Yellowstone Science

A quarterly publication devoted to the natural and cultural resources

Clarifying the Park's Muddy Waters

A Grand Fisheries Experiment

Grizzly Bears: A Book Review

Camping and Forest Structure

Volume 5 Number 1

Going with the Flow

I tend to look for the connections between things, and lean toward establishing an underlying theme for each issue of this magazine. In planning this one I thought the connection is *water*: scientists look into the turbid waters of northern Yellowstone's rivers and provide clarity on the sources of sediment and how events such as wildfires, high snowpacks, and floods affect the waters. Concern for the water quality and its influence on fisheries was a major impetus for beginning the sediment study. So not coincidentally, we finish the story, begun in the previous volume, of the history of fisheries management in the park. Finish, that is, telling what we can as history, leaving entire (and surely quite fascinating) chapters yet to be written as humans, fish, and the rest of the park's inhabitants continue interacting in and around the waters of Yellowstone. The popularity of the waters and their shores draws the park's highest numbers of backcountry travelers and results in some documented alteration in forest areas that host those campers. Management of backcountry use to minimize effects is a continual challenge, especially since human and wildlife use is so influenced by the lakes and rivers. They provide ease of access yet sometimes serve as barriers to movement; they quench the literal thirst for sustenance and, for many of us, also provide an aesthetic backdrop or magnet that draws us into the wilderness to reflect and reconnect with ourselves and our environment...I can hear the trickle of Cabin Creek flowing past as I recall my last backcountry trip there...I can picture the raging, muddy waters of the Yellowstone after a late spring rain...I remember crossing Yellowstone Lake on the park boat, soaking up the views of the Absaroka Range to the east and watching the depth-finder for deep spots where I imagined lake trout lurking beneath the surface, threatening turmoil under the apparently calm waters...ah, it *flows*, this issue, one article to another, it appeals to my sense of connectivity...

Then someone asked, but where is the *charismatic* story? It's good to present articles featuring the spectrum of scientific studies on park resources, but we must be realistic, we must *grab* the potential reader's attention; we cannot assume that our audience will be equally drawn by stories of sediment and sapling structure—albeit worthy research—as they might by tales of wandering wolves and migrating elk calves. Or can we? Should we give them what they want (or what we think they want)? Doubtless every editor, or park interpreter around the campfire program, considers this dilemma of how to provide more information yet hold the audience. Still, doesn't each person in every audience vary in where they are on the road to what a teacher of mine once called "the eternal quest for knowledge," so that we cannot worry overmuch about which stories or facts will appeal? Ah well, "saved" by a book review on those ever-charismatic grizzlies; it doesn't flow so well with the theme, but perhaps it will assuage the interest of those who thirst for something different than water. SCM

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On the cover: Fishing Bridge in the 1950s. See Part Two of the history of fisheries management in Yellowstone on page 3. Photo NPS archives. Above: An SCA volunteer taking water samples from the bridge at Corwin Springs, Montana in May of 1991. Photo courtesy Roy Ewing.

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Suspended Sediment in the Rivers of Northern Yellowstone

Assessing Changes from the 1988 Fires

by Roy Ewing

"How on earth did I get here? Is this really worth it? This is crazy." I remember 1 a.m. on a cold night in early June 1986. The Lamar River was swollen with water that had melted from the winter snowpack and picked up a lot of mud on the way down the watershed. My supervisor, park hydrologist Jana Mohrman, and I were suspended over the river in an aluminum car that rode on a thick steel cable just below the canyon downstream of Slough Creek. Through the snow that blew intermittently, I could see the heavy brass water sampler—also known as the "fish"—as it fell toward the roaring river below. As it plunged into the river, the swift current carried it downstream, jerking the little cable car down and tilting everything off vertical. We steadily winched the fish down until it touched the river bottom and then cranked it back up. As we hoisted in the swaying sampler and retrieved the glass pint bottle, the cable car was freed from the currents and bounced around wildly. I recall loading another bottle into the sampler, keeping an eye peeled for floating logs coming down the river, and wondering how I got into this situation.

That late-night river sampling was part of a study to identify major sediment-producing tributary watersheds in the northern portion of Yellowstone National Park, including the Yellowstone and Lamar rivers (Fig. 1). Our research began in 1985, in response to the concerns of the Livingston (Montana) chapter of Trout Unlimited. Local anglers and businesses dependent on river activities were concerned about the levels of suspended sediment in these rivers. The sediment carried by a river can endanger fish populations by smothering spawning beds and reducing the supply of aquatic invertebrates on which fish feed. The periodic debate over the level of ungulate grazing on Yellowstone's northern range prompted concerns about high levels of erosion in the park as a source of this sediment.

An ad-hoc consulting committee that included representatives from the Montana Water Resources Division of the U.S. Geological Survey (USGS), the Snow Survey branch of the Soil Conservation Service, the Gallatin National Forest, the Montana Department of Fish, Wildlife and Parks, the Montana Water Quality Bureau, the Park County (Montana) Conservation District, and Trout Unlimited recommended a study to obtain baseline information on suspended sediment and other properties of the Yellowstone River and several of its tributaries. In addition to identifying major sediment-producing watersheds, sampling the Yellowstone and Lamar rivers over time would establish a benchmark for comparison for future studies to determine whether suspended sediment transport from the park was changing. The study was directed by the Fisheries Assistance Office of the U.S. Fish and Wildlife Service, which at that time conducted aquatic monitoring programs for Yellowstone National Park. From 1985 to 1992 researchers could be seen sampling the Yellowstone River from the Corwin Springs bridge and the Lamar River near its confluence with the Yellowstone.

How Rivers Carry Sediment

Generally, rivers carry the most suspended sediment when they receive the most runoff from their watersheds. In this northern Rocky Mountain region, this occurs during spring when the snowpack melts, rains fall, and the rivers flow at the highest streamflow levels of the year. Depending on the nature of the snowmelt season, rivers are turbid or murky from suspended sediment from April to July. From July on, the rivers become clearer

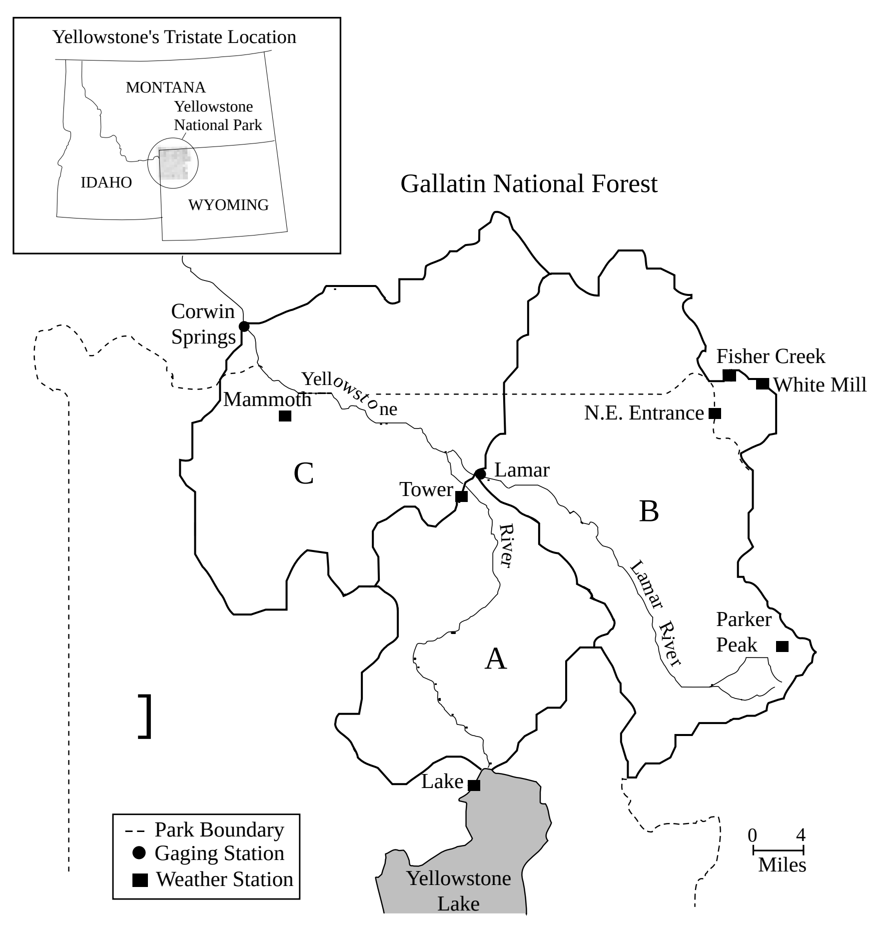

Figure 1. Study area in northern Yellowstone National Park, the Gallatin National Forest, and private lands in Montana. Study drainage subareas include: A. Yellowstone River from Yellowstone Lake to Lamar River; B. Lamar River Basin; and C. the Yellowstone River from the Lamar River to Corwin Springs, Montana.

and the level or stage of streams continuously falls until the next year's snowmelt. Periodic summer rainstorms cause runoff that carries sediment to the streams, and this intense, concentrated precipitation on a watershed can erode more sediment than snowmelt waters due to the impact of rain drops or hail. Thus, rivers in this region can get even muddier during summer than in spring, although less sediment is carried because rainstorms don't contribute as much runoff as does the snowmelt.

Other factors influence the amount of erosion and sediment transport in a watershed. The nature of the bedrock and soils is important, with soft rocks (such as shales) and unconsolidated sediments (such as prehistoric lake sediments) eroding most easily. Bedrock and soil also influence the vegetation present in a watershed. Vegetation intercepts rainfall, reducing the impact of raindrops on the soil surface, and also binds the soil with root networks. When vegetation is removed, as during construction of buildings and roads, erosion of sediment into streams is increased; most states require sediment control barriers and procedures to reduce this impact.

Rivers carry sediment in two ways: as bed load and suspended load. If you think of the river as a mode of transport, it carries a load like a truck or train. Heavier sand, gravel, pebbles, and cobbles are rolled or bounced along the river bottom during periods of high flow. This sediment, referred to as the "bed load" of the river, is difficult to measure. The lighter, individual mineral grains of sediment that produce the muddy water we see in rivers during snowmelt or after rainstorms is known as the "suspended load." It is sampled using the previously mentioned brass sampler operated from a bridge or cableway over the river.

Suspended sediment can vary greatly in space and time. Several procedures must be followed to obtain representative estimates of the sediment being carried in a river at any given time. Multiple samples are taken across the width of the river to establish a coefficient or multiplier to adjust daily samples taken at a single point. During the spring thaw, snow melts faster as each day warms up; a maximum melt rate occurs at about 3 p.m., after which the melt rate declines. This produces a diurnal surge of water and sediment that may take some time to reach the sampling station. Sediment sampling may therefore have to occur at odd hours in order to obtain representative samples of the daily sediment transport. The same is true for sediment plumes from summer thunderstorms—the afternoon storm plume may not reach the sampling station for hours or days. To adjust for yearly variations in runoff, sediment must be sampled during both low and high precipitation years.

Variations in precipitation and snowmelt from 1985 to 1987 caused the Yellowstone River to carry widely varying amounts of runoff (volume of water). In 1985, the runoff at Corwin Springs was 78 percent of the long-term average (1961-1988), while the warm spring of 1986 resulted in a large snowmelt runoff and overall runoff that was 116 percent of the average. In 1987, a near-drought resulted in runoff that was just 56 percent of the average. These variations enabled us to sample suspended sediment during low, moderate, and high flow years and obtain a good estimate of the relationship between streamflow and suspended sediment. As it happened, the drought of 1987 extended through 1988, contributing substantially to the record fires experienced throughout the ecosystem.

After the 1988 Fires

As the smoke from the 1988 fires cleared, resource managers needed to assess the dramatic changes that had taken place in Yellowstone, including those in aquatic ecosystems. Many studies have found that several factors cause suspended river sediment to increase in burned watersheds: raindrop impact on the soil increases because the tree canopy that intercepted raindrops is reduced or gone; surface flow increases because of groundcover destruction; and sediment delivery patterns change. Because increased suspended sediment may harm fish populations, we decided to continue our studies and estimate changes in suspended sediment output from the Yellowstone River drainage after the wildfires. The objectives of the extended study, which lasted from 1989 through 1992, were to measure postfire streamflow and suspended sediment on the Yellowstone and several tributaries at the same places as in our original study, and to identify fire-related changes in river sediment. Volunteers from the Student Conservation Association assisted park staff in sampling rivers and gathering hydrologic information. The National Park Service (NPS) and USGS used the same techniques used in our prefire study to collect water samples, measure streamflow, and analyze the data.

Postfire Changes in Precipitation, Runoff, and Suspended Sediment

As it happened, average total precipitation was greater during the postfire study period (1989-1992) than it was from 1985 to 1987. Although this was also true for postfire winter and spring averages, summer precipitation was less than the prefire average. Although the years after the fires had greater average precipitation than in the prefire period, cooler snowmelt periods resulted in lower streamflows. The largest postfire snowmelt runoff (116 percent of average) and total April-September runoff (102 percent of average) on the Yellowstone River at Corwin Springs occurred in 1991 (see Table 1). In contrast, the greatest streamflow prefire year, 1986, had a snowmelt runoff of 126 percent and total runoff of 116 percent of the long-term average.

Suspended sediment increased in the Yellowstone and Lamar rivers following the 1988 wildfires. The question that arose was "How much of this increase was due to greater precipitation and runoff (climatic factors) and how much was due to fire-related effects, such as increased erosion?" The postfire average total suspended sediment load increased 69 percent over the prefire average for the Yellowstone River and 34 percent for the Lamar River (see Table 2). The postfire snowmelt average load was 74 percent greater than prefire on the Yellowstone River but only 23 percent greater on the Lamar River. The Lamar River experienced much greater increases in summer sediment load (743 percent over prefire) than did the Yellowstone River (16 percent over prefire).

Fire-Related Changes in Sediment

Because greater precipitation and resultant runoff during the postfire period was likely to have caused higher levels of suspended sediment, two methods were used to try to isolate the changes in suspended sediment due to fire effects. In the first method, suggested by USGS hydrologist John Lambing, the monthly measured load (in tons) was divided by the monthly measured runoff (in acre-feet) to express the suspended sediment load as an amount per monthly runoff (tons per acre-feet). The resulting measures for postfire and prefire periods were therefore independent of river flow (or precipitation) and could be compared. Using this method, changes in river sediment could be identified that were most likely related to fire effects.

For the Yellowstone River as measured at Corwin Springs, postfire increases in monthly sediment load- per- unit- runoff occurred most notably during the snowmelt months of April, May, and June, when the postfire monthly average (1989-1992) increased 156, 105, and 42 percent over the prefire (1985-1987) monthly average values. Summer postfire changes were more variable, with the July postfire average less than prefire (-1 percent), August postfire average 100 percent greater than prefire, and the September postfire average 20 percent more than the prefire. The Lamar River, on the

Table 1. Prefire 1985-1987 and postfire 1989-1992 monthly and seasonal runoff as a percentage of long-term prefire mean runoff of the Yellowstone River at Corwin Springs, Montana.

Prefire	April	May	June	Snowmelt	July	August	Sept	Summer	April-Sept Total
1985	118.20	126.77	63.56	87.07	53.92	72.04	85.46	63.70	77.65
1986	155.10	105.52	132.14	125.69	94.70	109.09	111.96	101.23	115.83
1987	140.62	94.17	38.68	63.36	39.43	53.87	56.93	46.02	56.37
Mean	137.97	108.82	78.13	92.04	62.68	78.33	84.78	70.32	83.29
Postfire									
1989	161.08	136.47	83.90	105.83	70.11	78.56	77.61	73.53	92.82
1990	242.26	91.17	86.95	99.88	79.66	84.98	85.54	82.00	92.67
1991	96.56	138.20	107.30	115.99	76.90	83.92	88.28	80.55	101.71
1992	194.08	147.48	58.29	95.86	63.36	66.96	75.61	66.25	83.93
Mean	173.49	128.33	84.11	104.39	72.51	78.61	81.76	75.58	92.78

Table 2. Mean monthly and total suspended sediment load of runoff for the Yellowstone River and the Lamar River for the postfire (1989-1992) period.

	April	May	June	July	August	September	April-September Mean	April-June Mean	July-September Mean
Percent Postfire Change - Yellowstone River									
Tons	253	154	13	-1	107	11	69	74	16
Tons/Acre-Feet	156	105	42	-1	100	20	79	80	26
Percent Postfire Change - Lamar River									
Tons		60	-8	319	1476	179	34	23	743
Tons/Acre-Feet		12	-11	114	1183	279	68	2	627

other hand, was most influenced by postfire sediment during the summer, when the postfire averages were greater than prefire: 114 percent greater for July, 1,183 percent greater for August, and 279 percent greater for September. This occurred despite the postfire reduction in precipitation. In contrast, the Lamar snowmelt postfire averages for May and June were close to or less than prefire values (+12 percent for May, -11 percent for June). The reasons for this seasonal difference are unclear, but may be related to the cooler postfire snowmelt periods and higher elevation of the Lamar River basin.

Although expressing sediment as load-per- unit- runoff permits comparison of sediment loads between periods with different streamflows and examination of loads on a month-by-month basis, this method may include some sediment that was climate-controlled rather than fire-related, because similar amounts of streamflow may be caused by different combinations of precipitation events. For example, because of a greater snowmelt runoff, a prefire July with few rainstorms could have a similar streamflow to a postfire July that had a lower snowmelt runoff and many rainstorms. In that case, the increase in July sediment after 1988 would be storm-caused (or climate-caused) rather than fire-related.

A second method to identify fire-related changes in sediment was suggested by hydrologist Phil Farnes. Instead of grouping the data by month, sediment and streamflow data was divided into two seasons: snowmelt, April-June (May-June for the Lamar River) and summer, July-September. These seasons were, in turn, divided into rising-discharge and falling-discharge days. A rising-discharge day has the same or higher mean daily discharge than the previous day (possibly caused by a snowmelt surge or a rainstorm); a falling-discharge day has a lower mean discharge than the previous day. This method enabled us to analyze snowmelt surge or summer storm days separately from other days and thus be able to better compare prefire and postfire storm periods.

To identify fire-related increases in sediment not caused by climate changes, we determined regression equations that describe the relationship between streamflow and sediment for the prefire period and used them to calculate the predicted sediment loads for the postfire period. If an actual postfire load was greater than the predicted load for a given season, then the increase could be related to the fire events. For example, we first determined equations that related suspended sediment to streamflow for all the rising-discharge days during the prefire (1985-1987) snowmelt periods. Using the measured streamflow for each postfire (1989-1992) snowmelt rising-discharge day in the prefire equation, we calculated the predicted sediment load for each day and then summed these daily values to obtain a predicted load for all the postfire snowmelt period rising-discharge days. This would be the total sediment load that the Yellowstone or Lamar rivers would be expected to carry during snowmelt (rising-discharge days) if the fires had not occurred. We then compared this predicted load to the load actually measured for all the postfire snowmelt rising-discharge days. If the measured load was greater than the predicted load, a fire-related increase was suggested. This procedure was followed for the other three datasets: snowmelt falling-discharge days, summer rising-discharge days, and summer falling- discharge days.

Although this "predicted-versus-measured load" method indicated a pattern of fire-related changes similar to that shown by the monthly load-per-unit-runoff method, the magnitude of changes in sediment was different. The Yellowstone River again appeared to have major fire-related increases in suspended sediment in the snowmelt season, when snowmelt rising- and falling-discharge day sediment increased about 60 percent. Summer increases were 30 percent for rising-discharge days and 7 percent for falling-discharge days. The Lamar River, on the other hand, appeared to have its largest fire-related increases in the summer: 473 percent for rising-discharge days and 390 percent for falling-discharge days. No fire-related snowmelt increases in suspended sediment were evident on the Lamar River using this method (Fig. 2).

Climate and Variation in Fire Effects

Our research indicated that fire-related increases in suspended sediment occurred on the Yellowstone and Lamar rivers following the 1988 wildfires, but not in all seasons, and that the hydrologic behavior of burned watersheds can vary greatly. Postfire increases in suspended sediment were most evident on the Yellowstone at Corwin Springs during spring snowmelt, while the Lamar did not transport abnormally large sediment loads. On the other hand, summer suspended-sediment loads increased dramatically in the Lamar, but were not measured downstream on the Yellowstone at Corwin Springs. Evidently the runoff from unburned watersheds or those not receiving summer storms were enough to dilute the sediment effects from the Lamar River.

The bulk of suspended sediment in this region is transported in rivers during the spring snowmelt season; even large increases in summer sediment load are small by comparison to snowmelt loads. Thus, despite large postfire increases in summer sediment loads for the Lamar River, its mean postfire load (18,253 tons) was less than 10 percent of the mean total load (193,669 tons).

Postfire climate played an important role in influencing the sediment response of the Yellowstone and Lamar rivers. The first two years following the fires had relatively cool springs and few prolonged warm intervals, resulting in modest snowmelt runoffs. Watersheds are most vulnerable to accelerated erosion in the years immediately after wildfires, when burned surface vegetation has not had time to regenerate. If there had been high snowmelt runoffs in the springs immediately following the fires, sediment transport could have been much higher. The cooler postfire snowmelts from 1989 to 1992 may have also mitigated the snowmelt sediment response of the higher elevation Lamar basin, which was burned over a greater area than many of the other watersheds in the Yellowstone drainage from Yellowstone Lake to Corwin Springs. We would naturally expect that it would also show the greatest suspended-load response to the fires.

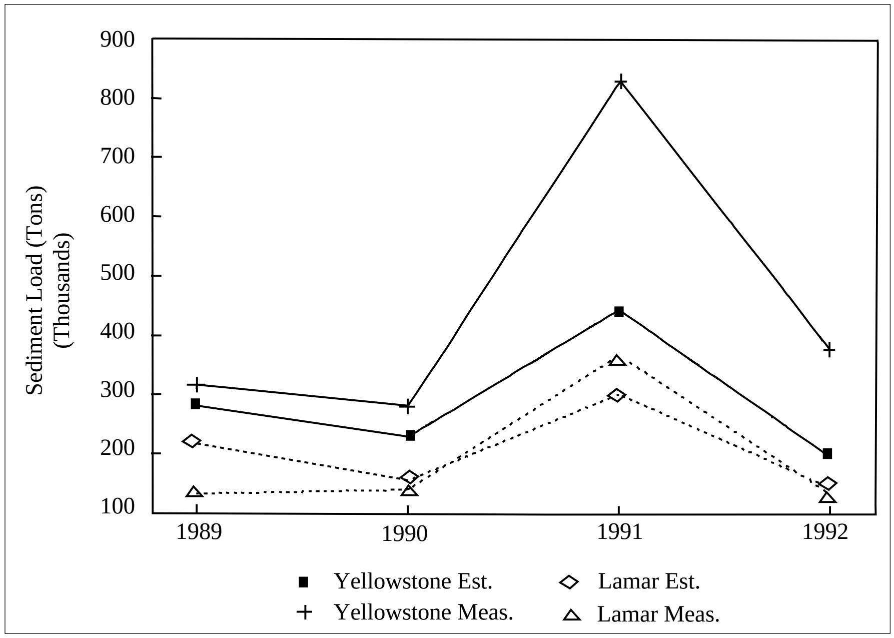

Figure 2. Estimated and measured suspended sediment loads for the Yellowstone River (April-September) and the Lamar River (May-September) for postfire years 1989-1992.

Again, this study attempted to measure the effects of the fires only upon suspended sediment, not total fluvial sediment, in two of Yellowstone's major rivers. The portion of total sediment load carried as bed load (coarser sediment) is often larger as one approaches the mountainous headwaters of rivers. The behavior of coarser sediment in mountainous watersheds following fires may be different from the suspended or finer sediment portion of the total sediment load in magnitude or timing of its response. Indeed, there is evidence to suggest that there were substantial coarse sediment and mass movement responses to the Yellowstone fires. Studies of burned and unburned watersheds in the Shoshone National Forest indicate that there were major events of coarse sediment transport in the first years after the fires without a corresponding increase in suspended sediment. Forest staff conducted field trips of fire-affected watersheds scoured and incised by high-volume coarse sediment flow during summer storms. Field trips in the Lamar River basin found numerous instances of burnt-out woody debris jams which would release impounded coarse bed-load sediment upon the first high-streamflow storm. Likewise, Grant Meyer documented the effects of fluvial, hyper-concentrated, and debris flow events in the Lamar watershed in 1989 and 1990 in his study of fire and alluvial change. These observations indicate major changes in the amounts of coarse sediment transported and in sediment-delivery patterns in the steep mountain stream channels following the fires and provide a complementary, if qualitative, picture of fire-effects on sediment transport.

Management Implications

Findings of the postfire sediment study useful to resource managers fall into two areas: direct information and analytical tools. Establishing the normal ranges of suspended-sediment transport out of Yellowstone is direct information that can be used to compare to future sediment loads associated with specific management practices. Our sampling for sediment and streamflow before and after the fires provides baseline information on such streams as Soda Butte Creek, which could have been affected by recent developments outside the park.

This study indicates that managers can

expect climate to exert the primary influence upon the amounts of suspended sediment sent into and carried out by streams after wildfires. The spring snowmelt runoff carries most of the year's suspended sediment in streams, and the character of postfire snowmelts are critical to sediment responses. The scenario for least-transported sediment is one where the spring is cool with few prolonged warm periods, an average or low winter snowpack, and little spring precipitation. The scenario for a large post-disturbance sediment response has a warmer spring, with at least one period of several consecutive days of warm temperatures, an average to large winter snowpack, and a lot of spring precipitation.

Summer suspended-sediment transport in the badly burned steep mountain drainages of the Lamar River basin increased dramatically after the fires and yet the effects downstream were evidently mitigated by runoff from unburned watersheds or those unaffected by storms. Changes in coarse sediment delivery may have been as great or greater as these watersheds released sediment stored behind burned woody debris dams and experienced mass movement, debris, and high fluvial streamflows immediately following the fires. The mountain watersheds have been readjusting coarse sediment delivery ever since the 1988 fires and are storing released sediment behind new woody debris jams. Comparison of predicted to measured suspended sediment in the Lamar River in 1992 suggests a return to prefire levels and may indicate that readjustment of sediment delivery patterns has been accomplished.

Both linear and non-linear regression equations relating suspended sediment to streamflow for prefire and postfire periods are among the useful analytical tools we developed. If direct suspended-sediment sampling is conducted in the future, these equations can be used to compare predicted loads to measured loads. Estimations can be made as to whether the Yellowstone River drainage has returned to prefire levels of sediment transport or whether the river is becoming muddier due to wildlife grazing or other factors. For the spring snowmelt season, streamflow-sediment rating equations can be used to estimate sediment transport levels on the Yellowstone and Lamar Rivers without further sampling. Based on values of mean daily streamflow, values of suspended sediment can be assigned to each day using the proper prefire rising- or falling-discharge rating equation.

A less expensive tool to monitor sediment transport levels on the rivers can be developed from suspended sediment-turbidity data we collected. Turbidity can be measured more easily and cheaply than suspended sediment and estimates of contained suspended sediment can be made using our sediment-turbidity data and equations. These would be particularly useful during summer, when streamflow-sediment rating equations are not as accurate as those for turbidity-suspended sediment.

Relationships between precipitation at park weather stations and runoff at the Corwin Springs gaging station were revised after the wildfires. These multiple regression equations describe the precipitation-runoff relationship and were used with historical flood data to produce equations that can predict the date of peak snowmelt runoff on the Yellowstone River for a given season. This information can be of value in planning for closing areas due to high water, predicting earliest dates for fording rivers, or other activities that require knowledge of the date of peak river flow. Finally, information on suspended sediment levels and hydrological patterns can be useful to fisheries and aquatic ecology studies.

The Importance of Baseline Data

As the United States becomes more developed, we need to measure the physical and ecological processes in wildland areas so that we can judge possible effects of natural or anthropogenic disturbances. If we do not know the hydrologic and sediment behavior in unmanipulated landscapes, we cannot know how far watersheds will deviate from normal when modified by construction, agriculture, or natural disturbances such as fires. Put another way, how can we judge if a stream is acting "naturally" without comparing it to streams in wild, unmodified landscapes? Few undammed or undiverted watersheds such as the Yellowstone River are left to study in the United States. It was fortuitous that three years of sampling and measurement had been completed before the 1988 fires, for without it, we could not have measured the effects of the fires upon suspended sediment loads. Resource managers now have a suspended sediment database that can be used as a yardstick in the future. For instance, comparison of 1992 data to the prefire average indicated that the Yellowstone River had not yet returned to prefire levels of sediment transport. How long did the effects of the 1988 fires last? Are the effects, in fact, over? Is the Yellowstone River getting muddier due to wildlife overgrazing, as anglers suspected in the days of the sediment study? Is uplift of parts of the Yellowstone plateau by underlying magma causing increasing sediment transport? These questions cannot be addressed, much less answered, without a historic database of natural resource information.

In retrospect, driving many miles each week, hiking up burned-out mountain streams, sampling in the rain and snow, and hanging out over rivers late at night, proved to be only slightly crazy and well worth the effort.

Roy Ewing studied northern Yellowstone's watersheds from 1985 to 1994, seeking to shed some clarity on the murky issue of muddy waters. He has a master's degree in geology from the University of Tennessee. While with the Peace Corps in India he worked on a water drilling project. He currently lives in his home state of Tennessee.

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A Grand Experiment

The Tide Turns in the 1950s: Part II

by Mary Ann Franke

As the years passed, it became evident that if Yellowstone were to be preserved as an example of wild America, all of its pieces and processes must be preserved. In 1949 the National Park Service (NPS) asked the U.S. Fish and Wildlife Service (USFWS) to determine the impact of egg collection on the ecology of Yellowstone Lake. This launched a 12-year study of the lake's trout population, including the size of spawning runs; the extent of egg, fry, and spawner mortality; and the role of tributary streams. The researchers concluded that the hatchery program posed a serious threat to the lake's cutthroat trout population. Although some fry were returned to the lake, the eggs were scrambled, mixing together distinctive genotypes. In addition, the reduced escape of spawners had combined with fishing pressure to cause the virtual collapse of spawning migrations in some streams.

The last substantial collection of eggs from Yellowstone fish occurred in 1953 and the hatcheries officially closed in 1957. The USFWS turned over most of its fish culture buildings to the park; today some of them are part of a historic district at Yellowstone Lake. The last fish stocking for the benefit of anglers occurred in 1955; since then, sanctioned fish planting has been limited to experimental restoration of rare native species. By the 1950s, Yellowstone's native fish were facing problems of angler pressure that could not be relieved simply by halting egg collection and fish stocking. Despite the large size and seemingly inexhaustible trout population in Yellowstone Lake, humans have had a significant effect on its ecosystem. The very characteristics that made the cutthroat so popular as a sportfish—its abundance and vulnerability to angling—may also have imperiled it. By the 1980s, cutthroat between Yellowstone Lake and Sulphur Caldron on the Yellowstone River were caught an estimated average of 9.7 times during the 108-day catch-and-release season, many of them two or three times in a single day.

The decline of the Yellowstone fishery continued to be managed with more restrictions on anglers rather than on fish. Starting in 1950, only fly fishing was permitted on the Madison and Firehole rivers, and in 1954 the daily creel limit was reduced from five to three fish. The primary goal of these regulations was to compensate for swelling angling pressure, not to protect the park's natural aquatic ecology. Although by now the implications of the park's dual mandate to both protect the resource and provide for enjoyment were more clearly defined, fishery managers still hoped that "enjoyment" could mean ever-increasing numbers of anglers removing a great many fish from park waters.

In Hope of Maximum Sustained Yield

At the same time that Yellowstone fish culture operations were expiring, the USFWS was shifting its stocking efforts from natural bodies of water to the new reservoirs that were a ballyhooed fringe benefit of the extensive dam construction taking place throughout the west in the 1950s and 1960s. With its Yellowstone fishery researchers needed elsewhere, the USFWS replaced them in 1961 with a team of managers whose mission was to apply the research findings. This included the concept of "maximum sustained yield" (MSY), which had become accepted by fishery biologists throughout the world. According to MSY theory, the number of fish that can be harvested annually without causing the fishery to collapse (the "harvestable surplus") is considered both a goal and a restraint. As the MSY is approached each year, the catch per hour starts to decline and anglers catch fewer large fish and presumably stop fishing. If no more than the MSY is removed, the fishery can be sustained indefinitely, but exceeding the MSY results in recruitment failure and the population will plummet.

Embedded within this complex equation is the old idea that all forms of wildlife go forth and multiply to produce a surplus of animals, leaving the human species with the duty to harvest them. At Yellowstone, this meant it was thought beneficial to occasionally cull the elk and bison herds, ship "extra" bears to zoos, and harvest fish for their own good. It was simply a scientific matter of determining how many animals could or should be removed. In 1963, the MSY for Yellowstone Lake was estimated to be 325,000 cutthroat trout a year. (The Yellowstone Lake harvest had peaked at about 390,000 fish in 1959.) However accurate MSY may have been in theory, the fishery managers found it unworkable in practice. Random fluctuations in the environment upset the balance of recruitment and harvest—high spring waters might increase spawning mortality, or fine summer weather could increase angler days—making the MSY goal infeasible. The fishery managers didn't know what the annual harvest target would be each year until it was too late to do anything about it; its "accuracy" was meaningful only in a historical context.

When a "Fishing for Fun" program began in 1962, instead of being required to keep and count all fish toward their daily limit, anglers were encouraged to return fish to the water. But this first step toward catch-and-release fishing increased exploitation in popular fishing areas because anglers no longer had to stop after three fish: they could keep going until they'd landed three *big* ones. This reduced the spawning stock and, with the use of bait still permitted, hooking mortality for released fish was estimated to be 18 percent. And even with catch-and-release encouraged, many fish were deliberately wasted. "Investigations have shown that in the Fishing Bridge area in a single month, 7,500 fish were discarded in garbage receptacles," according to the Superintendent's Annual Report for 1966. By then, the USFWS had recommended that "Fishing for Fun" be suspended. To better distribute anglers by encouraging use of remote lake areas, they recommended permitting larger boats on the lake and increasing the daily limit to five fish in certain areas. They even proposed building a road around the lake to "equalize fishing pressure." The park did not regard such measures as the solution to increasing angling pressure and declined to adopt them.

Even if the 1963 MSY estimate of 325,000 cutthroat trout was accurate, prior years of excessive harvest, especially of spawning age trout, produced dire results. During the period from 1963 to 1969, the catch rate fell from 0.71 to 0.45 trout per hour, the lowest on record. And two years after the estimated number of anglers on Yellowstone Lake reached its all-time high of 242,000 in 1967, the annual harvest dropped to 175,000 trout.

While fisheries managers were still trying to apply MSY theory, the Interior Secretary's Advisory Board on Wildlife Management set forth a far more momentous idea in 1963. Known as the Leopold Report, for chairman A. Starker Leopold, it advised: "As a primary goal, we would recommend that the biotic associations within each park be maintained, or where necessary recreated, as nearly as possible in the condition that prevailed when the area was first visited by the white man." As the report prophetically recognized, "The implications of this seemingly simple aspiration are stupendous."

A New Form of Angler Pride

With the impetus of the Leopold Report and the threat of resource damage from increasing visitation, Yellowstone began to move toward more "natural" ecosystem regulation when Jack Anderson became Superintendent in 1967. Although the transition initiated a period of great controversy in elk, bison, bear, and fire management, changes to the fishery program received wide-spread support. The perspective of the USFWS and of anglers themselves was shifting; many realized that without tighter controls on the number of harvested fish, their fishing days would be numbered.

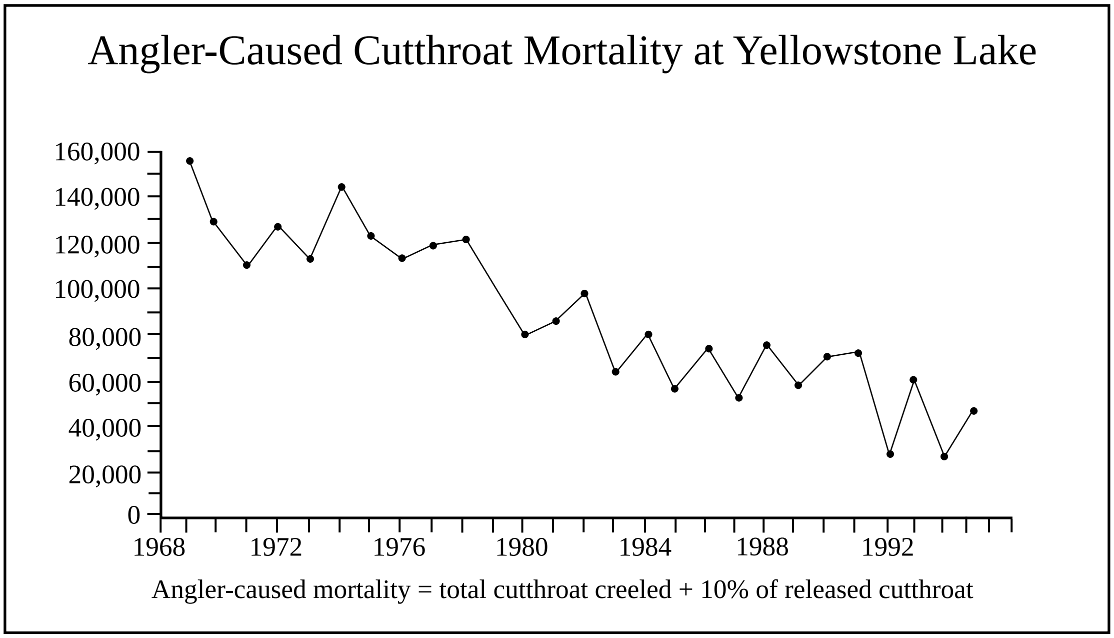
To bolster its fish populations, Yellowstone adopted stricter angling regulations that varied by species and location. In 1969 bait fishing was prohibited to foster catch-and-release fishing and to prevent the planting of non-native species caused by bait dumping. Starting in 1970, cutthroat trout from Yellowstone Lake had to be at least 14 inches long to be kept. In 1973, the daily creel limit for most park waters was dropped to two fish and many streams were designated catch-and-release only. Some waters, including the Yellowstone River at Fishing Bridge and in Hayden Valley, were closed entirely to fishing to protect spawning runs, for aesthetic reasons, or to allow waterfowl and wildlife to use the shoreline waters undisturbed.

With the new size and creel limits, by 1974 the cutthroat harvest from Yellowstone Lake had dropped to an annual average of about 100,000 trout, while the landing rate had risen to almost one trout an hour. Despite signs of population resurgence, the 14-inch *minimum* size limit had the unfortunate effect of removing the older and larger cutthroat trout. By 1974 data showed that the average size of cutthroat prespawners had begun to decrease to levels observed before the 14-inch minimum was set.

> "I fully realize how humanly chest-expanding it is to empty a full creel before an admiring circle of friends. But there is a great kick in the other point of view if only you can once acquire it. There is a great kick in taking a fine trout who has fought you well, gently removing the hook, holding him firmly behind the pectoral fins, and placing him a few seconds in the water whilst he recovers his breath, then watching life come back, his tail begin to wag as though in gratitude, and finally seeing him glide away happily into the element from which you took him... You will not be saving just one trout; you will be sponsoring a new form of pride amongst anglers which in time, I hope, will replace the pride in the long string of dead fish." — Howard Back, *The Waters of Yellowstone With Rod and Fly,* 1938.

To improve the age structure and further reduce the annual harvest, the size limit was changed to a 13-inch *maximum* in 1975. Three years later, however, the prospects for Yellowstone Lake cutthroat were still in doubt. According to the Fishery Management Program report for 1977: "The total annual kill on Yellowstone Lake may still be too large to achieve compatibility under current use trends. Either increased effort and/or improved catch-per-unit-effort will significantly increase the total kill over current levels. Providing optimum sport fishing requires that the trout stock is at a population density well above the MSY level to insure sufficient density, competition, and voraciousness to provide said sport. From our experience on other no-kill cutthroat fisheries in the park, catch-and-release only fishing on Yellowstone Lake is definitely indicated."

The fishery managers were more pessimistic than appears warranted, at least so far. Although the landing rate has remained high during the last 20 years, the proportion of older and larger cutthroat trout in both angler catch and in spawning streams has increased. Because the fish have become larger, fewer have



Data source: Fishery Management Program annual reports

been small enough to be kept and more have remained in the lake to spawn. Both the fish and the angler have benefitted in certain ways from the shift to less consumptive angling. Since catch-and-release fishing was established on the Yellowstone River between Yellowstone Lake and the Grand Canyon, the percentage of anglers who land at least one trout there has almost doubled, to 62 percent. According to visitor surveys, catching at least one fish is the most important component in providing anglers with a satisfying experience.

The "improvement" cannot be measured simply in numbers. What many anglers want from their fishing experience has changed. In the 1930s, some anglers objected to stocking "catchable" size trout rather than eggs and fingerlings; they preferred catching "stream-grown" fish, which they considered "wild trout fishing." Today, quality angling in Yellowstone is officially defined as "the opportunity to fish for wild trout in a wild setting," with less emphasis on numbers or sizes of fish caught and more on the total experience. A total experience in an undisturbed environment means that fish are primarily available to other animals as food.

Although there may be a computable "harvestable surplus" of fish that can be removed from Yellowstone each year without damaging its native species, the goal of the fisheries program is no longer to achieve it. In the same way that elk, bear, and bison populations are now permitted, insofar as possible, to control their size through natural regulation, the decline of angling pressure on Yellowstone's lake and streams will permit fish populations to be controlled to a larger extent by other factors. As a result, fish populations have been restored to a level more closely resembling their primitive state and are functioning more naturally as part of the park's nutrient chain.

Why is Fishing Permitted in Yellowstone?

While fishing is provided for by law in some national parks, it exists by tradition in others like Yellowstone. As park managers have learned how to best provide an enjoyable fishing experience while preserving the fish resource, they must still address the question: "Why isn't fishing prohibited as hunting is?"

Of the many possible answers—tradition, the dependence of the local economy on fishing, the greater popularity of angling compared to hunting, the lack of danger posed to other park visitors and wildlife posed by fishing compared to hunting—none will satisfy the purist. Angling is an anomaly in a park whose primary purpose is to preserve natural environments and native species in ways that maintain natural conditions.

While the growing number of wildlife viewers provided much of the stimulus for hunting bans in national parks, fish have always been regarded differently than other wildlife and lacked such defenders. For most people, wildlife appreciation entails direct observation of animals whose family relationships and behavior can be more easily viewed and anthropomorphized than those of fish. However, anglers can help in the defense of the cutthroat trout in Yellowstone Lake, according to John Varley, Director of the Yellowstone Center for Resources and former staff member of Yellowstone's Fisheries Assistance Office (FAO). "We're absolutely going to need the angler to help us with lake trout control. We can't afford to replace their 250,000 hours of effort a year in removing that non-native predator."

Still Angling After All These Years

To help determine the effect of angling limits and monitor fisheries trends, the FAO established the Volunteer Angler Report (VAR) in 1973. Using a combination of park exit surveys and postage-paid return cards given to anglers with their licenses, the VAR system keeps records on angling pressure, harvest, landing rate, mean length of fish, and compliance with fishing regulations.

Estimated Park-Wide Angling	1977 (no fee)	1993 (no fee)	1995 (no fee)
Total anglers	154,600	141,100	85,400
Percent park visitors who fished	6.2	4.8	2.7
Total hours angled	725,300	1,026,100	681,300
Total fish landed	485,400	942,600	580,800
Fish landed per hour	0.98	0.92	0.85
Mean length	13.4 in.	13.5 in.	13.3 in.

Until 1993, as annual park visitation rose to almost 3 million, the number of anglers fluctuated between 117,000 and 161,000 (5-6 percent of all park visitors) with no apparent trend. Since 1994, when the park began charging $10 for a 7-day fishing permit, the estimated number of anglers has fallen by more than a third, and their portion of total park visitation has dropped to 2.7 percent. Even though a smaller number of anglers are landing more fish, the catch-per-hour has remained about the same because the angling effort park-wide (the total number of hours that anglers spend fishing) has increased to an average of eight hours per angler, more than three hours longer than in 1977.

Angling records for Yellowstone Lake go back to 1950, but because different census methods were used before 1975, comparison with VAR numbers is only approximate. However, some overall trends can be discerned. Although the landing rate has improved significantly, the number of fish removed from the lake is less than one-tenth of what it was 30 years ago. This has resulted from the combined effects of the declining numbers of anglers and changing fishing restrictions.

Although Yellowstone Lake remains the park's most popular fishing spot, with about a third of all angler days spent there, it no longer dominates park fishing as it did twenty years ago, when it accounted for more than half of angler days. The Yellowstone River, the second most popular fishing water, has held steady with about 12 percent of the angler days. The remaining days are simply spread out over more lakes and streams. While the shift may be due to the increased angling restrictions on Yellowstone Lake, it may also reflect the different kind of fishing experience that today's anglers seek.

Interpreting angling trends is tricky because many factors may affect fish abundance and angling pressure in a given year, including snow pack runoff, survival rate of fish hatched four years earlier, weekend weather, and the price of gasoline, to name just a few. Although it may seem obvious that greater fishing pressure will lead to lower landing rates, the reverse can also be true: poor landing rates can result in fewer anglers in subsequent years. It's also difficult to determine the extent to which a decline in angling such as occurred from 1965 to 1970 may result from poor landing rates or new fishing restrictions. The number of anglers on Yellowstone Lake fell between 1977 and 1993 even though the landing rate remained stable and no changes were made in fishing regulations.

While the sudden drop in the total number of park anglers after 1993 is

Yellowstone Lake Angling Trends	1965 (3 fish)	1969 (no bait)	1970 (14-inch min)	1977 (2 fish, 13-inch max)	1993 (no change)	1995 ($10 fee)
Total anglers	241,189	205,562	177,334	73,775	43,554	28,584
Percent of total park angler days	N/A	N/A	N/A	53	35	33
Fish landed per hour	0.68	0.45	0.66	0.90	0.94	1.05
Total fish landed	346,044	174,924	251,440	336,200	333,895	262,487
Total fish removed	346,044	174,924	106,570	95,400	33,592	31,494

easily attributed to the new permit fee, it also seems reasonable to expect that, as total park visitation has grown and become more diverse, the percent of visitors who come to Yellowstone primarily or partly to fish would decline. Meanwhile, the park has also been tracking the extent of "non-consumptive" use of fish resources, by which is meant the enjoyment of fish without benefit of rod and reel. In 1994, there were an estimated 176,400 observers at LeHardy Rapids on the Yellowstone River, where spawning cutthroat can be seen jumping the rapids, and 167,000 at Fishing Bridge, where hundreds of trout can be seen feeding, fighting, and mating in the water below. However, these numbers also dropped after 1993, suggesting that many of the spectators are also sport fishermen.

A Transition Period for Fishery Management

For decades the park's fisheries program was guided by an interagency agreement whereby the NPS helped to fund the fishery monitoring and management activities carried out by USFWS staff working in the FAO. While the NPS has been responsible for policy guidance and setting and enforcing the park's fishing regulations, it has been USFWS staff who have gathered and analyzed the data on fish populations and angler use needed to come up with appropriate restrictions for each species and body of water. Along with its more dubious legacies, the long history of fishery management in Yellowstone has established a long-term database on the park's fish species that exceeds that for any other park animal. For example, FAO activities included:

§ Backcountry stream and lake surveys for baseline chemical, physical, and biological characteristics; preparation of watershed maps, and evaluation of the habitat's ability to support fish.

§ Spawning surveys related to grizzly bear predation on fish.

§ Monitoring the effects of fire activity and fire retardants on fish populations.

§ Removal of non-native brook trout from Arnica Creek to prevent invasion of Yellowstone Lake and other tributaries.

§ Gill-netting of non-native lake trout in Yellowstone Lake.

§ Testing for whirling disease, which has not yet been found in the park, but which fisheries biologists believe is a major cause of trout declines in the Madison River outside the park.

§ Collecting brood stock from the Yellowstone River to help restore cutthroat trout in its range outside the park (in cooperation with the Montana and Wyoming game and fish departments).

However, as a result of its own budget constraints and priorities shifting toward restoration and management of imperiled species, the USFWS closed its Fisheries Assistance Office in September 1996. "Because our role in Yellowstone was one of technical advice rather than management responsibility, it became a luxury item the Fish and Wildlife Service could no longer afford," explained Lynn Kaeding, former project leader for the USFWS Fishery and Aquatic Management Program in Yellowstone.

But Kaeding looks back with some satisfaction on the progress made in creating a better balance between angling pressure and natural regulation of fish populations. Fish populations that were long depleted have been restored to a level more closely resembling their primitive state, and are functioning more naturally as part of the park's nutrient chains. "Although they came in before my time, I'd have to say that the regulation changes made in the 1970s were a high-water mark for this office. Part of their success is due to the fact that Yellowstone has exclusive jurisdiction over its waters and can implement the kind of restrictions that would be difficult or impossible elsewhere. There is only one Yellowstone and only one fishery resource like this."

"The Fish and Wildlife cooperative agreement with the park has been a good thing," agreed Dan Reinhart, resource management coordinator for the Lake District, "and we are going to miss them dearly, especially now that we have the lake trout crisis to deal with."

Lynn Kaeding and one of the other FAO fishery staff members have been reassigned to the USFWS office in Bozeman, Montana, which is involved in interagency efforts to restore river populations of Arctic grayling, bull trout, and westslope cutthroat trout, and to address the whirling disease threat to trout fisheries in the Northern Rockies. Another USFWS staff member has chosen to remain in Yellowstone and transfer to the NPS. Dr. Jack McIntyre, a retired fisheries biologist with extensive experience in the university and federal domains, has been volunteering as interim head of the park's fisheries program since July 1996.

Fisheries Assistance Office personnel during grayling egg-taking operations (above) at Grebe Lake in June 1976, and transporting grayling via helicopter bucket to Canyon Creek (below) in September of the same year.

Although the park expects to add more permanent aquatic or fisheries biologists to its staff during the next few years, Stu Coleman, chief of the Natural Resources Branch at Yellowstone, looks forward to continuing cooperative efforts with the USFWS. "We think that it is essential that this long-standing partnership be maintained for the benefit of the aquatic resources of the park and surrounding greater Yellowstone area," he said. "Currently the park and the Bozeman unit are drafting a Memorandum of Understanding to outline areas of mutual concern and support."

The Limits of Restoration

Although taking on full responsibility for running the Yellowstone's fisheries

> "Restoring the primitive scene is not done easily nor can it be done completely... Exotic plants, animals, and diseases are here to stay. All these limitations we fully realize. Yet, if the goal cannot be fully achieved it can be approached." — A. S. Leopold et al., *Wildlife Management in the National Parks,* 1963

program will present a financial challenge at a time when budgets are already strained, John Varley does not see the departure of the USFWS staff as resulting in any significant changes of direction. "Our three major objectives will remain the same: to manage aquatic resources as an integral part of the ecosystem; to preserve and, where feasible, restore native fishes and their habitats; and to provide high-quality fishing opportunities that are consistent with the first two objectives." More specifically, the priorities during the coming years will be to:

§ Assess the magnitude of the possible impacts of lake trout on the Yellowstone cutthroat trout population and monitor the effects.

§ Control lake trout abundance to the extent necessary to prevent decline of the cutthroat trout to no more than 10 percent of 1985-1995 population levels.

§ Reestablish westslope cutthroat and fluvial grayling in park waters where appropriate.

§ Eliminate exotic fish and snails from park waters where feasible and desirable.

§ Maintain fishing regulations and opportunities that are consistent with quality angling, fish populations, and other wildlife goals at each location.

If Yellowstone could bring the wolf back, shouldn't it remove the rainbow, brook, and lake trout? Some environmentalists regard the question of returning waters like Lewis and Shoshone lakes to fishlessness as a measure of Yellowstone's commitment to restoring the ecosystem to its primitive state. For the immediate future, the discussion remains largely philosophic because there is no feasible means to entirely extirpate non-native fish without damaging native resources—bombing the lakes to save them, as it were. Furthermore, because Yellowstone waters generally received only one or two plantings a long while ago and have remained relatively undisturbed since then, the park's populations of both native and exotic species have become valuable as a gene pool.

"We believe we have very pure strains of both Loch Levan and Von Behr brown trout," said John Varley. "And we may have unique strains of rainbow trout that could become important in addressing the problem of whirling disease." For the last decade, lake trout eggs from Lewis Lake, which were stocked from Lake Michigan a hundred years ago, have been used to reestablish "genetically pure" lake trout in Lake Michigan, where they had been extirpated by commercial fishing, parasitism by non-native sea lamprey, and pollution.

Efforts to restore fluvial grayling in the park have been hampered by the lack of suitable sites; much of their former habitat is now occupied by non-native species with which they cannot compete. In 1976, the brown and rainbow trout were poisoned in Canyon Creek and a barrier waterfall was constructed to prevent upstream recontamination, but neither the poisoning nor the transplant endured as the grayling slipped downstream. More recently Cougar Creek, which is in the grayling's native range, was chosen for experimental planting because it contains only hybridized westslope cutthroat trout and mottled sculpin, species that have historically been sympatric with the grayling. Attempts at stocking various densities and age classes during 1993-1996 have not been encouraging. "The fluvial grayling don't seem to be very fond of Cougar Creek," John Varley observed. "They're a big river fish. But we'll probably get them back in the park someday."

Fish populations and fisheries management in Yellowstone have a profound effect on the species of birds and mammals that feed on them.

As part of its fundraising effort for the next year, the Yellowstone Foundation has pledged to raise $30,000 to restore westslope cutthroat to their native range in Canyon Creek. After Canyon Creek has been chemically "reclaimed" using a more sophisticated technique than was available in 1976, pure westslope cutthroat brood stock from the headwater areas in Montana, will be planted in the creek.

Into the 21st Century

Although its geographical remoteness and status as a national park did not prevent some apparently irreversible mistakes, Yellowstone still contains one of the most significant and unimpaired aquatic ecosystems in the United States. Through the blessings of politics and geology, it contains the headwaters of most of its watersheds, minimizing the possibility of receiving downstream pollution from developed areas. Despite the changes that have taken place in the park's original aquatic species composition and distribution, over the long run NPS policies have prevented or at least reduced habitat degradation from dam and road construction, mineral extraction, silting from deforestation, water diversion for irrigation, and livestock grazing.

So the grand Yellowstone experiment will continue into the 21st century. What has changed since Captain Boutelle requested the first planting of rainbow trout in 1889 is that we no longer expect we can improve upon the assemblage and processes that this particular portion of the earth arrived at without human assistance. Nor, having seen the results of human influence, can we simply retreat and "let nature take its course." Instead, with Yellowstone's fish, as with all its wildlife, we hope that by reaching a deeper understanding of how natural processes work without our interference we can better manage the wildlands and waters that are left to us to preserve.

Leave Only Footprints?

How Backcountry Campsite Use Affects Forest Structure

Photo James Taylor

by James Y. Taylor

Decades ago, Aldo Leopold stated that it would not be logging, mining, or roads that would threaten the wilderness, but the people who came to visit these areas. Although many camping-induced impacts may initially be subtle, campsites receive the greatest impact of any backcountry areas and land managers are concerned that cumulative and accelerated changes may be occurring. If management strategies and practices to conserve wilderness environments are to be developed, measurements of the impacts and environmental changes are essential. One such impact that had not been researched was that of camping-related activities on the forest structure surrounding backcountry campsites.

To determine if such changes are measurable, I studied 30 campsites in Yellowstone National Park (YNP) during 1993 and 1994.

My hypotheses were that:

- The density of tree saplings up to 140 cm (4.6 ft) height would increase as distance from the campsite increased.
- The forest structure around campsites would be measurably different depending on user type, i.e., sites used by backpackers compared to those used by campers arriving by canoes and motorboats.
- More annual campsite users would correlate with a larger area of impact.

This research was conducted as part of a master's degree program within the Department of Earth Science at Montana State University in cooperation with Tom Olliff of the Backcountry Office in Yellowstone, with funding provided by the Yellowstone Center for Mountain Environments (now the Mountain Research Center) at Montana State University. David Cole, of the Aldo Leopold Center for Wilderness Research, Intermountain Research Station, U.S. Forest Service, also provided financial and technical support which proved invaluable.

Previous Research

Research within mountainous environments (Cole 1982, 1989) has shown that forest tree species and other woody vegetation are more susceptible to damage by trampling than are forbs. In the Eagle Cap Wilderness (Cole 1986) and the Bob Marshall Wilderness (Cole 1983), saplings were found to be more susceptible to trampling than were mature trees, and almost all saplings within campsite areas were eliminated because of trampling. The forest regeneration that did occur took place within isolated pockets of campsites where young trees were protected by mature trees.

Increasing campsite use has been positively correlated with increased impacts. It has been found that even with low use, campsite degradation, reductions in tree density, and changes in the percent of understory vegetation have occurred within mountain environments of the western United States. Studies of human use and campsite impacts have shown that the most influential factors of recreational impact included user behavior and mode of travel.

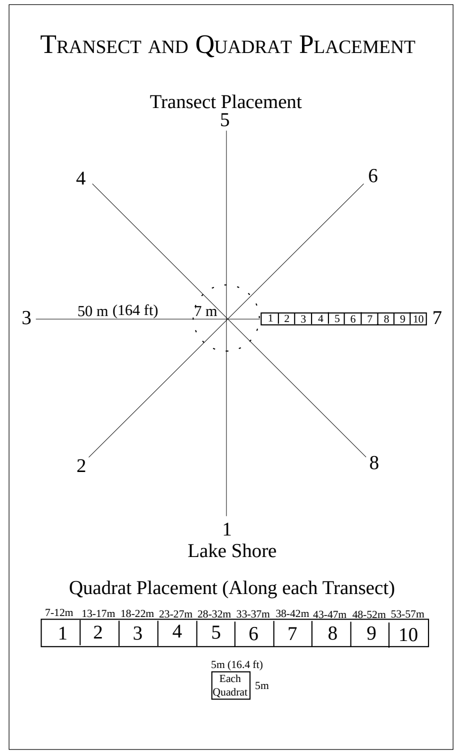
Sampling Method

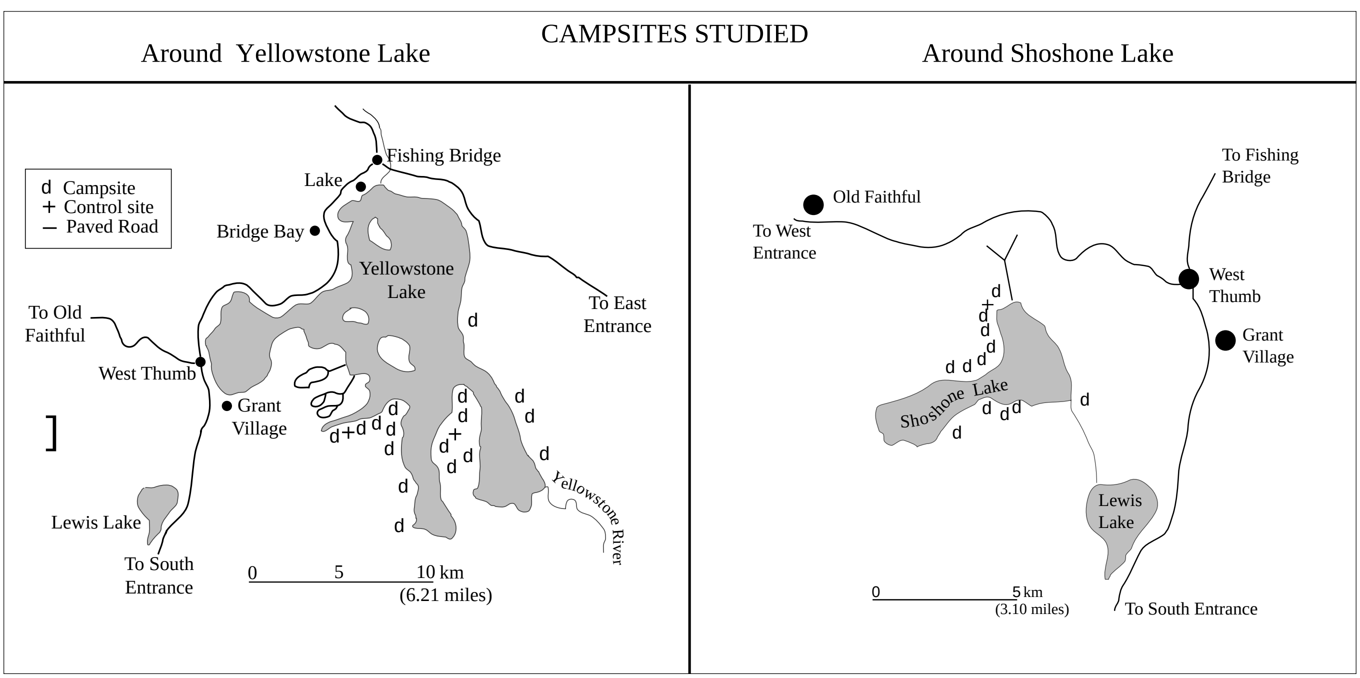
We chose YNP for this study because it has data available on the annual numbers of backcountry users and types of use for each campsite. This type of data is rare, and has been lacking in many previous impact studies. Topographic maps, aerial photographs, backcountry user data, surficial geology maps, habitat maps, cover type maps, and previous campsite inventories were used to select backcountry campsites on both Yellowstone Lake and Shoshone Lake, which had multiple user types and an abundance of campsites at similar elevations with similar microclimatic conditions.

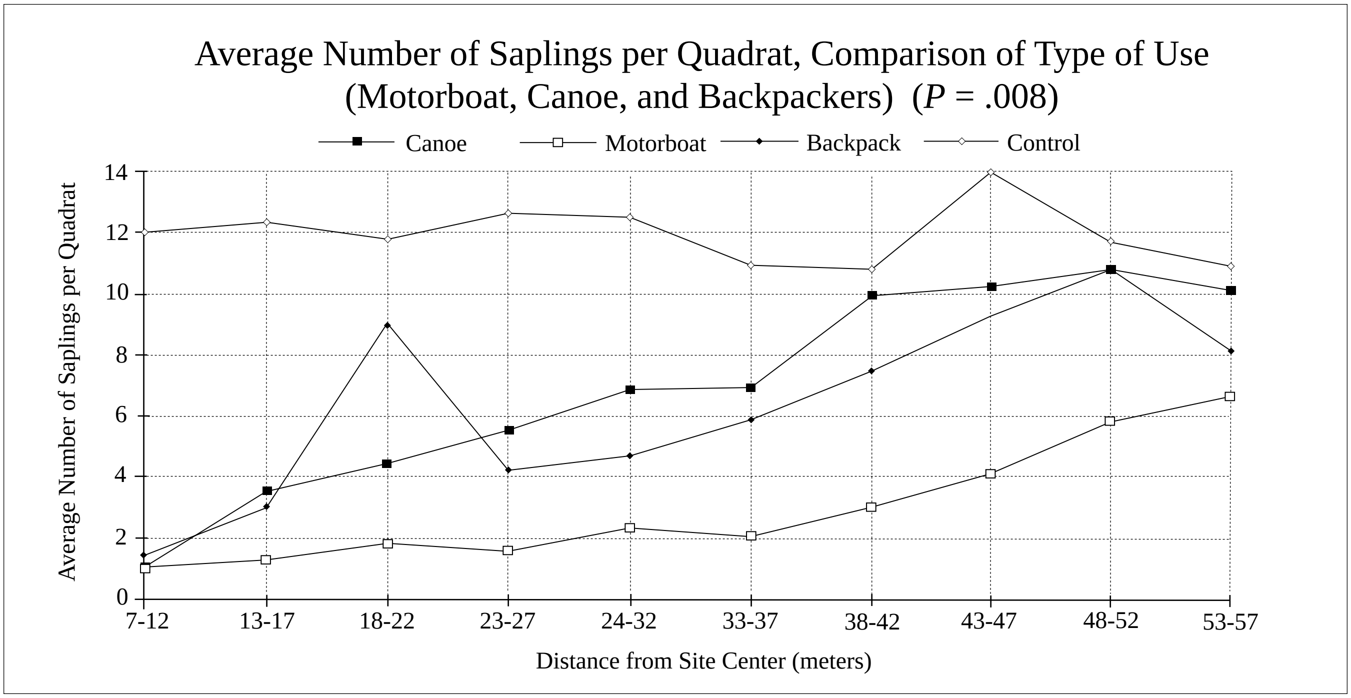
This study included 30 campsites within the lodgepole cover types (LP1 and LP2 as used by Don Despain of the National Biological Service in Yellowstone): 12 were exclusively motorboat sites, 13 were exclusively canoe sites, and 5 were exclusively backpacking sites. (There are no stock sites on Yellowstone or Shoshone lakes.) The average annual number of users at each of the 30 campsites ranged from 37 to 756. To maintain an even rate of regeneration potential, sites in older forests and those recovering from recent fires were not used. Three control sites, which showed no signs of prior use, were measured in the same way as the campsites so that as many natural factors as possible would remain constant. These non-camping control sites were randomly located 1 km along the shoreline from every tenth campsite studied.

Sampling techniques were based on two pilot studies and previous literature. Eight 57-m transects radiated outward from the center of each campsite. The first transect was placed perpendicular from the campsite center to the lake shore, and the other seven transects were placed at 45° angles apart from each other. Along each transect, 10 consecutively placed quadrats 5 x 5-m were sampled, for a total of 2,000 m^2 or 20 percent of the forest surrounding each site. This sampling structure made it possible to collect data on the direction, the intensity, and the spatial extent of camping impacts.

The biotic components sampled included tree size and species, understory vegetation cover, and percent canopy cover. Trees were classified into three classes up to sapling height of 140 cm. For taller trees, trunk diameter at breast height (dbh) measurement allowed classification into two classes of 0-15 and 15+cm. Canopy density was measured by placing a spherical densiometer in the center of each quadrat. Understory vegetation was sampled by type (moss, grass, sedge, forb, shrub) and percent cover.







Effects on Sapling Occurrence

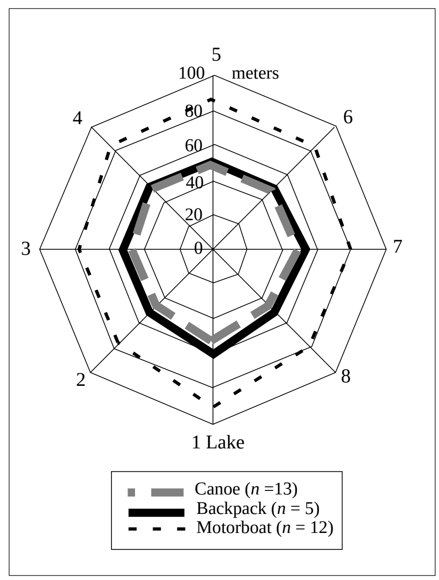
The campsites had an average of 5.22 conifer saplings per quadrat; the control sites had an average of 11.96 saplings per quadrat. This difference in density was significant ($P = 0.00002$), and an important impact that we investigated further. The intercept point where the average number of saplings per quadrat at the campsites equalled the average density at the control sites was graphed. This provides a visual assessment of the change in sapling density showing the spatial extent and possible impact of backcountry use at the campsites.

Density of saplings. The spatial impact and density of saplings around the campsites are best understood by looking at each transect separately. All transects within the campsites were significantly different from those in the control sites. Within the campsites, the average density increased from 1.09 saplings in quadrat 1 to 8.35 saplings in quadrat 10 (farthest from the campsite center), indicating a strong positive correlation ($r = 0.97$) between distance from the center of the site and the density of saplings. The average number of saplings per quadrat increased outward along all campsite transects except in the transect from the center of the site to the lakeshore.

A comparison of the average density of saplings at the three types of campsites shows the different effect each user type had on forest structure. Campsites used by canoe and backpack groups had an average of 6.9 and 6.4 saplings per quadrat, respectively, while sites used by those traveling by motorboat had an average of 2.9 saplings.

Spatial extent. At all campsite types, sapling density increased with distance away from the center of the site; the positive correlations between density and increasing distance for canoe, motorboat, and backpacking use were 0.96, 0.92, and 0.77 respectively. The difference in the average density of saplings at the three campsite types was significant ($P = 0.00000002$). A radar graph compares their spatial impact, i.e., the distance from the center of each campsite type where the average density of saplings equaled the average density at the control sites. The motorboat sites had the largest spatial impact, with an average intercept point that was 82 m from the campsite center.

Number of users. The negative correlation ($r = -0.70$) between the number of backpackers and the number of saplings shows that as use increases, the density of saplings around the campsite decreases. The number of motorboat users and the number of saplings also had a negative correlation ($r = -0.40$). The lack of any substantial correlation ($r = 0.16$) between the number canoe users and saplings indicates uniform density of saplings even as canoe site users increase.



Spatial representation of the distances from the center of campsites in which tree saplings are affected by canoe, backpacking, and motorboat users.

Other Effects on Forest Structure

Forest Canopy. The percent canopy cover in the campsites is an important component of forest structure because

Photo Renee Evanoff

A young couple canoeing from their campsite on Peale Island, Yellowstone Lake.

canopy influences microclimates. A decrease in canopy cover may result in increased amounts of precipitation reaching the forest floor, stronger local forest winds, and increased radiation, which can affect tree survival. According to my research, this aspect of forest structure has also been affected by campsite use. The average percent forest canopy cover differed significantly (P = 0.00003) between the campsites and the control sites. A positive correlation (r = 0.31) between distance and canopy cover at all campsite types showed that percent canopy cover increased as distance from the campsite centers increased.

Bare Area. The percent bare area also differed significantly (P = 0.0005) between the campsites and the control sites. There was a negative correlation (r = -0.95) between the distance from the center of a campsite and the percent bare area: as one might expect, the percent bare area decreased as distance from the campsite increased.

Understory Vegetation. For this study we measured moss, grasses, sedges, forbs, and shrubs. The average percent understory vegetation differed significantly (P = 0.01) between the campsites and the control sites for all understory components except forbs.

Total Potential Effect

As expected, the forest structure surrounding the campsites at Yellowstone Lake and Shoshone Lake has been affected by campsite use. As measured by the percent of bare area and the occurrence of trees, the changes are focused near the center of the campsites but also extend into the periphery forest. This is similar to the effects seen in other popular backcountry areas (Cole 1983, 1986).

In measuring the spatial extent of change, we found that the average number of saplings per quadrat at the campsites did not equal that at the control sites until a distance of 45 m from the center of the campsite was reached. This means that average affected area was 6,362 m^2 per campsite, or a total affected area of 190,860 m^2 for the 30 backcountry campsites studied. Extrapolating to all 302 backcountry campsites that existed in YNP in 1994, that could equal a potential impact of 1,921,324 m^2.

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My finding that the density of saplings increases as distance from the campsite center increases implies that campsite-related activities have an impact on the regeneration and survival of forest saplings. A better understanding of the attributes of this important relationship is needed in order for managers to develop management strategies and conservation practices to preserve the forested ecosystem. Campsite use could result in the near elimination of forest regeneration, which in turn could lead to reductions in tree density and the unwanted creation or expansion of nonforested areas.

Implications for Wilderness Management

There has been rapid growth during the last century in recreational uses of wild lands. These are the lands that have been protected by agencies such as the NPS, and laws such as the Wilderness Act of 1964, which states that we are to manage designated wilderness areas so that "natural conditions are preserved and the imprint of man's work remains substantially unnoticeable." But Leopold appears to have been correct when he stated that people have a substantial impact on the wilderness areas they visit. The use of backcountry areas for camping is not entirely benign and has a spatial attribute that should be better understood if a management goal for YNP is to balance sustainable recreational use while maintaining environmental integrity. It is important that we understand that a continual increase in recreational use might lead to greater effects on the forests. Educating recreational users in backcountry ethics to reduce trampling, group size, and social trails, and encouraging use of canoes or backpacking over motorboat use may reduce the impact to conifer saplings surrounding backcountry campsites in YNP.

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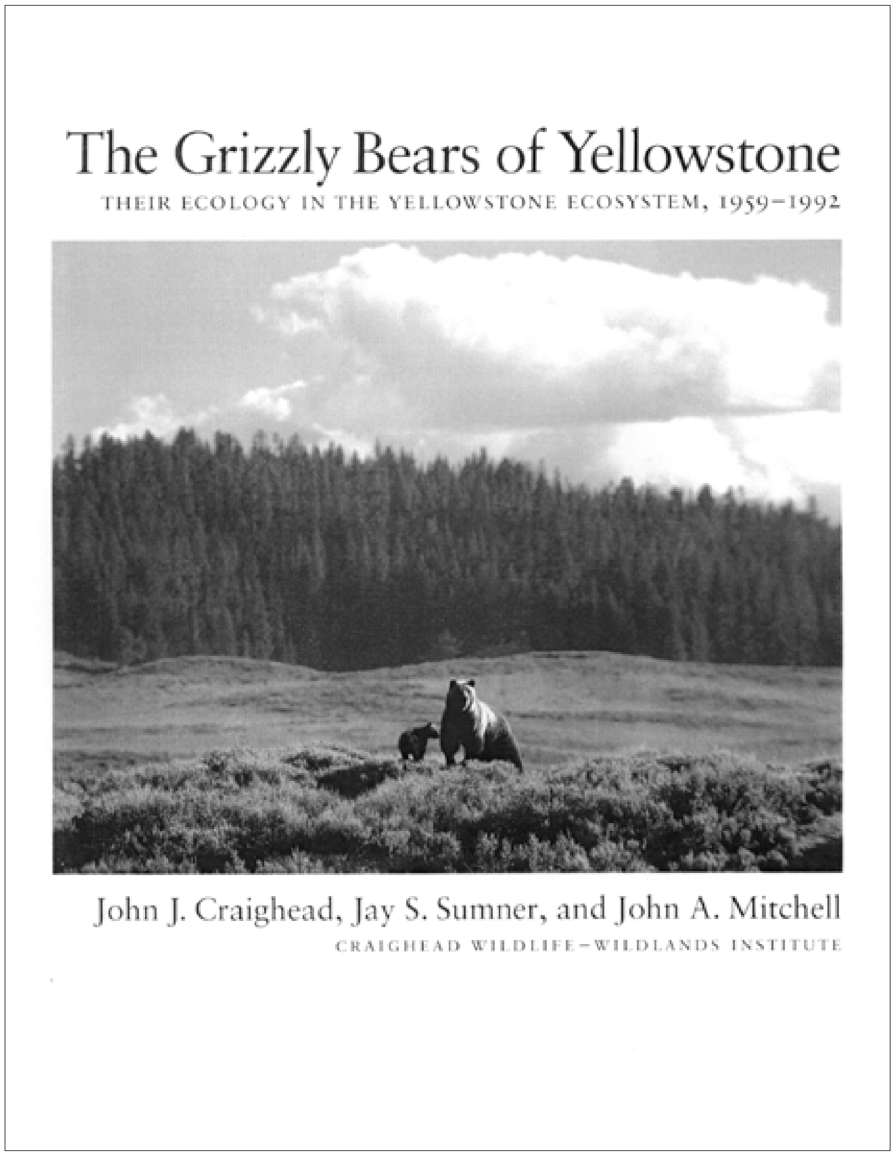
Review Essay

The Grizzly Bears of Yellowstone

Their Ecology in the Yellowstone Ecosystem, 1959-1992

by Mark S. Boyce

The Grizzly Bears of Yellowstone: Their Ecology in the Yellowstone Ecosystem, 1959-1992 by John J. Craighead,, Jay S. Sumner, and John A. Mitchell. Island Press, Washington, D.C., 1995, 535 pages. $100.



One evening in 1992 during a visit to Nagarahole National Park in southern India, I joined other park visitors after a day looking for tiger, leopard, gaur, elephant, chital, sambar, and sloth bear to watch a wildlife movie. Imagine my surprise, halfway around the world from my home in Wyoming, when we were treated to a 25-year-old flick featuring John and Frank Craighead and families in Yellowstone. The film illustrated pioneering applications of radiotelemetry for the study of grizzly bear movements and behavior, but mostly characterized the exciting lives of the Craigheads.

The Craighead brothers have been among the world's most celebrated wildlife biologists during the second half of the 20th century, and for good reason. Their studies have pioneered a number of wildlife techniques that have revealed important facts of behavior, movements, and ecology of many raptors and several species of large mammals, especially elk and grizzly bears. The broad scope of their contributions to natural history is exemplified by their authorship of dozens of scientific papers on grizzly bears and elk as well as *A Field Guide to Rocky Mountain Wildflowers* in the Peterson Guide Series. Their lives dedicated to nature study have been emulated by a generation of aspiring field biologists.

The Grizzly Bears of Yellowstone is the capstone contribution by John Craighead, who turned 80 this year. The volume is a fitting tribute. Island Press has done a spectacular job producing the book with glossy coated paper and an abundance of color plates. Throughout, the book is well written and produced with few typographical errors. At $100 I expect few people to buy the book, but given the wealth of data and the quality of production, the price seems reasonable.

In 1979, John's brother, Frank Craighead, wrote his own book summarizing their joint Yellowstone field studies of 1959-1970 entitled *The Track of the Grizzly* (Craighead 1979). In contrast, *The Grizzly Bears of Yellowstone* is more a research monograph with more technical detail than in Frank's story. *The Grizzly Bears of Yellowstone* summarizes 35 years of grizzly bear studies in the Greater Yellowstone Ecosystem (GYE) with principal focus on the 1959-1970 period. The book is divided into two major sections: "The study (1959-1970)" totaling 345 pages of text that details investigations by the Craigheads, and "Population comparisons (1974-1992): the era of decreed research" which spans 133 pages reviewing the work of the Interagency Grizzly Bear Study Team (IGBST), principally Richard Knight and Bonnie Blanchard, subsequent to the Craighead investigations.

The purpose of the book was to describe the structure of the population of grizzly bears in the GYE (p. 91). Although the scope of the book is vast, including discussions of genetics, population biology, behavior, physiology, parasitology, and management, most of the book summarizes population studies and behavior observations. Given the nature of the beast, this research is necessarily descriptive natural history rather than experimental science. The behavioral sections of the book include few functional analyses of mechanisms underlying the behaviors. Instead the authors report detailed descriptions of behavior of bears in aggregations, such as those associated with major food sources, and include considerable detail about dominance hierarchies.

When the Craigheads began their field studies in Yellowstone in 1959, the National Park Service was still allowing bears to feed at several garbage dumps distributed throughout the park. For a variety of reasons, Park Service officials decided that such feeding was inappropriate in a national park and decided to close the dumps and truck the garbage outside the park. The Craighead brothers argued vigorously that to close the dumps meant death to enormous numbers of bears that had grown accustomed to feeding at the dumps. They were right! Mortality of grizzly bears was very high in the years following the closure of the dumps during the period of adjustment to natural food sources. All evidence suggested that the bear population continued to decline during the period 1970-1983 at which time the Interagency Grizzly Bear Committee (IGBC) promulgated strict rules for management of public lands designed to reduce mortality on grizzly bears.

The disagreement between the Craigheads and the National Park Service is a classic story in biopolitics. The conflict became so polarized that the National Academy of Sciences formed a committee to review appropriate courses for management of Yellowstone's grizzlies. In this book we again read the Craighead view that seems to have changed little in 25 years. Anyone interested in an alternative account of the history should consult Schullery's (1992) book on *The Bears of Yellowstone*. I will not reiterate the details here, preferring to focus on biological issues.

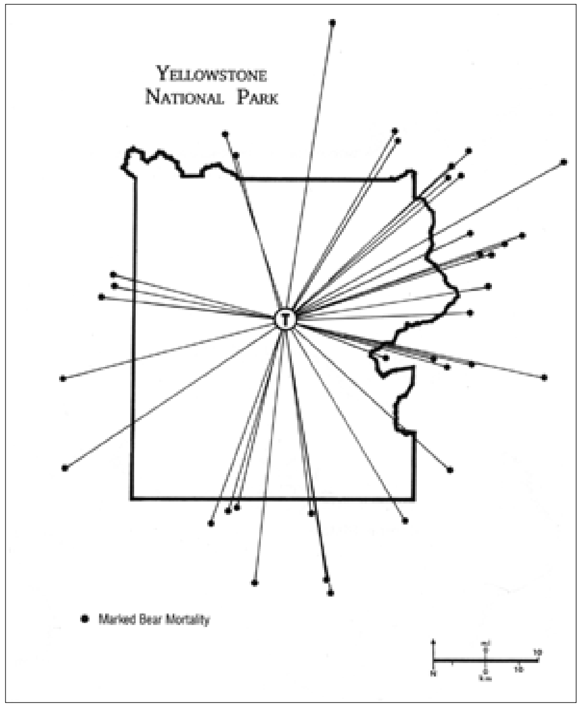
Craighead et al. present detailed demographic data for the grizzly bear population during 1959-1970 and include valuable discussion of the sampling problems associated with these data. In particular, I found the treatment of reproduction to be useful for reducing biases involved with estimates of reproductive rates. Even though much of the data from the Craighead studies is available elsewhere, this book provides insight into the interpretation of these data that is not previously published.

Chapter 9 of the book is devoted to a controversial discussion of density dependence. Several authors have criticized earlier work of the Craigheads that ignored the role of density-dependent survival and reproduction as stabilizing forces in population dynamics. These criticisms are dealt with rather firmly in Chapter 9, but an alternative analysis explaining where density dependence occurs in the population is not provided. No mention is made of the studies by Mark Shaffer (1983) showing that reproductive rates are density dependent in the Craighead's data. In fact, they claim that no evidence exists for reproductive compensation. I have recently reanalyzed much of the IGBST data to discover that density-dependent survival prevails during the period 1975-1995. Perhaps density-dependent survival operates due to density-dependent food limitation under current management whereas loss of cubs to males was more of a factor during the Craighead era when bears were concentrated for feeding at the dumps. Alternatively, perhaps mortality of bears during the Craighead era was lower because movements out of the park were less necessary (p. 301).

A major focus of this monograph is to examine the phenomenon of "ecocenters," i.e., garbage dumps or other concentrations of food, and their consequence to the ecology and behavior of grizzly bears. Despite the conclusions in the National Academy of Sciences review of the Craighead analysis that there existed some backcountry bears that did not use the dumps, Craighead et al. insist that during the 1959-1970 period all bears were feeding at the dumps, at least part of the time. In support of this view they present radiotelemetry locations for a number of bears showing how their home ranges typically included the dumps. The authors conclude that ecocenters result in subpopulations of bears "whose members moved routinely between the ecocentered aggregation . . . and the backcountry." Clearly the dumps substantially altered the social and demographic environment for the bears of the GYE. Remarkably, Craighead et al. believe that we should have kept the dumps.

Of course some natural bear populations are focused on ecocenters, e.g., brown bears feeding on salmon in Alaska. But this was not largely the system of the Rocky Mountains and, to my mind, the Craighead argument that we should be maintaining ecocenters to sustain large populations of grizzly bears certainly flies in the face of ecological-process management for national parks, i.e., trying to maintain natural ecological processes with minimal human intervention. Supplemental provisioning can sustain a larger grizzly population in an area, but at the heavy cost of completely altering the social and demographic environment of the bears, not to mention the consequences to other ecosystem components that are influenced by a large bear population. Conservation should involve considerations beyond the necessary preservation of populations and gene pools. Somehow there must be value in preserving places like Yellowstone with minimal human influence, and allowing natural ecological processes to prevail.

The National Park Service took a big risk in 1970 when they decided to quit feeding bears in Yellowstone. The high mortality associated with the dump closures subjected the grizzly bear population to great risk of extinction. The



The records of marked grizzly bears illustrating the natural movement patterns from the Trout Creek ecocenter to localities of death outside the park from 1959 to 1974. (Fig. 5.10 from Craighead et al. 1996).

Craigheads believe that this might have been alleviated had the dumps been phased out, but we have no evidence that this is true. Regardless, the government has achieved a magnificent recovery since 1983 when the IGBC was formed with its aggressive programs to target and eliminate sources of mortality for grizzly bears.

According to Craighead et al., the heyday for grizzlies in the GYE was when supplemental food was available at ecocenters (dumps). To ensure recovery of grizzly bears in the GYE they advise restoring ecocenters. A number of possibilities are reviewed including a carcass dump to provide bears with access to roadkills and winter-killed animals. Alternatively, large quantities of surplus grain or commercial food pellets could be deposited to create bear ecocenters. But seemingly most attractive to Craighead et al. is the reinstatement of garbage dumps. After all, "Garbage has proven nutritional qualities, is essentially cost-free, and its transport, placement, and site management are relatively simple, well-understood processes in operation every day."

Given that such ecocenter structure will create bizarre social and demographic circumstances for the bears, the only justification can be to increase the number of bears. As Craighead et al. point out, a larger bear population is expected to have lower probability of extinction due to demographic and environmental stochasticity, or genetic malfunctions. But I prefer their suggestion that we should have a larger bear population dispersed over a larger area because this could allow the maintenance of a relatively natural bear population. This is certainly practical, but will require elevating the protection status of potential habitats (e.g., the Wind River Range in Wyoming) from Situation 5 [*in which consideration for grizzly bears and their habitat is not directed—ed.*] to something more tolerant of bears. Sadly, none of the four grizzly bears that showed up in the Wind Rivers during the summer of 1996 near Pinedale, Wyoming, were allowed to stay and were either killed or relocated to the core of the GYE. Expanding grizzly bear recovery zones south of their current boundaries and removing conflicts such as sheep grazing allotments could achieve the same objectives of increasing the bear population without the undesirable ramifications of reopening Yellowstone's garbage dumps.

Few people will read this massive tome from cover to cover as I did—it's just too big. The book will be required reading for serious biologists and students of the controversy, but I cannot recommend the book for the uninitiated or those looking for a balanced story about the Yellowstone grizzlies of today. Although the book contains a number of invaluable insights, to my mind the most significant appears at the end of the Preface: "The major conclusion of our study is that resource management agencies must focus on the broad problem of preserving and managing habitat in a resource exploitative society where politics and economic policies thwart sustainable resource management." But the habitat chapter on Yellowstone grizzly bears has yet to be written.

With this book, I had hoped that Craighead et al. would finally bring to closure the long and sometimes bitter controversy over management of grizzly bears in Yellowstone. Instead they add fuel to the fire. Although I cannot accept the intensive feeding prescriptions for bears that they outline in this book, I understand and respect their desire to increase the grizzly bear population. But artificially feeding to increase the number of bears seems to violate everything that Yellowstone is all about.

Because grizzly bears have such large area requirements and are so incompatible with humans, the bear is touted as an "umbrella" species implying that managing for grizzly bears entails ecosystem management. Recent data demonstrating how the grizzly bear population has increased subsequent to the strict management protocols implemented by the IGBC in 1983 give me confidence that allowing natural ecological processes to prevail on the landscape can be compatible with preserving viable populations of grizzly bears in the Greater Yellowstone Ecosystem.

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Research Proposed on New Brucellosis Vaccine

A new research project proposed in the park will provide an *Evaluation of Brucella Abortus Vaccine Strain RB51 in Bison Calves*. As part of a commitment toward identifying new brucellosis vaccines for possible use in wildlife, the National Park Service is proposing to work cooperatively with the Wyoming Game and Fish Department (WGFD) to evaluate the effects of a new vaccine on bison calves.

The bacteria *Brucella abortus*, which causes bovine brucellosis, was likely introduced to North American wildlife through importation of infected livestock from Europe. Brucellosis in domestic cattle has been drastically reduced through a nationwide program to eradicate it. Although vaccines do not insure 100 percent immunity in cattle, they substantially reduce the frequency of abortions in adult animals. *Brucella abortus* was first detected in Yellowstone in 1917, and concern exists regarding the potential transmission of the bacteria from wild bison to domestic livestock outside the park. Vaccination of bison in Yellowstone has been advocated periodically, but clinical evaluation of vaccination has not been conducted on free-ranging bison.

The effectiveness of a vaccination program is strongly related to the efficacy of the vaccine, which may vary by age and sex of the animal vaccinated. Strain 19 vaccine has been used on domestic cattle for several decades; the efficacy of this strain varies from 65 to 75 percent in individual animals. It also often confounds serological testing because antibody response to the vaccine is difficult to differentiate from field strain infections. Dosages of strain 19 suitable for cattle imparted little or no immunity in female bison calves and caused abortions in pregnant adult bison cows.

The study will last two years, and focus on testing strain RB51, a newly developed vaccine approved for use on domestic cattle calves. In cattle, RB51 imparts about the same level of immunity as strain 19 but does not confound the serological tests. The research proposal calls for capturing 36 bison calves (18 each year) during trapping operations conducted by the Montana Department of Livestock as bison migrate from the park. The calves will be card-tested for the presence of *brucella* antibodies; calves testing negative would be transported to the Wyoming Game and Fish Department's Sybille Wildlife Research Unit near Wheatland, Wyoming. The proposed research will evaluate the physiologic and pathologic effects of administering RB51 to bison calves and will determine if live bacteria resulting from the vaccinations are shed into the environment. The proposal indicates that since opportunities to sample wild bison are infrequent, each animal will also be tested for the existence of a genetic marker indicative of resistance to brucellosis.

Moran Paintings in National Display

The Thomas Moran paintings that helped persuade Congress to create the world's first national park will be part of the first-ever retrospective exhibition of the artist's work to be seen in 1997 at the National Gallery of Art. Twenty-one watercolors by Moran and two of his sketchbooks featuring pencil and watercolor sketches of park features are among the items from the park's museum collection approved for loan to the National Gallery. Most of the watercolors and one of the sketchbooks were produced by Moran during the 1871 Hayden Survey, which he accompanied, and are considered to be among the finest and most important works of art held by the National Park Service. Four volumes of rare photos by William Henry Jackson, photographer of the Hayden Survey, are also included in the loan and will be incorporated into the part of the show focusing on Yellowstone.

In recognition of the importance, value, and fragility of the Moran paintings and Jackson photos—and as a way of thanking the park for making the works available for the show—the National Gallery will re-mat and re-frame each watercolor using the latest museum-quality conservation materials, then hermetically seal each work within its new frame to exclude gases from park thermal features and airborne pollutants. Photographers will photograph each painting, each page of the sketchbooks, and each of the nearly 200 photographs contained in the four Jackson albums. The park will receive high-quality negatives and prints; digitized images; and same-size, exhibitable reproductions of the Moran paintings that can be displayed in the Albright Visitor Center while the originals are on loan. Digitized images will be used to improve researcher access to these materials.

Wolf Project Proceeds Well in First Two Years

The 14 wolves released in Yellowstone in 1995 bore two litters totalling nine pups. In 1996, 17 more wolves were released, and had four litters totalling 14 pups. Eleven wolves have died—three were illegally shot, three killed by vehicle collisions, two were killed by other wolves, one was removed due to depredation on livestock, one was burned fatally in a hot spring, and one pup died of unknown causes. Another pup was accidentally injured and subsequently sent to live in a captive facility. Ten pups were brought to Yellowstone in the summer of 1996 from northern Montana and have yet to be released. The goal to restore wolves to Yellowstone and begin delisting them by approximately 2002 appears to be within reach, perhaps even ahead of schedule and under budget. ❄

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