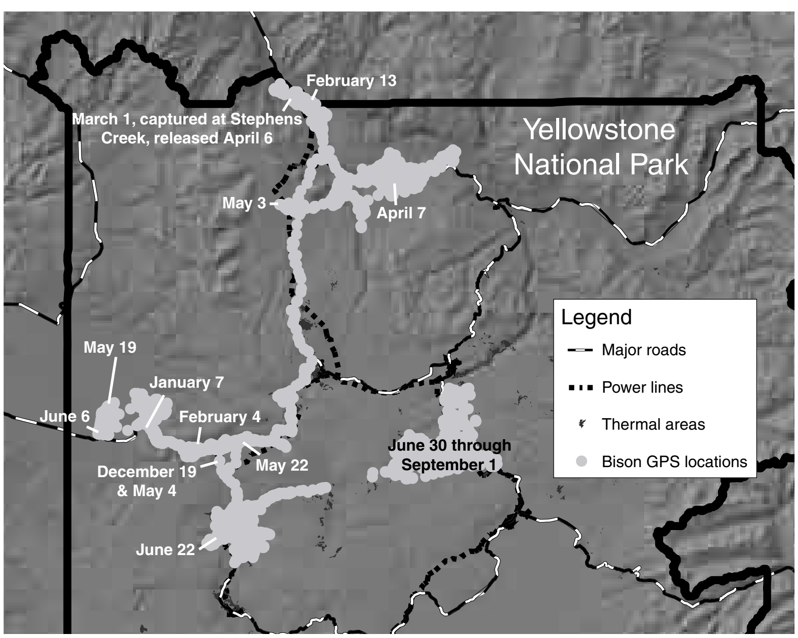
conditions. The central ranges, in contrast, usually accumulate much deeper and longer-lasting snow, except in geothermally-influenced areas. The warmth generated by the thermal features may allow a longer growing season and reduce snow cover. In addition, snow melt and spring greenup occur earlier in the West Yellowstone area than in Hayden and Pelican valleys (Despain 1990).

“All models are wrong, but some models are useful.”

The Gates Report concluded that bison move toward the park boundaries in winter “in response to forage limitation” in the park that may result from a combination of factors, including previous summer precipitation, snowpack characteristics, and grazing pressure by bison and elk. As the bison population has increased, therefore, so has the extent of its movements and the likelihood that a group of bison will look for forage beyond the park boundary. “Exploratory movements by mature bulls, which subsequently establish annual migration paths to and from peripheral ranges, likely precede range expansion by cow/juvenile groups,” states the report. “More bison use more space,” Gates puts it more simply.

Since monitoring of female bison with radio collars began in 2002, park staff have tracked some bison that move from Hayden Valley toward both the west and the north boundaries in the same year. However, range expansion cannot entirely compensate for population growth, because “high quality foraging patches are limited in overall area, are patchily distributed and depleted first, forcing bison to shift to poorer quality patches as [bison] density increases.” The likely responses to increased bison density, according to the Gates Report, are “decreased fecundity and increased juvenile mortality,” reducing the rate of population growth.

Bison appear to travel on roads in winter where it is convenient, that is, where the roads are aligned with corridors that bison would be expected to use because of terrain, habitat features, and bison behavior. Consistent with this hypothesis, the Gates Report notes, bison rarely use the road segments from Canyon to Norris, East Entrance to Sylvan Pass, South Entrance to Old Faithful, or the western half of the groomed road between Seven Mile Bridge and West Yellowstone. As for a reduction in natural winter mortality that might result from bison use of groomed roads, the Gates Report could find in the available population data no “detectable” change in the growth rate of the Pelican Valley herd after grooming began.



GPS locations of a five-year-old female bison from the central subpopulation between December 2003 and September 2004. Rick Wallen, Yellowstone bison biologist, believes that this extent of northward and westward movement may now be typical of up to one-third of the central herd.

Developing a Bison Distribution Model

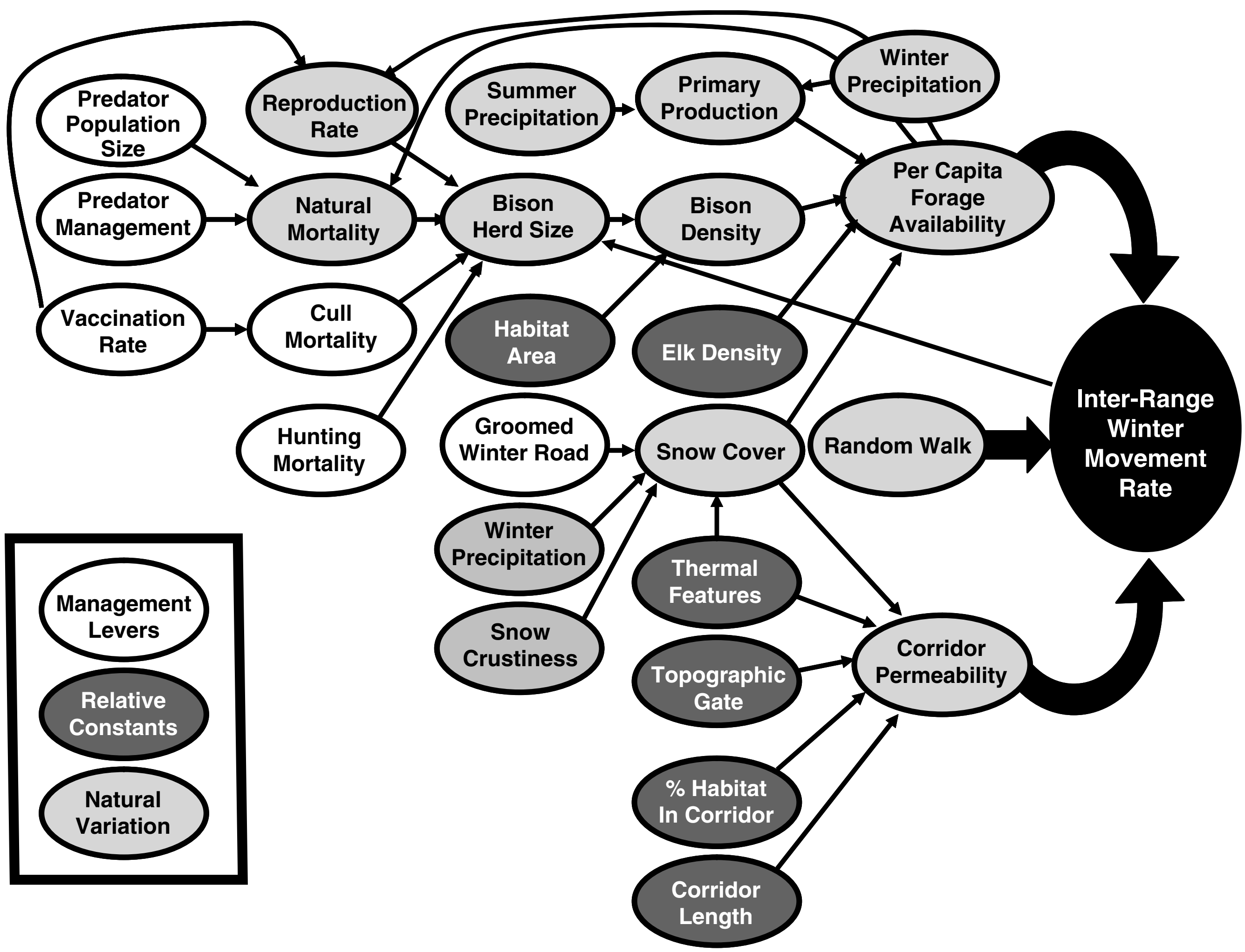
Computer-based models are increasingly used to explore the structure of ecological systems, how their components interact, and how changes to one component may affect the others. The process of closely analyzing these relationships can be as valuable as the resulting model. As Mark Boyce has written,

> *We can clarify our understanding of ecological processes by developing a model of the system in question. In fact, one might argue that the system cannot be clearly understood until we develop an explicit model. And as our understanding of the ecosystem improves, so, too, our models will need to be constantly refined. . . . Any mathematical model of an ecological system is a heuristic tool, and is necessarily a simplification. But simplification does not invalidate ecological models. Indeed, simplification is needed to make the system comprehensible. One hopes to incorporate major limiting factors or driving forces in the system so that the model mimics reality (Boyce 1991).*

Although the complexity of ecosystems makes predictions difficult, models can be used to gauge the range of possible outcomes and compare the relative impact of different natural or human-induced changes. As part of their analysis, Gates and his colleagues developed a Yellowstone National Park Bison Distribution Model that can simulate the effects of various ecological scenarios and management actions on bison population size and movement in midwinter. Because of the limitations of the data and the imprecise assumptions upon which models are based, the report explains, "models cannot be 'right' in a predictive sense, but rather should strive to be 'reasonable' in their structure, assumptions, and relationships." As Gates puts it more bluntly, "All models are wrong, but some models are useful."

To develop a model that would be useful in examining the relationship between bison movement and multiple variables, Gates began by creating a graphic representation called the "Impact Hypothesis Diagram" (IHD). It illustrates how the components in the system interact with each other. "Each arrow connecting variables in the IHD is described as a mathematical relationship derived with the key informants or based on empirical relationships taken from the literature."

Existing data were used to delineate the variability in summer and winter precipitation, forage production, and bison use of ranges and movement corridors. To limit the variability of possible environmental conditions that the model would have to take into consideration, however, it was specifically designed to simulate mid-February in Yellowstone. For example, "per capita forage availability" is the amount of forage available per bison in mid-February, which is assumed to depend on three key variables: precipitation during the previous summer, snowpack characteristics, and grazing pressure by bison and elk. The "permeability" of each movement corridor to migrating bison in mid-February was assumed to depend on five variables: prevalence of thermal features, topography, habitat characteristics, corridor length, and mid-February snow conditions (which would depend partly on whether the road is groomed). At workshops conducted by Gates and Stelfox, groups of key informants ranked the importance of each variable, making



This diagram was used as the basis for the Yellowstone National Park Bison Distribution Model. The variables are color-coded to indicate those that are treated as constants in the model, those that can be simulated as random variables, and those that can be controlled by management decisions. Although "Elk Density" does vary over time, it was treated as a constant in this model to simplify the variables used in the simulations. The "Random Walk" variable refers to inter-range bison movement that is unrelated to forage availability or bison density; it was estimated to account for 10% of the total bison movement in the park.

it possible to rate the permeability of each corridor with and without road grooming during a 100-year simulation during which precipitation varies randomly within a historical range.

Four models were developed from the five workshop groups. (Two of the models were so much alike that they were combined.) Three of these four models produced similar results when simulations were done; they were used to construct a "majority average model." The model based on the constraints set by Group 4 (Mary Meagher's group) differed from the majority model primarily because Group 4 believed that bison would be unwilling to move through snow that had a snow water equivalent (SWE) of more than 10 cm. (This is approximately equal to one meter of snow, but varies depending on the density of the snowpack: the denser the snowpack, the higher the SWE. From 1949 to 2002, the average SWE in the park interior was about 20 cm compared to 7.5 cm on the northern range.) In the majority model, the threshold that would halt bison movement was set at 19 cm. The majority model therefore rated the bison movement corridors as more "permeable" than did the Group 4 model at a given level of SWE.

In non-road grooming scenarios using the Group 4 model, in many winters bison movement would only occur through the Gardiner basin-to-Lamar Valley corridor. Using the majority model, however, bison would be able to maintain a trench through the snow in three of the four most heavily used corridors even without road grooming. The exception is the Firehole-to-Mammoth corridor, which was thought to be relatively impermeable in many winters if the road was not groomed. "The calculated migration of Central Range bison to the Northern Range would likely not have developed in the absence of the groomed road between Madison Junction and Mammoth," the report states. ("Calculated migration" is movement by animals to a destination already known to them.) The Firehole-to-Mammoth corridor was considered an exception because of its length and the particular challenge presented by the Gibbon Canyon. According to the Gates Report, "The road segment through the Gibbon Canyon is the single area in the park where snow cover in combination with steep terrain may deter bison movements in the absence of grooming and snow compaction by over snow vehicles." Most of the key informants thought that bison would be unable to push through the snowpack that could accumulate on an ungroomed road in the 6-km length of Gibbon Canyon. However, now that the northern range destination is known to the bison, some key informants (including Mary Meagher) believed that if bison began packing a trail through the Gibbon Canyon early in the season, they could maintain a trail there in the absence of road grooming despite additional snow, as bison do over Mary Mountain. Another possibility suggested by some informants is that bison might be able to navigate along the geothermally influenced Gibbon River, where less snow accumulates. A power line

> The debate about road grooming is moot now. The Pelican bison were key to the changes in population distribution and numbers. Their land-use patterns were shaped by winter severity and the geothermal survival factor. This unique "bison ecosystem" has been altered irrevocably over the past two decades.
>
> —*Mary Meagher, September 17, 2005*

NPS

This bison near Giant Geyser shows how the animals usually use their massive heads rather than their feet to dig below the snow for forage.

located about one kilometer east of the road could provide an alternative route, but otherwise the areas surrounding the canyon are too steep and heavily forested to allow bison travel.

How much snow does it take to stop a bison? The answer may depend on factors such as terrain; the bison's condition, age, and sex; and the distance to a previously used foraging area. In addition to depth and density of the snowpack, the hardness of an icy crust on the snowpack can affect bison movements by making it difficult or impossible for bison to reach the forage that may be present below.

Although a groomed corridor was rated more permeable than the same corridor without grooming in all models, the increase in permeability was larger in interior corridors than for boundary corridors. This suggests that road grooming may have a greater influence on bison movement between interior ranges than between interior and boundary ranges. Simulations using the majority model showed no difference in the number of bison culled at the park boundary when comparing road grooming to non-road grooming scenarios over the long term. However, it appeared that road grooming might reduce the periodic large bison exoduses that occur in some years by distributing bison movements out of the park more evenly from year to year. Natural winter mortality was higher in the road grooming than non-road grooming scenarios in simulations using the majority model. This difference may be attributed to the greater movement between ranges that occurs with road grooming, which could increase the "probability that higher bison densities may occur on any given winter range," and that forage there would be insufficient.

The snow conditions under which bison will move was the only variable on which the key informants expressed a significant difference of opinion, but development of the model exposed other gaps in what is known about Yellowstone bison ecology. Additional research is needed in these areas to refine the model and improve the accuracy of the assumptions used to run the simulations. Uncertainties include the extent of the interchange between the northern and central bison herds and the ability of wolves to affect bison abundance and distribution in the park. Even in those components of the model on which considerable data were available, small changes in the mathematical relationships built into the model can produce large changes in the resulting simulations.

Recommendations from the Gates Report

Monitoring and Science

1. Yellowstone National Park should implement an internally funded bison population monitoring program that collects and manages data on population size, vital rates, and winter distribution in the long term.
2. Yellowstone National Park should define a minimum viable bison population for the northern range.
3. Yellowstone National Park should encourage and coordinate research focused on reducing key uncertainties over a full range of densities as the population fluctuates in response to environmental stochasticity or management actions.
4. An adaptive management experiment should be designed to test permeability of the Firehole-to-Mammoth corridor under variable snow conditions, with a specific focus on the road section between the Madison Administrative Area and Norris Junction.
5. Yellowstone National Park should install a SNOTEL or snow course station in the Pelican Valley, monitor snow conditions in the Pelican–Hayden corridor, and re-evaluate the two existing snow models.

Management Structures and Processes

6. Engage the U.S. Institute for Environmental Conflict Resolution in an independent situation assessment that includes advice on designing an integrated agency and public planning strategy to represent the common interest.
7. The Yellowstone Center for Resources should play a lead role among agencies and researchers in coordinating data sharing, research, and monitoring of bison and other research relevant to bison ecology and management, by developing a stable collaborative science and management framework.
8. Develop or refine appropriate systems models and other decision support tools to help agencies and other stakeholders to understand key uncertainties and system properties, and to evaluate outcomes of management scenarios defined through value-based decision processes.
9. The National Park Service should increase its support for the appropriate agencies to secure agreements for key winter range for bison and other wildlife adjacent to the park in the northern range.

Recommendations for Monitoring, Research, and Management Process

The Gates Report makes nine recommendations, five of which pertain to additional research and monitoring of bison. Given the large extent of the migration from the park's interior toward the north boundary in some years, and the possibility of lethal management actions for those bison that cross the boundary, the Gates Report recommends conducting a management experiment "to test the hypothesis that the Central population's movement to the Northern Range is possible [in mid-winter] only with grooming of the snowpack on the road, in particular in the Gibbon Canyon." Such an experiment should be designed to "test the effectiveness of unaltered snowpack as a barrier to winter movements between the Central and Northern Ranges in relation to varying environmental conditions including forage production, winter severity, and population size." The report also notes other gaps in the data available to make bison management decisions, and recommends that these be addressed through systematic research, for example, on the ability of bison to move through or forage in snow under the variety of circumstances present in Yellowstone.

"On its own scientific knowledge is insufficient for making effective decisions."

The other four recommendations "are offered to improve the process of creating broadly supported management policy and actions." They go beyond the science of bison ecology to the means by which the National Park Service makes decisions about bison management in conjunction with other government agencies. "It was understood from the outset that one of the central causes of ongoing conflict was not a lack of knowledge but a lack of policy process by which people and institutions can be constructively engaged in integrative decision-making using the best available science," the Gates Report notes. "The role of science in supporting high quality decisions cannot be overemphasized, but on its own scientific knowledge is insufficient for making effective decisions. Establishing the organizational structures and processes to link science to value-based decision-making is perhaps more challenging than conducting research." YS

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Mary Ann Franke began writing and editing for the National Park Service in 1991. She has spent 10 summers and one January in Yellowstone, but migrates to Sedona, Arizona, each fall in response to the shortening days and increasing snowpack.

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Fungi in Yellowstone's Geothermal Soils and Plants

Joan Henson, Regina Redman, Rusty Rodriguez, and Richard Stout


JENNIFER WHIPPLE

Hot springs panic grass is often found in Yellowstone's geothermal areas.

DESPITE TEMPERATURES of 70°C (158°F), acidic pH, toxic levels of heavy metals, and low organic matter content, geothermally heated soils in Yellowstone National Park harbor many species of fungi. Some of these fungi secrete enzymes that may be of commercial interest, because they may be more heat-resistant than enzymes from cooler soils. In addition, fungi growing in geothermal areas tolerate relatively high concentrations of heavy metals, a trait that may be exploited for bioremediation of metal-contaminated soils. For example, areas around metal smelters, such as the abandoned one located near Anaconda, Montana, lost their vegetation because of toxic heavy metals precipitating from the smelting process. Toxic topsoil can become aerosolized by wind, and metal-tolerant fungi, with their network of filamentous cells, could stabilize the topsoil or remove metals from the soil by absorption processes.

Fungi inhabiting harsh geothermal soils may also colonize and live inside (endophytically) the sparse vegetation found there. A plant often found on hot ground in Yellowstone's geothermal areas is hot springs panic grass (*Dichanthelium lanuginosum*). This grass serves as a host for the fungal endophyte *Curvularia protuberata*. Laboratory experiments support the idea that this fungus and this plant are mutualistic with regard to heat tolerance, that is, they are more thermotolerant together than they are alone. Together, the endophytic fungus and its host plant could also be useful for remediating contaminated soils.

Living organisms differ greatly in their ability to adapt to high temperatures. This is nicely summarized in Thomas D. Brock's classic booklet, *Life at High Temperatures*, which can be found at visitor centers throughout Yellowstone National Park. In the latest edition of this booklet is a table showing that

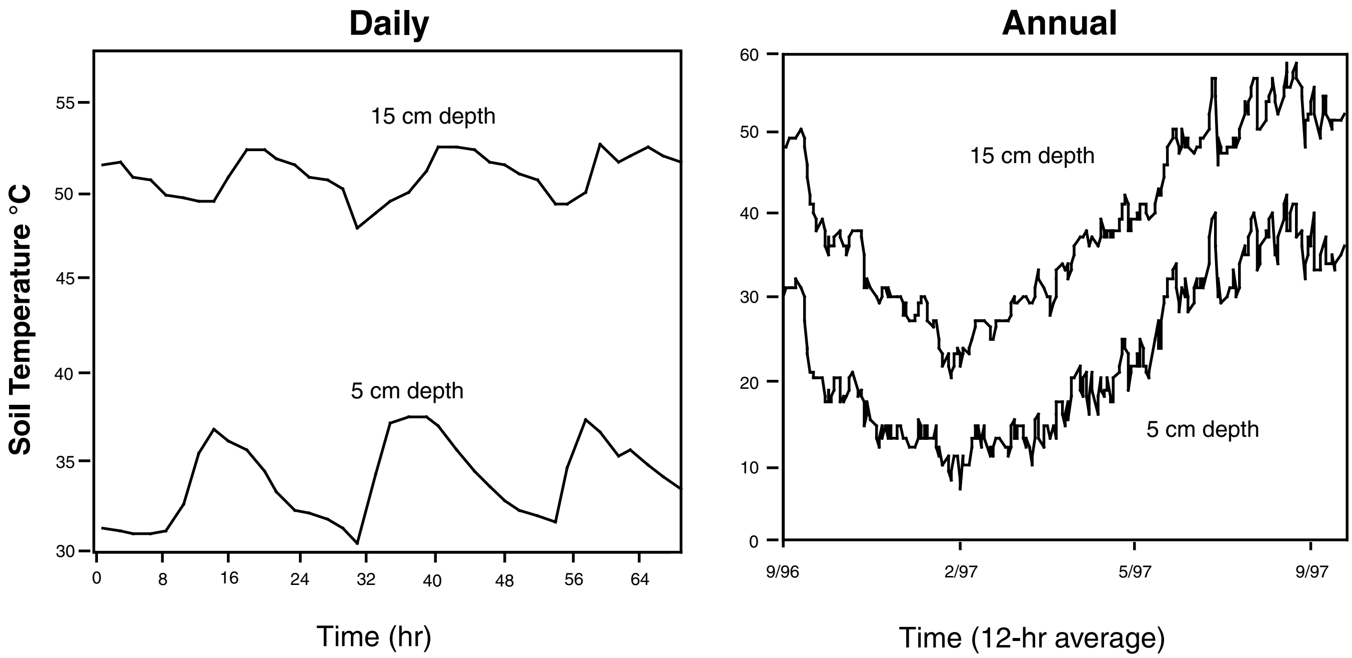


Figure 1. Diurnal cycle of soil temperature at Amphitheater Springs site 1a. Data were collected hourly from thermocouple probes positioned at 5 and 15 cm under the soil surface. Temperatures from one of the warmer mesocosms (a bigger core, ~15 cm wide and 40 cm deep, which can be repeatedly sampled) over a 72-hr period (left) and over an entire year (right) are shown.

Mesocosm/Core	Associated Plants	Initial pH Range	Initial Temperature 5 cm	Initial Temperature 15 cm	Annual Temperature Range (°C) 5 cm	Annual Temperature Range (°C) 15 cm
Mesocosm 31	*D. lanuginosum*	4.5–7.5	31°	46°	5–44°	19–56°
Mesocosm 32	*D. lanuginosum*	4.4–6.3	35	50	2–44	12–58
Mesocosm 33	*D. lanuginosum*	4.7–5.4	24	36	1–38	11–45
Cores 36A–D	*D. lanuginosum*	4.6–4.9	34	41	9–34	14–41
Cores 37A–C[a]	mixed grasses	6.1–6.3	22	19	<0[b]–22	<0[b]–14
Cores 4A–D	*D. lanuginosum*	3.9–4.5	42	56	10–42	18–56
Cores 6A–D	*D. lanuginosum*	4.2–5.0	28	38	11–30	18–38
Cores 8A–D	*D. lanuginosum*	4.3–4.9	27	33	8–30	15–33
Cores 11A–D	decaying log	2.7–4.0	98	107	55–98	91–107
Cores 13A–D	*D. lanuginosum*	4.2–4.7	43	47	8–43	14–47
Cores 25A–D	*D. lanuginosum*	3.9–4.2	20	23	2–24	10–24
Cores 27A–D[a]	lodgepole pine	ND	9	7	ND	
Core 28D[a]	mixed grasses	ND	12	10	ND	
Core 29A[a]	sagebrush	ND	12	11	ND	
Core 34	*D. lanuginosum*	4.2–4.4	3	8[b]	3–29	8–32
Core 35	*D. lanuginosum*	5.1–5.2	32	47	10–32	18–42

Ambient air temperature at Amphitheater Springs ranged from –36.1°C in January 1997 to 31.7°C in August 1997.
A=5 cm, B=10 cm, C=15 cm, D=20 cm. Where A–D is not noted, samples were only taken at 5 and 15 cm depth.
While soil samples were taken at up to four different depths, temperature was measured only at 5 cm and 15 cm.
[a] Non-geothermal cores
[b] Frozen ground, temperatures not recorded

Table 1. Temperature and pH ranges of selected soil mesocosm/core samples from site 1a near Amphitheater Springs in Yellowstone National Park (ND = not determined).

prokaryotes (*Eubacteria* and *Archaea*) are much more heat-tolerant than eukaryotic organisms such as plants and fungi. Fungi are considered thermophilic if they grow between 20 and 60°C (about 70–140°F). Indeed, in the 1970s, Professor Brock and colleague M.R. Tansey were the first to report that some fungal species could be isolated from geothermal features.

Our objectives in this study were 1) to identify and characterize fungi isolated from both geothermal soils in Yellowstone National Park (YNP) and the plants growing there and 2) to describe the natural habitats of these fungi. A rationale for pursuing this research is that fungal isolates from geothermal soils may secrete useful thermotolerant enzymes because they are adapted to unusually hot soil environments. These fungi may be useful in the bioremediation of metal-contaminated soil or water because they are sometimes found in geothermal soils containing high levels of metals such as iron and lead. In addition, they offer an opportunity to gain insight into cellular mechanisms of both thermotolerance and thermoresistance utilized by higher (eukaryotic) organisms.

Geothermal soils and site characterization. Our investigations were mainly conducted in the Amphitheater Springs area of YNP (44.80°N/110.72°W), approximately 20 miles south of Mammoth Hot Springs. At this field site (1a), we collected 37 cores where the geothermally-heated soil temperatures ranged from 3 to 107°C. Soil temperature was measured in several thermal areas, and all thermal soils tested showed diurnal fluctuations in soil temperatures that were recorded by a datalogger with temperature probes at 5 and 15 cm (Fig. 1). In almost all geothermally-heated soil cores, the lowest temperature occurred at the 5-cm depth and the highest at the 15-cm depth (Table 1), a situation that was reversed in non-geothermal soils, which ranged from 9 to 19°C at 5–15 cm depths. Each core was sampled at 5, 10, 15, and 20 cm depth. All geothermal soils tested had low organic carbon (OC) levels (Table 2) and most geothermal cores were acidic (pH 2.7 to 5.8). Geothermal soils are acidic because of sulfuric acid produced by oxidation sulfides such as hydrogen sulfide (H_2S) and pyrite (FeS_2). This

Soil Analyses of Amphitheater Springs Cores 1–10

Site/ Core	Soil Depth (cm)	OC %	P µg/g	Pb µg/g	Fe µg/g	S µg/g	SO4 µg/g
1a-1	5.0	4.6	455	7.0	13,199	8,800	107.4
	10.0	3.0	375	3.3	13,173	7,100	64.0
	15.0	2.5	385	5.1	12,214	7,600	35.2
	20.0	2.2	375	5.7	13,255	8,500	40.2
1a-2	5.0	31.9	395	4.9	11,917	58,100	2445.6
	10.0	2.5	365	4.9	13,449	15,100	595.2
	15.0	2.2	375	3.5	13,121	12,900	523.8
	20.0	2.1	419	6.0	13,269	15,400	447.8
1a-3	5.0	5.9	565	8.4	10,146	18,500	114.1
	10.0	2.7	435	6.9	12,551	15,500	100.0
	15.0	3.9	655	7.3	15,175	15,600	206.0
	20.0	2.3	410	6.1	7,635	59,700	212.4
1a-4	5.0	9.5	540	17.9	13,959	13,000	23.8
	10.0	3.5	368	8.2	16,871	8,100	38.7
	15.0	2.3	250	3.6	14,818	9,500	27.6
	20.0	2.2	250	3.9	14,645	13,100	27.8
1a-5	5.0	16.1	725	19.3	4,082	11,400	31.9
	10.0	3.2	564	19.6	1,123	5,700	8.4
	15.0	3.9	528	15.9	3,065	5,600	6.0
	20.0	18.4	610	19.8	4,642	12,700	33.3
1a-6	5.0	4.5	322	7.4	7,737	42,000	23.0
	10.0	2.7	326	3.9	4,959	3,800	21.6
	15.0	2.7	410	4.1	2,639	3,600	38.8
	20.0	3.2	526	3.5	2,210	42,000	71.8
1a-7	5.0	8.2	593	14.0	12,035	12,500	53.5
	10.0	6.2	590	18.1	11,004	16,500	97.7
	15.0	3.0	401	6.9	9,932	4,900	121.1
	20.0	2.1	301	4.3	6,935	7,300	119.4
1a-8	5.0	15.8	685	12.8	3,946	12,900	52.2
	10.0	3.7	523	5.8	2,705	9,700	52.3
	15.0	3.2	506	5.9	4,878	14,200	50.6
	20.0	3.1	515	4.0	4,115	12,900	57.4
1a-9	5.0	10.4	660	15.2	4,145	13,700	275.8
	10.0	4.2	436	12.0	4,600	9,200	90.5
	15.0	1.7	243	10.2	3,603	64,000	6.7
	20.0	0.6	94	6.4	1,002	2,700	8.4
1a-10	5.0	3.9	302	11.6	2,993	9,500	254.7
	10.0	2.0	199	14.6	2,684	11,000	47.4
	15.0	1.3	142	18.0	1,926	3,900	21.8

Table 2. Analyses of organic carbon (OC), phosphorus (P), lead (Pb), iron (Fe), total sulfur (S), and sulphate (SO_4) in selected geothermal soil cores from site 1a near Amphitheater Springs.

acidity increases soil metal content by dissolving metal ions and transporting them to the surface soil. Many of our thermal soil samples had elevated levels of phosphorus, lead, iron, and/or sulfur (Table 2). For comparison, non-geothermal soils typically have greater than 12% OC and less than 5 µg/g lead, 500 µg/g sulfur, and 100 µg/g iron.

With regard to vegetation cover at these sites, the geothermally-heated soils displayed low plant diversity, with hot springs panic grass (*D. lanuginosum*) typically the predominant flowering plant species (Fig. 2).

Culturable thermotolerant and thermophilic fungi. Fungi were cultured from two areas that had significant temperature variation between and within soil core samples (Table 1). Sixteen fungal species were cultured and screened to determine optimal temperature and pH for growth (Table 3). *Acremonium alabamense* and *Scolecobasidium sp.* were the only true thermophilic isolates, because they grew at 55°C and failed to grow at 25°C and 20°C, respectively. Six other species (*Absidia cylindrospora, Aspergillus fumigatus, Aspergillus niger, Penicillium sp. 1, P. sp. 3,* and *P. sp. 4*) exhibited thermotolerant profiles; although they were unable to grow at 55°C, they could grow when shifted to 35°C after exposure to 55°C for one week. All other fungi reported in this study were not thermotolerant or thermophilic.

We also collected samples near individual plants or several feet away from *D. lanuginosum* plants, the roots of which can tolerate sustained temperatures of 50°C (Fig. 2). The number of culturable fungi was 10–100 times less in soils that were devoid of plants, which suggests that plants provide nutrients and/or shelter for the fungi.

Extracellular enzyme activity and metal tolerance. All fungal species tested exhibited some level of extracellular protease and/or cellulase activity, with the exceptions of *Scolecobasidium sp.* and *Sporothrix sp.* (Table 3). Hot springs panic grass and other plants in geothermal soils likely provide nutrients in root exudates for soil fungi. However, the fungi may also

Genus/Species	Optimal pH[1]	Optimal temperature[2]	Classification with temp. range[3]	Extracellular proteases	Extracellular cellulase
Absidia cylindrospora	5.0–6.0 (4.2)	35 (18°)	TT (20–45°)	+ (pH7–8)[4]	–
Acremonium alabamense	5.0 (3.9)	45 (44)	TP (30–55)	+ (pH5–8)	+ (pH6–8)
Acremonium ochraceum	6.0 (3.6)	25–35 (55)	M (20–45)	ND	ND
Aspergillus fumigatus	4.0 (5.8)	35 (68)	TT (20–50)	–	+ (pH6)[4]
Aspergillus niger	5.0 (4.0)	35 (20)	TT (20–45)	+ (pH7–8)	+ (pH8)
Chaetomium erraticum	6.0 (3.5)	35 (52)	M (20–45)	–	+ (pH6–7)
Cunninghamella elegans	5.0 (4.8)	35 (21)	M (20–45)	+ (pH7)	–
Penicillium piceum	5.0 (4.8)	35 (28)	M (20–45)	–	+ (pH8)
Penicillium sp. 1	5.0 (4.8)	35 (50)	TT (20–45)	+ (pH5–7)	+ (pH8)
Penicillium sp. 3	5.0 (4.8)	35 (40)	TT (20–40)	+ (pH5–7)	–
Penicillium sp. 4	4.0 (4.2)	35 (19)	TT (20–45)	+ (pH5)	+ (pH7)
Penicillium sp. 7	5.0 (4.5)	25 (21)	M (20–45)	+ (pH5–7)	+ (pH8)
Penicillium sp. 8	6.0 (4.7)	35 (68)	M (20–45)	ND	ND
Scolecobasidium sp.	6.0 (4.7)	45 (21)	TP (25–55)	–	–
Sporothrix sp.	6.0 (4.2)	35 (27)	M (20–45)	–	–
Torula sp.	5.0 (4.7)	35 (26)	M (20–45)	ND	ND

[1] pH of soil in parentheses
[2] temperature (°C) of soil sample in parentheses
[3] M=mesophile (maximal growth below 50°C and can grow above 0°C), TP=thermophile (doesn't grow at 20°C and has an optimal temperature at or above 50°C), TT=thermotolerant (temperatures=0°C)
[4] pH secreted
ND=not determined

Table 3. Optimal pH, growth temperatures, and extracellular enzyme production of fungal soil isolates. Proteases are enzymes that break down protein, and cellulases are enzymes that break down cellulose.

COURTESY JOAN HENSON AND RICH STOUT

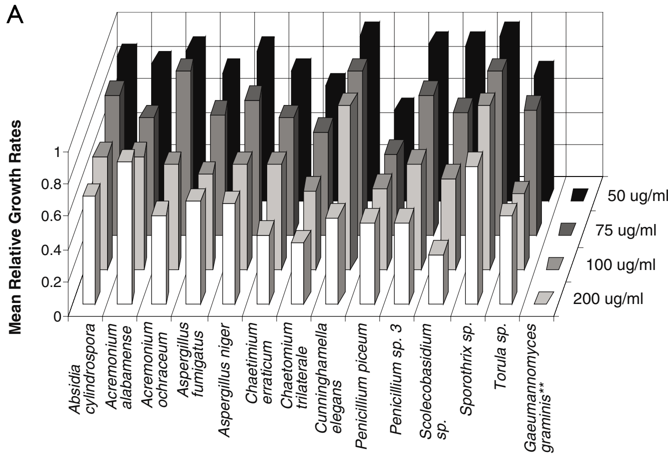
Figure 2. *D. lanuginosum* at Amphitheater Springs with rhizosphere (root zone) temperature reading above 50°C.

utilize plants as a nutrient source by establishing symbiotic or saprophytic associations. Their production of extracellular enzymes suggests that the fungi are saprophytic; that is, they degrade and metabolize organic matter from dead plants. Thermostable enzymes from fungi are gaining interest, in part because of the ability of fungi to degrade a broad spectrum of chemicals. It will be of interest to further investigate several of these enzymes secreted by thermophilic or thermotolerant fungi.

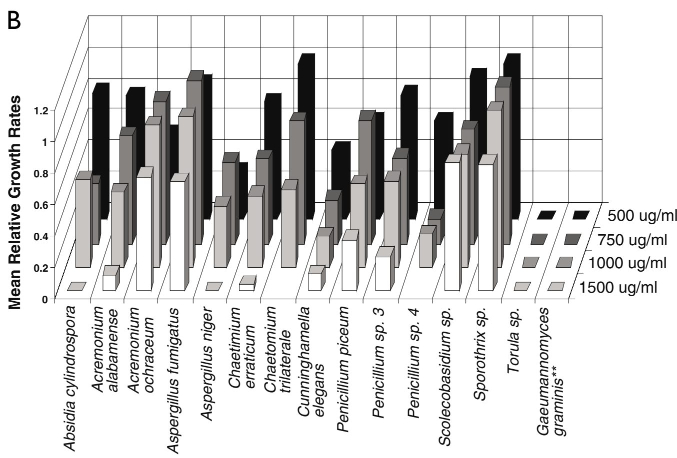
Some of Yellowstone's geothermal soil fungi are apparently also well adapted to high levels of iron and lead, and hence may be useful bioremediating agents for metal-laden soils, generated as waste products of the mining industry. Because the geothermally modified soils studied often contained relatively high levels of lead and iron, representative fungal isolates were tested for their metal tolerance on media containing up to 1,500 µg/ml of iron sulfate ($FeSO_4$) and 200 µg/ml of lead nitrate ($PbNO_3$; Fig. 3). Almost all fungi from YNP that we isolated grew on media supplemented with these two metals. For example, growth of *Acremonium ochraceum* appeared unaffected by 75 µg/ml $PbN0_3$, and *Cunninghamella elegans* and *Sporothrix sp.* were unaffected by 100 µg/ml of $PbN0_3$ (Fig. 3A). Moreover, *Chaetomium trilaterale* and *Sporothrix sp.* grew as well with $FeS0_4$ (500 and 1000 µg/ml, respectively) as without supplemental iron, and *Aspergillus fumigatus* grew faster with 750 µg/ml of $FeS0_4$ than without added iron (Fig. 3B). In contrast, a typical soil fungus from non-geothermal soil, *Gaeumannomyces graminis,* was unable to grow on these toxic concentrations of iron and lead.

Endophytic *Curvularia protuberata* and its mutualistic symbiosis with *D. lanuginosum.* As an endophytic fungus, *Curvularia protuberata* is able to live inside plants, and is exclusively associated with plants in geothermal soils (Fig. 4). Over the past 10 years we assayed for this fungus and found it was present in 100% of >200 panic grass plants tested both from at least seven different geothermal areas in Yellowstone National Park and from an additional geothermal soil in Lassen Volcanic National Park. To assess the effect of the endophyte on the thermotolerance of *D. lanuginosum,* we germinated and grew endophyte-free (non-symbiotic) plants and plants inoculated with *Curvularia* (symbiotic plants). After several weeks

A



B



**control mesophilic fungus not isolated from YNP

Figure 3. Iron and lead tolerance by geothermal soil fungi from Amphitheater Springs. **A)** Lead tolerance by different isolates. **B)** Iron tolerance by different isolates. Metal concentrations are listed on the right.

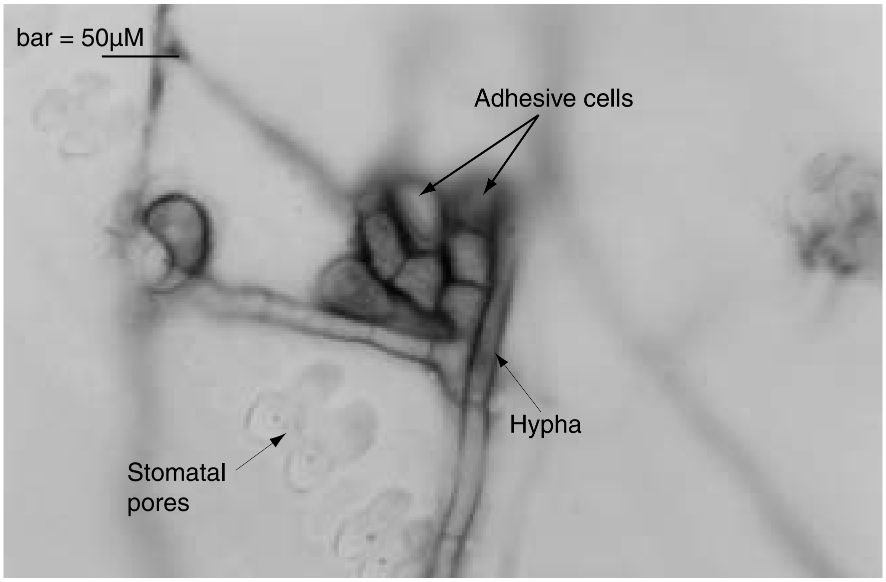


Figure 4. Hyphae, composed of filamentous fungal cells, and adhesive cells of *C. protuberata* on a *D. lanuginosum* leaf.

of growth at room temperature, these plants were exposed to several days of heat treatment. (In the laboratory, electrical heat-tape was used to warm the pots in which the plants were growing in order to simulate the natural geothermal heating of the roots). Endophyte-free host plants shriveled and died after three days of 50°C root zone temperature. In contrast, symbiotic plants thrived during this heat treatment. In addition, we re-isolated *C. protuberata* from heated plant roots of all the symbiotic plants. Because *C. protuberata* cannot survive this temperature when growing alone, our finding that it survived inside the plant provides evidence that the fungus and the host plant provide mutual protection from thermal stress.

This was the first demonstration of thermotolerance provided to both symbiotic partners as a result of their mutualistic interaction. Mechanisms of thermotolerance are currently unknown, but could include activation of plant stress responses, or the production of fungal compounds that enhance plant thermotolerance, desiccation tolerance, or both. For example, fungal melanin, a pigment that binds unstable oxygen radicals generated during heat stress, could provide thermotolerance. Future studies will address these possible mechanisms. Whatever the mechanism of thermotolerance, it is likely to operate in all populations of hot springs panic grass in Yellowstone (and possibly Lassen Volcanic National Park), because all plants tested carry endophytic *Curvularia*. YS

Acknowledgements

Special thanks to the staff of the Yellowstone National Park Research Permitting Office. This work was supported by grants from the U.S. Geological Survey, National Science Foundation (9977922), the U.S. Army Research Office (DAAHO4-96-1-01194 and 35824-LS-DP), and NASA (grant NAG 5-58807 to the MSU Thermal Biology Institute).

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COURTESY JOAN HENSON AND RICH STOUT

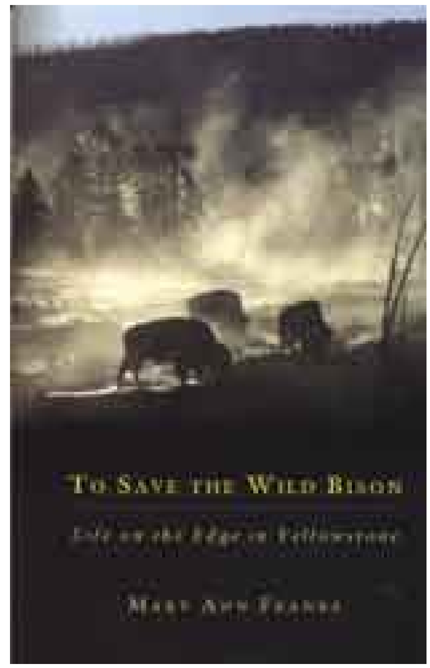
Left to right: Rusty Rodriguez, Joan Henson, Richard Stout, Regina Redman, Kris Hale, and John Noreika. **Joan Henson** and **Richard Stout** are professors at Montana State University in Microbiology and Plant Sciences, respectively. **Regina Redman** is an affiliate professor of microbiology at Montana State University and the University of Washington and is married to **Rusty Rodriguez**, a research scientist at the U.S. Geological Survey in Seattle, Washington. This is the 10-year anniversary of the authors' collaboration and friendship. Kris Hale and John Noreika are students at Montana State University.

Book Reviews

To Save the Wild Bison: Life on the Edge in Yellowstone by Mary Ann Franke

Robert B. Pickering

(Norman, OK: University of Oklahoma Press, 2005. xx plus 328 pages, preface, introduction, illustrations, maps, notes, references, index. $29.95 cloth.)

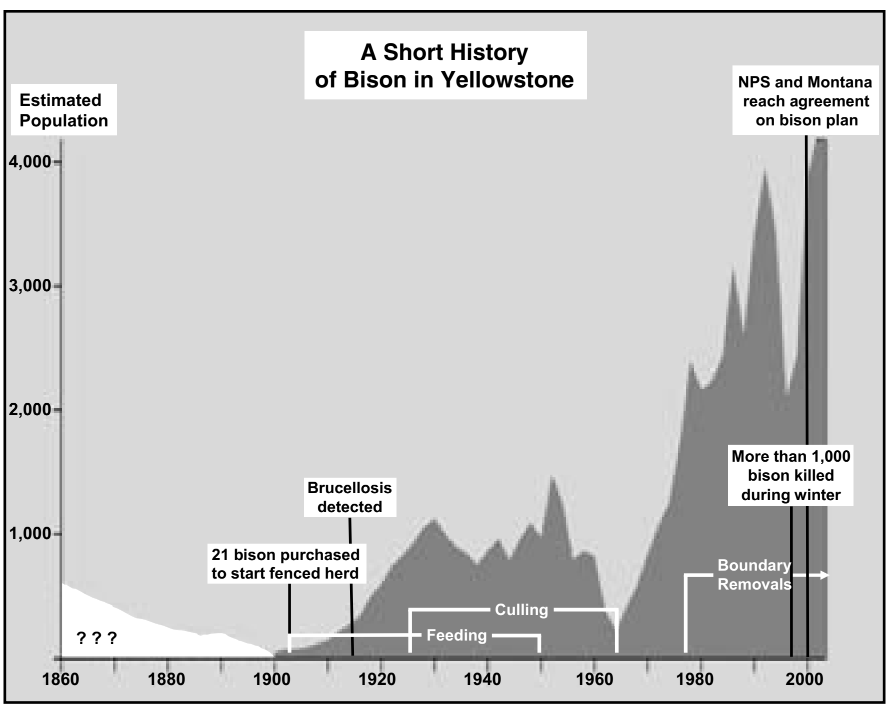


MARY ANN FRANKE

ANYONE READING today's newspapers sees that Yellowstone National Park is a lightning rod for many issues concerning public access, conservation, and wildlife. Of particular note is the park's management philosophy related to bison, the presence of brucellosis, and the testy legal relationship between the park and its neighbors—individuals and state governments. Mary Ann Franke's fascinating new book, *To Save the Wild Bison,* traces the controversies back to the founding of Yellowstone itself. Franke clearly presents not one or two, but multiple sides of the story.

Ms. Franke addresses the history of bison in the park in five sections comprised of 16 separate chapters. The notes section at the end is valuable to any serious researcher. In the first section, Ms. Franke presents a comprehensive discussion of bison in North America and the founding of Yellowstone National Park. For the reader interested in the national scope of bison history, there are other sources that provide more detail. However, this section's focus on the specific history of Yellowstone's bison is excellent.

The second section of the book delves into the romanticism that founded the park and the question of what to do about bison. Coming on the heels of the nineteenth century Great Slaughter, the need to save the bison was not a unanimously held belief. Poachers, who had greater interest in personal gain than in following the law or preserving this great species,



Wildlife counts in Yellowstone are always subject to error because of the unknown number of animals that may go undetected, but estimates made before 1900 were especially unreliable because they were often based on hunches and chance observations rather than systematic surveys.

considered the park to be their own private hunting grounds. The local controversy over hunting bison and other animals in the park led to the writing of national laws. Thus, the federal government became more active in species and habitat conservation.

Section three introduces a marvelous phrase, "brucellosis in Wonderland," to describe the early contact and conflict between the park's bison and the cattle of neighboring ranchers. Not unlike the poachers, nineteenth century ranchers saw the park as a way to increase their personal gain by grazing their cattle within park boundaries. Franke presents a bare-knuckles assessment of the competing ideas regarding brucellosis in Yellowstone. Some factions propose eradicating the bison altogether. The other end of the spectrum suggests extending the park boundaries to ensure that bison have sufficient winter range and cattle could be totally separated from bison. Interestingly, some of the same folks who want to eliminate bison to get rid of brucellosis seem to turn a blind eye to the elk that also carry the disease and range beyond the park's boundaries at will. When I began reading this section, I thought I knew what Ms. Franke's perspective was going to be. However, she is relentless in pointing out the inconsistencies, fuzzy thinking, and less-than-professional actions that can be found on all sides of this debate. Neither the park officials, the Washington lawmakers, the ranchers, nor the environmentalists are spared from her critical examination.

Section four connects the bison issue with current hot topics in Yellowstone, such as the reintroduction of wolves, snowmobile access, and the expanding grizzly bear population. Here is the background behind the front-page news stories. Again, Franke pulls no punches in her assessment of the actions and motives of the various players in this debate.

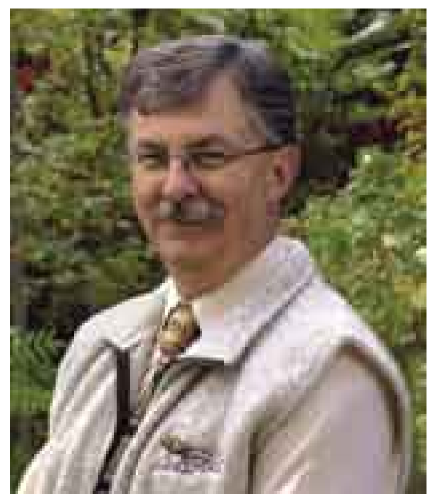
Section five enriches an already complicated story by introducing the role of Native Peoples in the park, both historically and as they assert their rights to be players at the table when bison are discussed. Here, we see the historic park stance that overtly diminished, if not totally denied, the role of Native Peoples on the land that became Yellowstone National Park. As tribes have asserted their sovereignty and rights on many other topics from gambling to water, so too, they want to help shape the future of the buffalo—the animal that physically and spiritually sustained Plains peoples for so many generations. However, people representing the tribes are subject to the same critical assessment of actions and motives as Franke gives to all other factions in this great debate.

In summation, this is a straightforward, fact-filled presentation of the state of bison in Yellowstone. On the surface, bison have made an incredible recovery in the last hundred years thanks to the efforts of many people and many diverse organizations. However, there are still powerful interests, private and governmental, who would reverse the success. This is not a book for the casual reader. Franke doesn't tell a pretty story. However, if Yellowstone National Park, bison, and sound governmental policy are important to you, this is a great book.

YS

NPS

The Yellowstone area is the only place in the United States where wild bison have been present since before the first Euro-Americans arrived.



COURTESY ROBERT PICKERING

Dr. Robert B. Pickering has served as Deputy Director for Collections and Education at the Buffalo Bill Historical Center (BBHC) in Cody, Wyoming, since 1999. He also serves as Director of the Cody Institute of Western American Studies (CIWAS), a forum for researching, discussing, and disseminating significant information on topics of the American West. Dr. Pickering has been involved in museum education, exhibit development, and anthropological research for more than 25 years. His experience in a variety of museums, including the Field Museum of Natural History in Chicago, the Children's Museum of Indianapolis, and the Denver Museum of Nature & Science, as well as the BBHC, makes him keenly aware of the opportunities and challenges offered by museums as well as the needs of the audiences they serve.

Decade of the Wolf by Douglas W. Smith and Gary Ferguson

Hank Fischer

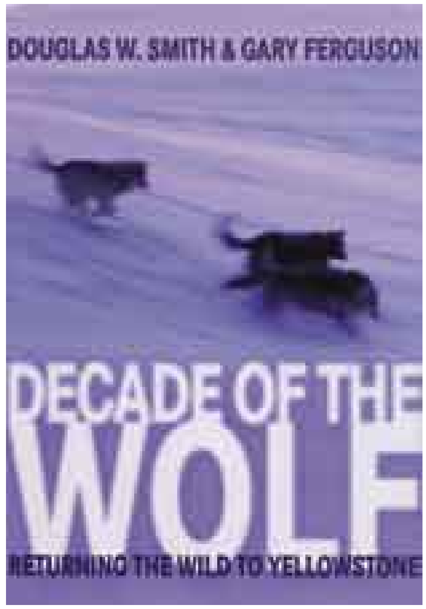
(Guilford, CT: The Lyons Press, 2005. viii plus 212 pages, acknowledgments, graphs, endnotes, index. $23.95 cloth.)

IN HIS 1930 BOOK, *Animal Life of Yellowstone National Park*, noted biologist and federal employee Vernon Bailey wrote dispassionately about shooting the adult wolves from one of Yellowstone's last packs, and then killing their pups in a den on the slopes overlooking Hellroaring Creek. It's a remarkable book because it so graphically captures what was then the prevailing American attitude toward *Canis lupus*.

Fast-forward 75 years, and *Decade of the Wolf*, a book by biologist and federal employee Doug Smith (with co-author Gary Ferguson) provides a new outlook, as well as powerful evidence for how dramatically viewpoints have changed.

This is not a dry, academic science book, and Doug Smith is not an unemotional, just-the-facts-ma'am style of biologist. Smith is enthusiastic about wolves and the wild country they inhabit, and his ardor for the natural world permeates the entire book. This is a guy who can look into a wolf's eyes from a Super Cub airplane traveling 100 miles per hour and imagine what the wolf is thinking (he does it twice in the book!). Moreover, Gary Ferguson is an excellent writer who can bring great stories to life.

Strong narrative connected with good science is what makes this book sing, particularly when Smith and Ferguson tell the fascinating life stories



of individual wolves. For instance, the dramatic story of wolf #9F underscores how important individual animals can be to a population; genetics studies in 1999 revealed that she was related to 75% of Yellowstone's wolves.

The science in *Decade of the Wolf* tends more toward the descriptive than the quantitative. Smith clearly admires the pioneer biologists who studied wildlife by spending long hours in the field using acute observational skills. But Smith and Ferguson also do an excellent job of weaving important Yellowstone research findings into their wolf life histories. We learn that on average, a 10-member wolf pack kills about 180–190 elk per year. We find out that about 70% of wolf dens used each year have been used in previous years, that 35–40% of Yellowstone's wolves are radio-collared, that researchers have only been able to document two bighorn sheep and two mountain goats killed by wolves, that an average of 29 ravens attend every wolf kill, and that the average life span for a Yellowstone wolf is 3.4 years.

An absorbing chapter, "The Wolf Effect," discusses how wolves may influence plant and animal life in Yellowstone. It's an intriguing subject—one on the cutting edge of conservation biology—and the introduction of wolves to Yellowstone provides a textbook opportunity for understanding how top predators can make ripples through the entire food chain. The discussion centers on how willows have begun to grow along river banks and beaver have started to increase on the park's northern range since the Gallatin National Forest reintroduced 150 beaver in the early 1990s, coincident with wolf reintroduction.

What Smith and Ferguson could do better is to distinguish their informed conjecture from actual research findings. Many factors other than wolves are at play in the Yellowstone ecosystem (e.g., drought, global warming, and fire), and so far there is little data that cements the connection between wolves and the vegetation changes that appear to be occurring now. But such questions are of interest mainly to the science community, and that's plainly not who this book is for. The legions of people hungry for more details about Yellowstone's wolves will find a feast of information in this book, and can be counted on to gobble it down enthusiastically.

YS

COURTESY HANK FISCHER

Hank Fischer worked for 25 years as Defenders of Wildlife's northern Rockies director. He was deeply involved with Yellowstone wolf reintroduction, which was the subject of his book, *Wolf Wars*. He currently works as special projects coordinator for the National Wildlife Federation in Missoula, Montana, and leads wolf and grizzly trips to Yellowstone (www.fischer-outdoor.com).

NPS PHOTOS

The GYCC panel (above, Regional Forester Jack Troyer, USFS Intermountain Region. Above right, left to right: Superintendent Mary Gibson Scott, Grand Teton National Park; Refuge Manager Barry Reiswig, National Elk Refuge; Forest Supervisor Becky Aus, Shoshone National Forest; former Yellowstone Superintendent Bob Barbee; and moderator Yellowstone Superintendent Suzanne Lewis); below, their audience.

8th Biennial Scientific Conference Explores 21st–Century Conservation

Alice Wondrak Biel

THE 8TH BIENNIAL SCIENTIFIC Conference on the Greater Yellowstone Ecosystem, *Greater Yellowstone Public Lands: A Century of Discovery, Hard Lessons, and Bright Prospects,* was held October 17–19, 2005, at the Mammoth Hot Springs Hotel. The conference set a new attendance record, with 209 registered attendees. This year's conference was highly anticipated as being one of the most immediately pragmatic in the 14-year history of the series, and one of the most directly useful to public land managers. Participants focused on the mandates, "cultures," relationships, and accomplishments of the numerous local, state, and federal management agencies responsible for Greater Yellowstone's public lands.

Interagency cooperation was a primary theme, and the meeting kicked off with a screening of *The Greatest Good,* a two-hour film celebrating the centennial of the U.S. Forest Service (1905–2005). On Monday night, U.S. Forest Service Chief Dale Bosworth delivered the opening keynote address to a packed Map Room at the Mammoth Hotel, lit by emergency lights, candles, glowsticks, and flashlights due to a localized power outage. Chief Bosworth outlined what he believes to be the four biggest threats to U.S. national forests: (1) unmanaged recreational use, (2) invasive species, (3) loss of open space, and (4) the unnatural accumulation of fuels, leading to dangerous fire conditions. The chief's declaration that "The day when people can go where they want cross-country (on off-highway vehicles) is over," received a round of applause from the crowd.

Former forest service chief Jack Ward Thomas, now the Boone and Crockett Professor of Conservation at the University of Montana, presented the A. Starker Leopold Lecture on Tuesday night. Dr. Thomas traced 100 years of conservation in the U.S., from its roots in simply preventing resource exploitation to today's ecosystem and multi-use management mandates. Canadian conservationist and activist Harvey Locke delivered the Superintendent's International Lecture. In an inspiring speech that received a standing ovation, Mr. Locke stated that if the dream of the twentieth century was unmitigated progress based in a wealth of natural resources, the dream of the twenty-first century should be ensuring that what was done to the land and resources in the twentieth century is undone. He also detailed the Yellowstone-to-Yukon initiative, expressed confidence in the prospects for the project's success, and told the audience of the most important lesson he's learned in conservation work: never give up.

The Aubrey L. Haines lecturer was Sarah Boehme of the Buffalo Bill Historical Center's Whitney Gallery of Western Art. Dr. Boehme's talk, "Yellowstone Paintings: Artistic Discoveries, Hard Rides, and Golden Vistas," discussed the influence of Yellowstone-inspired art on Washington policymakers as they considered the park's creation and supported the subsequent conservation movement.

In other keynotes, landscape ecologist Dr. Monica Turner presented an amalgam of lessons and surprises from post-1988 fire research in Yellowstone, and former NPS Intermountain Region director Karen Wade shared her thoughts on the importance of science and individual responsibility in conservation. On Wednesday afternoon, Dr. Richard Knight provided a heartfelt summary of the three days' events that emphasized the import of considering traditional conservation issues from a broad perspective, rather than a narrow focus. According to Knight, we need to concentrate less on endangered species, off-highway vehicles, and ranching, and more on invasive species, unmanaged recreation, and private lands. He also reminded those assembled that their role as scientists and conservationists has changed in recent times; that in the past, they were often the decisionmakers. Today, they are the catalysts, because conservation must operate, and its value be felt, at all levels of the populace.

Harvey Locke, of the Canadian Parks and Wilderness Society, received a standing ovation for his inspiring speech.

Karen Wade, former Intermountain Region Director of the National Park Service, spoke on Wednesday morning.

Community-based conservation, an important theme of the 7th Biennial Scientific Conference, *Beyond the Arch*, was also a recurring topic at this conference, reminding attendees that, in the words of Dr. Knight, in order to manage effectively in today's world, "we will have to manage differently." Broadening the scope of people involved in conservation will require clear explanations of why conservation is important to everyone, and of the science behind it. Thus, another theme that emerged was the importance of training scientists and managers to express themselves clearly, and to perceive of their audience as consisting of far more than other scientists. Drs. Gary Machlis and Alice Wondrak Biel addressed this issue in a description of The Canon National Parks Science Scholars Program, and the conference itself seemed to have achieved this goal when Dr. Knight declared that overall, it had been "not just science for scientists."

The conference was interdisciplinary, as is its hallmark, with panels, sessions, posters, and speakers covering topics that ranged from remote sensing to art history. Superintendent Suzanne Lewis moderated a blue-ribbon panel on Tuesday morning that featured former Yellowstone superintendent Bob Barbee and local, high-level leaders from the U.S. Forest Service, U.S. Fish and Wildlife Service, and the National Park Service, focusing on the history and current challenges of the Greater Yellowstone Coordinating Committee. There were also sessions on history, mammals, biocomplexity, water resources, fire, human values, native plants, and trophic cascade questions, all with a cross-agency or cross-boundary perspective.

More than 30 papers were presented and 20 posters displayed.

Greater Yellowstone Public Lands was sponsored by the Yellowstone Association; Yellowstone National Park; the Draper Museum of Natural History (Buffalo Bill Historical Center); Grand Teton National Park; the University of Wyoming–National Park Service Research Center, Research Office, and Ruckelshaus Institute (University of Wyoming); the Rocky Mountains Cooperative Ecosystem Studies Unit; and the Greater Yellowstone Coordinating Committee, consisting of representatives from the National Park Service (Grand Teton and Yellowstone National Parks, John D. Rockefeller, Jr., Memorial Parkway), the U.S. Fish and Wildlife Service (National Elk Refuge, Red Rock Lakes National Wildlife Refuge), and the U.S. Forest Service (Beaverhead-Deerlodge, Bridger-Teton, Caribou-Targhee, Custer, Gallatin, and Shoshone National Forests). It was planned and organized by the Resource Information Office of the Yellowstone Center for Resources, in conjunction with other YCR staff and a program committee of independent scholars and non-Yellowstone federal agency personnel. The proceedings should be available sometime next year.

YS

Opening night in the Map Room, with emergency lights during the power outage.

U.S. Forest Service Chief Dale Bosworth gave the opening keynote.

FROM THE ARCHIVES

"Whether or not I shall be able to save them [the park's bison] remains a doubtful problem. The forces of nature and the hand of man are alike against them, and they seem to be struggling against an almost certain fate."

—Captain George S. Anderson, 1896
Acting Superintendent of Yellowstone National Park

YNP, PHOTO ARCHIVES, YELL #118718

C.J. (Charles Jesse) "Buffalo" Jones, then Yellowstone game warden, with a domestic cow and two bison calves in the Mammoth Hot Springs area of Yellowstone National Park in the early 1900s. These calves may have been among those in the captive herd that received milk from a domestic cow rather than a bison. Brucellosis, caused by the bacterium *Brucella abortus,* may be transmitted through oral contact with the afterbirth or milk from an infected cow.

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NPS/JIM PEACO

Hayden Valley in Yellowstone National Park.


CHARLES R. PRESTON

Site of proposed Copperleaf development in Wyoming.

In this issue

YS

Coming this winter, *Yellowstone Science* features the Panther Creek Volcano and microbial ecology.

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