the best and probably the only locale for studying the kind of landscape changes that occurred for millenia in presettlement times.

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Wildfires in Northern Yellowstone
National Park, Douglas B. Houston

ECOLOGY

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WILDFIRES IN NORTHERN YELLOWSTONE NATIONAL PARK[1]

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Abstract. A sample of 40 fire-scarred trees was used to reconstruct the frequency and size of fires during the past 300—400 years in northern Yellowstone National Park. Best estimates of frequency suggested mean intervals of about 20–25 years between fires, after adjustments had been made for the recent influence of modern man. Agreement in fire dates over wide areas suggested the occurrence of 8 or 10 extensive fires in the past 300—400 years. Euro-American man has substantially reduced the natural fire frequency for about 80 years and has thus contributed to changes in plant succession.

INTRODUCTION

A comparison of historic with recent photos of northern Yellowstone National Park suggested the hypothesis that natural fires had been a major influence on plant succession (Fig. 1). The changes in vegetation have occurred on the "northern winter range" of the park, an area that supports a unique assemblage of native ungulates with their complement of predators and scavengers (Houston 1971*a*). Data on frequency and size of past fires were considered necessary to understand trends in plant succession and, eventually, the relations between ungulates and their habitats. The objective of Yellowstone Park, as a natural area, is to maintain representative ecosystems in as near pristine conditions as possible (Houston 1971*b*). Therefore an important purpose in this study was to assess the effects of attempting to suppress natural fires nearly since establishment of the park in 1872.

THE STUDY AREA

The 81,000 ha study area extends down the elevational gradients of the Yellowstone, Lamar, and Gardner rivers from about 2,600–1,500 m (Fig. 2). U.S. Department of Commerce Weather Bureau records (1960) for Mammoth Hot Springs at 1,900 m showed a 30-year (1930–59) mean annual precipitation of 39.49 cm. Precipitation on most of the area ranges 30—45 cm. Records show a mean annual temperature of 7.8°C; July, as the warmest month, averaged 30.8°C; January, as the coldest, −14.0°C. Reviews of historical records and of dendroclimatological data show that the area has been subjected to wide variations in precipitation, and periodic droughts have been common. Prevailing surface winds, an important consideration in interpreting fire data, are usually from the southwest but are often changed to west by the topography of the study area.

FIG. 1. Tower Junction, Yellowstone National Park. Upper photo by J. P. Iddings ca. 1885 (U.S. Geol. Survey No. 152); lower, D. B. Houston, 1970. The increase of *Artemisia tridentata* on bunchgrass steppes (in this case *Festuca idahoensis*), the increase in area and density of coniferous forest (*Pseudotsuga menziesii*), and the decline in aspen typify vegetative changes on the study area.

The vegetation of the area is primarily a steppe with interspersions of conifers occurring as single isolated trees or small stands at lower elevations, and as more continuous forests at higher elevations or on north slopes. The "mesic meadows" in valley bottoms are characterized by *Deschampsia* spp. and *Carex* spp. Bunchgrass steppes on upland slopes are characterized by *Agropyron spicatum*, *Festuca idahoensis*, *Koeleria cristata*, *Stipa* spp., and *Poa* spp.

[1] Received August 5, 1972; accepted February 18, 1973.

TABLE 2. Intrastand fire frequency

Stand	No. trees	Interval compared	Total no. scars for period	No. different fires[1]	Interval between fires $\bar{x}$	Min.	Max.[2]	Adjusted interval -80 yrs.
B_1	2	1776–1970	5 (3, 2)[3]	5	41	18	38	25
C_1	3	1603–1970	19 (8, 4, 7)	16	22	6	40	17
C_2	2	1693–1970	11 (7, 4)	10	28	7	45	20
C_3	2	1706–1970	9 (5, 4)	6	44	6	53	26
D_1	2	1646–1970	8 (5, 3)	6	54	14	60	41
G_1	2	1773–1970	8 (5, 3)	6	33	6	44	20

[1] ± 2 years allowed for agreement on fire dates.
[2] Excludes the interval from 1970 to most recent scar (see text).
[3] (No. of scars per tree)

54 to 69 years. Smaller samples from higher elevation (2,200–2,300 m) sites (BG) showed intervals of 53 and 96 years. The two trees from unit D were sampled above a series of natural fire breaks and supplemental increment coring from other portions of the unit showed that the interval of 88 years underestimated fire frequency. The interval of 87 years for unit A probably underestimates frequency because of a lack of suitable trees. The unit extends about 1,500–1,800 m at the lower limit of tree distribution: most trees occurred on riparian sites, on rock outcrops, and on talus slopes, which were poor locations to sample fire frequency. Additionally, many larger trees had been felled in this unit for construction and fuel during the early decades of the park. record for any one tree underestimated the frequency of fires to which the area had been subjected (because not all trees were scarred by every fire, or else scars were burned away by subsequent fires) or that, despite precautions in sampling, the record reflected many small fires. There appears to be no unequivocal means for separating these possibilities, but the correspondence in fire dates over wide areas and the obvious incompleteness of the records on some trees as a result of subsequent burning argue for the first possibility. Mean adjusted intervals of 20–25 years between fires were calculated by subtracting 80 years from tree ages and are considered to be the best estimate of the true fire frequency (Table 2). Substantial variation occurred in the intervals between

graphic variations (Stewart 1956. Komarek 1967. Hough 1926). Archeological records show that prehistoric man has occupied the Yellowstone area as a hunter-gatherer for at least 10.000 years BP (Wedel et al. 1968. Lahren 1971). Small resident groups of American Indians, the Tukudika, and various Plains tribes traveled and hunted the greater Yellowstone area until the 1870's. Russell (Haines 1965) described an 1835 attempt by Blackfeet Indians in the Yellowstone area to drive his party of furtrappers from concealment by setting fire to the vegetation. Doane (Bonney and Bonney 1970) considered that the large 1870 fire had been set to drive game. and Gillette (1870) specifically attributes this fire to Indians. It seems probable that aboriginal man contributed to the frequency of fires on the area, but a quantitative assessment of this contribution is not possible.

The earliest recorded exploration of the Yellowstone area by Euro-American man in 1807–08 was followed by a period of fur trapping from about 1826–40. Osborne Russell's (Haines 1965) detailed journal suggests that trappers probably had little influence on fire frequency. Except for transient miners in the 1860's, the Yellowstone area remained poorly known until organized scientific exploration began in the late 1860's and early 1870's, with the park established in 1872. Fire suppression attempts began with the administration of Yellowstone Park by military personnel in 1886 (Harris 1886). Regular fire patrols were instituted and suppression activities increased until by the summer of 1889 Boutelle (1890) reported that "Seventy fires are known to have occurred in the park, all of which, except three, were extinguished." The removals of resident Indians and disruption of surrounding Plains cultures by 1880 should be considered an additional influence on fire frequency by Euro-American man.

Taylor (1969) has traced the development of more recent fire suppression activities in the park. Effectiveness appears to have increased with greater expenditures of manpower and with improvements in technology. The latter has included deployment of fire lookouts with a sophisticated communications network and has culminated in the use of aircraft (by 1939) and chemical retardants (by 1960).

Modern man has also had a potential for adding to the fire frequency on the area. Taylor (1973) found that 43% of 1,298 fires occurring in the park 1930–1970 were man-caused. Ninety-six man-caused fires occurred on the study area from 1931 to 1971. These were suppressed; only four burned 4 or more ha, with by far the largest recorded at 185 ha. These records suggest that, under the climatic conditions which have prevailed, man has been able to almost completely suppress fires on the grasslands of the accessible study area for at least 30 years, and has substantially reduced the frequency of natural fires for as long as 80 years. (This interpretation may not apply to the more inaccessible forest areas in the remainder of the park.)

Discussion

Data from this study have provided strong support for the hypothesis that wildfires have been a substantial influence on plant succession in this area of Yellowstone Park. Fire scars are a relatively crude measure of frequency and may underestimate the past influence of fire in this ecosystem because they may be formed only under favorable circumstances, such as by particularly severe fires. The best interpretation may be that much of the area would have burned at least one to four times since establishment of the park were it not for the actions of modern man. Changes that have occurred in the vegetation seem best explained by a reduction in fire frequency but have also occurred within a fluctuating climatic regime (Bray 1971) and with concomitant foraging by herbivores. Separation of these various influences is not entirely possible, and the following interpretations are regarded as tentative. In general, the reduced fire frequency has resulted in greater expressions of "climatic climax" vegetation (Daubenmire 1968*b*) than would otherwise be present. This is undesirable in a natural area, but if fire were reintroduced it appears to be possible to return some plant communities to more natural conditions.

The conspicuous increase of fire-sensitive *Artemisia tridentata* in the steppe (Fig. 1) would certainly be reversed if fire were reintroduced, and some changes in the relative abundance of herbaceous species might also be expected (Daubenmire 1968*a*, Conrad and Poulton 1966). Forest succession on the area has changed the relative abundance of species and increased the density and distribution of forests. Conifers have increased and aspen—the only significant deciduous species—has declined. Conifer succession could certainly be returned to more natural stages if fire were reintroduced. Aspen clones were estimated to occur on 2%–4% of the area, and 21 of the 31 scarred fir trees used in this study were also felled within 45 m of aspen, suggesting that aspen had formerly been subjected to frequent burning. Aspen in the Rocky Mountains reproduce mainly by vegetative means and may require periodic burning to stimulate reproduction (Loope 1972). Clones that have been entirely replaced by conifers or that are now represented by only scattered overmature trees have almost certainly been lost. It seems improbable that other remnant stands with understories now dominated by the exotic grass *Phleum pratense* would respond to burning. This grass has completely

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SCIENCE

Ecosystems of National Parks

National parks are unique in seeking to limit man to nonconsumptive uses of the land.

Douglas B. Houston

The primary purpose of the National Park Service in administering natural areas is to maintain an area's ecosystem in as nearly pristine a condition as possible (*1*). This means that ecological processes, including plant succession and the natural regulation of animal numbers, should be permitted to proceed as they did under pristine conditions, and that modern man must be restricted to generally nonconsumptive uses of these areas.

These deceptively simple, and seemingly naive, ideas require explanation. Few of our parks are completely self-contained ecological units, and their problems have been repeatedly cataloged (*2–5*). These areas have obviously been affected by modern man's overall disturbance of the biosphere, as well as by his more specific disturbances, including elimination and introduction of species, designation of artificial park boundaries, and suppression of natural biotic processes. I will not minimize these problems: an Everglades without water or with a jetport would be a travesty. I contend that, despite man's intrusions into the ecology of national parks, the pristine ecosystem relations in many of them are comparatively intact or have some reasonable potential for being restored. This sounds incongruous, since visitors to several of these areas number in the millions annually. However, it is necessary to recognize that the uses

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man makes of these parks are largely nondisruptive and nonconsumptive; that is, man does not supply or divert significant amounts of materials and energy to or from the park ecosystem, and he is not a significant part of the food chain. There are exceptions in almost every park to the concept of nonconsumptive land use, but I think it can be shown that the objectives for natural areas are realistic and that national parks illustrate a type of land use that makes it appropriate to recognize a unique park ecosystem.

Research and Management in the Park Ecosystem

The maintenance of a natural park ecosystem requires a unique approach to research and management. Unlike other forms of land management, management of a park ecosystem generally involves preventing or compensating for man's altering of natural ecological relations.

Effective management is aided by a research program that provides information which is interpreted in light of park objectives. Much of the research in parks is directed toward documenting pristine conditions and processes, determining the completeness of park ecosystems, and developing management procedures to maintain or restore the ecosystem. A complete ecosystem, as the term is used here, would have both cycling of materials and energy pathways comparable to those in pristine conditions. Lack of ecological completeness may take a variety of forms, for example, unnatural reduction or elimination of predator populations or a park's having only a portion of the historical range of a migratory species—a problem common to mountain parks with ungulate populations and parks with a diverse avifauna. Recognition of this problem is by no means new (*2, 6*); putting it into the context of the ecosystem and trying to evaluate and compensate for incompleteness is comparatively new (*3–5, 7, 8*). A goal of many research plans is to describe the park ecosystem in more quantitative terms. This is being done by concentrating research on key relations in a given park's ecosystem, with the hope that, through them, we may understand the whole.

Evaluation and restoration of natural factors that shaped the vegetation (the producer level of ecosystems) are under way in many areas. Continued protection of the vegetation from the influences of man is all the "management" that is required in some areas. In others, the restoration of natural processes requires more active management. Natural fires have helped shape the vegetation of many areas, and their influence is being restored in the form of prescribed burns and by allowing naturally occurring fires to burn. The 7000-acre pinelands in Everglades National Park represent a fire-maintained forest of southern slash pine (*Pinus elliottii*). Prescribed burns have been carried out since 1958, and their effects have been documented (*9*). This program will be continued on a routine management basis. Fire also maintained the red fir (*Abies magnifica*) forests of Sequoia and Kings Canyon national parks (*10*). Prescribed burning was done on an experimental basis in these fir forests, and now naturally occurring fires above 8000 feet in the Middle Fork of the Kings River are being allowed to run their course. Fires also burned at 20- to 25-year intervals in the groves of sequoias (*Sequoia gigantea*) in these parks (*11*). Restoration of natural fires presents a problem in the sequoia groves. Past suppression has resulted in an accumulation of fuels and the development of an understory vegetation. Experimental prescribed burns and mechanical removal of accumulated fuels are being tried in these areas. The management goals are to reduce this unnatural fire hazard, restore a natural process, and provide a suitable habitat for sequoia reproduction (*10*). Plans to "restore" natural fires in the parks of the Rocky Mountains are in various stages of discussion.

The periodic attacks of certain of the native herbivorous insects upon susceptible trees in park ecosystems has no doubt occurred for millennia. Attempts at "control" are not compatible with the objectives of natural areas, and the deaths of susceptible trees by native insects should be recognized as a natural process. The mountain pine beetle (*Dendroctonus monticolae*) is responding to favorable environmental conditions in portions of Yellowstone National Park and is attacking stands of lodgepole pine (*Pinus contorta*). No attempts at control are being considered (*12*).

The maintenance of representative populations of native ungulates in natural areas requires an appraisal of ecosystem completeness. In the parks of the Rocky Mountains, ecological incompleteness may result from having the historic winter ranges of wild ungulates outside park boundaries. Under these conditions, populations are managed by public hunting that is carried on outside the park boundaries (*3, 7*).

Ungulate populations that are yearlong residents on ecologically complete ranges are of considerably more interest. An hypothesis being tested on some of these populations that occur in periodically severe environments is that they may not need artificial regulation; that is, the park ecosystem is complete enough to ensure that the numbers of these animals are regulated naturally. Four specific examples are given.

1) A study of the moose (*Alces alces*) population in Grand Teton National Park has shown that regulation of numbers occurs primarily through periodic winter mortality and by reduction in successful births after severe winters, complemented by the emigration of subadults (*13*). Regulation has also resulted from short-term fluctuations in the conditions of the willow (*Salix* spp.) forage sources on winter range areas. These fluctuations have not caused permanent deterioration of plants or adverse effects upon other faunal species.

2) An elk (*Cervus canadensis*) population of about 1000 animals lives yearlong in the Madison, Firehole, and Gibbon river areas of Yellowstone Park (*7, 14*). Regulation appears to result from rigorous winters and limitations on food supplies, with the complementary actions of predators, parasites, and disease. The elk provide food for a population of grizzly bears (*Ursus arctos*), a remnant group of gray wolves (*Canis lupus*) (*15*), and a variety of smaller predators and scavengers.

3) The elk and mule deer (*Odocoileus hemionus*) populations in the Middle Fork of the Flathead River drainage in Glacier National Park appear to be naturally regulated (*16*). Rates of reproduction of both species have been low. Population stability over the past 20 years has resulted from low mortality, balanced against low recruitment. The availability of winter yarding sites in coniferous forests probably determines carrying capacity. Differences in winter yarding areas and forage preferences appeared to reduce interspecific competition and permitted coexistence of both species.

4) A population of 100 to 300 bison

(*Bison bison*) has annually wintered in the Pelican Valley of Yellowstone Park since establishment of the park in 1872 (*17*). This population has been subjected to reduction in numbers by man only twice after having been poached to near-extermination about 1902. It is considered to be naturally regulated. Regulation has been accomplished by the effects of average and even mild winters on mortality and reproduction. This has resulted in long periods of near stability. Increases during particularly favorable periods have been offset by periodically more severe winters. Short-term occupancy of thermal areas during periods of extremely adverse conditions may permit survival of biologically essential components of the population.

Certain tentative conclusions may be drawn from these examples, since several of these populations appear to have characteristics in common (*14*). Realized annual recruitment to the population is low. Range conditions fluctuate, and some areas appear to be periodically "overgrazed," in terms of the usual criteria. Ungulates participate in plant successional processes and may be capable of reducing or eliminating remnant vegetation types that are no longer a number-limiting food source. Large predators represent only one of a complex of regulatory factors on ungulates and may have been overrated as a major control in harsh environments (*18*). However, it is still difficult to generalize upon the effects of predation (*19*). Once the existence of natural regulation has been determined from intensive research, the "management" of these ungulate populations will consist of monitoring population characteristics and habitat conditions.

This approach to the management of vegetation and native ungulates illustrates the uniqueness of park ecosystems. It follows that the criteria used in forestry or range and wildlife management, where vegetation and wildlife are harvested as a crop, do not necessarily apply to national parks. For example, having an elk population with a low rate of reproduction on ranges that appear temporarily overgrazed may be poor game management, but it is excellent management of a park ecosystem, as long as it is essentially natural. It is self-evident that the usual concept of "waste" (*20*) does not apply in parks; that is, the death of trees and ungulates is necessary to maintain ecological relationships.

Managing Man

Providing for the educational and esthetic enjoyment of man, while maintaining pristine ecological relationships, represents the greatest challenge in the management of natural areas. In broadest terms, man affects natural ecosystems by altering biogeochemical cycles and by quantitatively or qualitatively altering energy pathways. This latter influence includes such things as supplying energy to or diverting it from the system, altering the distribution and abundance of native species, and introducing exotic species.

Overnight camping, regarded as traditional and compatible with park objectives, is permitted under current policies (*21*). However, a natural ecosystem can absorb only a small number of these facilities, and the larger complexes (including lodges, housing areas, and so forth) have effects that extend beyond their immediate boundaries. For example, the disposal of sewage from such areas could alter energy pathways, as well as nitrate and phosphate cycles. The disposal of nearly 7000 tons of garbage annually within Yellowstone Park represents a substantial energy input and has contributed to management problems by altering the natural distribution of the grizzly bear (*22*).

Effects of the input of materials and energy into the ecosystem may be modified temporarily by refined treatments that prevent, or at least alter the form of, the input (*23*). This is being done in several areas. Management programs for the grizzly bear call for elimination of garbage as a food source, plus such related steps as increased campground sanitation and protection, and, perhaps, eventual removal of these complexes from prime bear habitat (*22, 24*).

To effectively resolve these conflicts with park ecosystems, major complexes should eventually be moved to at least the periphery of—and better still, outside—natural areas. The concept of maintaining large overnight facilities was developed in the early decades of this century, when modes of transportation were slower and population centers were further from parks (*4*). However, in this day of rapid transportation, there seems to be little real need for maintaining such facilities in the heart of a natural area.

Angling, as it is currently practiced in most natural areas, is a consumptive use of a natural ecosystem and may cause substantial alteration of energy pathways. Angling is considered a traditional, albeit controversial, use of parks. Some people hold that angling represents an anachronism with present pressures and that it should be eliminated (*4*); others hold that fish populations should be fully exploited and supplemented by stocking waters with fish raised in a hatchery. Angling in some form will no doubt be continued in the foreseeable future. However, the practice of stocking waters with hatchery fish, solely to maintain angling, has no place within a natural area. Furthermore, I consider maximum sustained yields to anglers to be too disruptive of ecosystem relations. Various races of native cutthroat trout (*Salmo clarkii*) still occur in the parks of the Rocky Mountains, although their distribution outside the parks has been greatly reduced.

Management objectives within these natural areas are to maintain wild populations of these and other native fishes in the aquatic ecosystems and to provide "quality angling" (*25*). "Quality angling" stresses the recreational aspects of angling: fish may be caught and released, but comparatively few, if any, are intentionally killed. This approach to the management of wild fish is being tested in several areas.

Sightseeing, which is considered a nonconsumptive use of parks, may also alter energy pathways unless it is regulated. For example, visitors have so damaged certain accessible areas of the fragile alpine tundra of Rocky Mountain National Park that initial recovery from trampling may require decades; complete recovery, centuries (*26*). This alteration was aggravated by such consumptive acts as picking flowers and removing stones. Management actions that may help correct the situation include channeling visitor activities by developing well-routed and maintained trails, relocating parking areas, and developing a visitor education program to explain the nature of tundra ecosystems.

These examples of the influence of man on natural ecosystems illustrate something of the conflicts facing park managers. Despite these conflicts, it appears to be feasible to maintain natural relations—if it is recognized that park ecosystems have a finite capacity for absorbing certain of man's disruptive and consumptive influences. This capacity has been reached in many areas.

Interpretation of the Park Ecosystem

The explanation of natural phenomena to the park visitor is another function of the National Park Service. Interpretation includes exhibits at museums, visitor information centers, and along roadsides; hikes and evening programs conducted by Park Service personnel; and self-guiding trails and auto tours. In addition, most areas offer a variety of publications that explain features of the park.

Visitor interest in these facilities and activities appears to be high. Nearly 20 percent of the 2.4 million summer visitors to Grand Teton Park in 1969 used visitor centers and attended more formal programs (*27*). Over 50 percent of the visitors to Yellowstone National Park during 1970 visited at least one of the six visitor centers, and about 10 percent attended one or more evening programs or nature walks (*28*). During the past several years, interpreters have used the ecosystem concept as a vehicle for communicating an understanding of park philosophy. Museum exhibits and brochures describe in laymen's terms the park ecosystem and objectives in managing natural areas. A skilled interpreter can build an entire program around a park's ecosystem.

A quality environment does not yet rank high as a national priority, despite current public interest in ecological problems. The National Park Service has an opportunity to contribute to the promotion of an environmental ethic that extends beyond park ecosystems to those of outside areas, and to such problems as environmental degradation and rates of human population increase. This opportunity is being used, and hopefully more emphasis will be placed on environmental problems in future interpretive programs. The contrast between the ecosystem of an unpolluted river in a park and a river such as the Thames [where perhaps one-half of the energy input is from sewage and detritus (*29*)] might be enlightening to many visitors.

Summary

The preservation and maintenance of natural park ecosystems, with modern man's being restricted to generally nonconsumptive uses of the park, represents one end of a spectrum of land use that extends through exploitation of natural ecosystems to the development of simplified agricultural ecosystems. Criteria for management of a park ecosystem must, of necessity, differ from criteria for other uses of land, since park management involves preventing or compensating for the influence of man. The objectives for natural areas appear to be ecologically feasible if it is recognized that these areas have a finite capacity for absorbing man's consumptive and disruptive influences. The interpretation of ecosystems to park visitors provides an opportunity to contribute to an environmental ethic that extends beyond the park environment.

References and Notes

1. The National Park Service administers "natural areas," "historical areas," and "recreation areas," with each type having distinct management objectives. "[N]atural areas shall be managed to conserve, perpetuate, and portray as a composite whole the indigenous aquatic and terrestrial fauna and flora and scenic landscape." This is interpreted to mean preservation of natural ecosystems. [*Administrative Policies for Natural Areas of the National Park System* (Government Printing Office, Washington, D.C., 1968), p. 17.]
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6. A. Murie, *Fauna of the National Parks, No. 4* (Government Printing Office, Washington, D.C., 1940).
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14. G. F. Cole, *Mission-oriented Research in Natural Areas of the National Park Service* (Research Note, Yellowstone National Park, 1969).
15. ———, *Status of Grey Wolf* (Research Note, Yellowstone National Park, 1969).
16. C. J. Martinka, "Ungulate winter ecology studies in Glacier National Park," in *Annual Report, 1969* (Office of Natural Science Studies, National Park Service, 1970), pp. 74–75.
17. M. Meagher, thesis, University of California at Berkeley (1969).
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20. "Waste" is usually defined as materials or energy not used for mankind's material welfare.
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28. W. W. Dunmire, personal communication.
29. K. H. Mann, in *Advances in Ecological Research*, J. B. Cragg, Ed. (Academic Press, New York, 1969), vol. 6.

30. I thank G. F Cole, C. J. Martinka, P. S. Hayden, and A. Murie for reviews of the manuscript. These and other research biologists of the National Park Service made unpublished data available for this article. Many of the ideas and arguments presented herein have not originated with me but have been formulated largely in discussions with these same gentlemen.