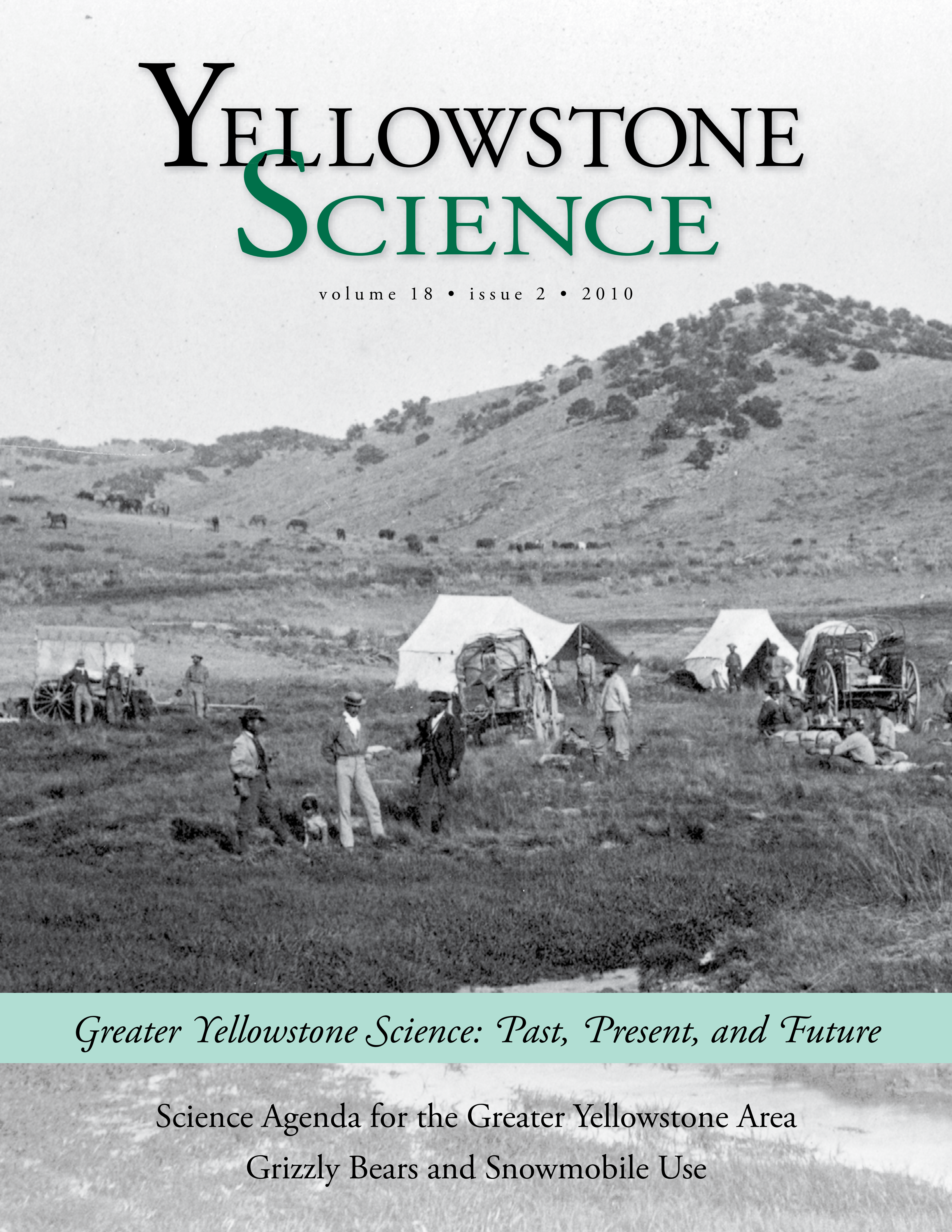
Yellowstone Science

volume 18 • issue 2 • 2010



Greater Yellowstone Science: Past, Present, and Future

Science Agenda for the Greater Yellowstone Area

Grizzly Bears and Snowmobile Use

LYNN WELLS

A grizzly sow and her cub emerge from their den and wander away amidst snowmobile tracks.

The *Aww* of Science

THIS PHOTO from Sarah Hegg's article of a grizzly sow and her cub is compelling for its *aww* factor, a reminder of why we live and work here. It is also an image of the resilience of nature that Paul Schullery talked about at a November 2009 science agenda workshop focused on climate change, land use change, and invasive species. Hegg's study provides an example of the tolerance that a bear can have for human activities. It also illustrates how scientific information can be used to manage a situation for the benefit of both wildlife and humans.

With all the uncertainty that climate change brings, getting scientific information that can inform decision making into the hands of managers is as relevant as ever. Managers and scientists agree that in the face of these global issues, cross-boundary partnerships and increased communication are critical to efforts to discuss management options in future scenarios. The November workshop was one of many current efforts to bring people together to develop viable, long-term, integrated approaches to ecosystem management. Tom Olliff et al. present some of the results from that workshop here as a Greater Yellowstone Area Science Agenda.

As Schullery reminds us in his talk, crises in the Yellowstone area have come and gone. Climate change opens a new chapter and offers new opportunities for mucking around, adaptive management, and plain old observation. How we make these choices will frame how historians speak of us.

Please join us at the 10th Biennial Scientific Conference on the Greater Yellowstone Ecosystem, *Questioning Greater Yellowstone's Future: Climate, Land Use, and Invasive Species*, October 11–13 at Mammoth Hot Springs, for lively discussions on these topics. For more information go to: www.greateryellowstonescience.org/gyesciconf2010.

We hope you enjoy the issue.

Hayden Survey camp on the large southwest arm of Yellowstone Lake in what would become Yellowstone National Park, 1871. USGS photo.

Yellowstone Science

a periodical devoted to natural and cultural resources

volume 18 • issue 2 • August 2010

Cover photo:

Camp of Hayden Survey party at Three Springs, Yellowstone National Park. USGS photo by William Henry Jackson, 1871.

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News & Notes

Endangered Species Act Protections Reinstated for Northern Rocky Mountain Wolves


Gray wolves in the northern Rockies continue to be protected.

The US Federal District Court in Missoula, Montana, issued an order on August 5, 2010, which reversed the delisting of the Northern Rocky Mountain Distinct Population Segment of the gray wolf. Wolves are again considered endangered throughout the Distinct Population Segment except where they are classified as experimental populations in southern Montana, Idaho south of Interstate 90, and all of Wyoming. While the delisting has been vacated, reinstated rules provide the states with authority for many management decisions.

Within the experimental population areas of Montana and Idaho and on the Wind River Tribal lands in Wyoming, states and tribes with approved wolf management plans can again operate under the 2005/2008 experimental population rules and lead wolf management within the boundaries of their respective state or reservation through interagency cooperative agreements. The US Fish and Wildlife Service (USFWS), state, tribe, or their agents may take wolves when circumstances warrant. In addition, anyone may legally shoot a wolf in the act of attacking livestock on their private land or grazing allotment, and anyone may shoot a wolf chasing or attacking their dog or stock animals anywhere except national parks. In certain circumstances these rules allow lethal removal of wolves where they are a major cause of the inability of ungulate populations or herds to meet established state or tribal population or herd management goals.

This USFWS and tribal management authority allows for great flexibility and timely response to local conditions. Additional take in the experimental population areas not specifically authorized by the 2005/2008 experimental population rules requires additional authorization.

Within Wyoming, the USFWS continues to be the lead management agency for wolves and the original 1994 experimental population rule still governs wolf management. The only exception is on Wind River Tribal lands, because those tribes have a USFWS-approved wolf management plan.

New Researcher Check-in Program for Yellowstone

This year, Yellowstone National Park Research Permit and Science Communication office staff worked closely with Greater Yellowstone Science Learning Center (GYSLC; www.greateryellowstonescience.org) contractors to develop a web-based application designed to enhance communication between park staff and permitted researchers. Until January 2010, park researchers were required to contact each ranger district they were working in by phone to report on their field research plans. The park has many ranger districts or subdistricts, sometimes requiring researchers to call up to 11 ranger stations. To streamline this process, the park took advantage of the GYSLC's flexibility and integrative functions and began developing an internet-based tool to collect concise trip information and help park research staff communicate with rangers through a single hub.

The new check-in website allows researchers with permits in the park to post trip itineraries. The system requests specific information from the researchers (number in party, vehicle description, phone numbers, dates, research discipline, and field activities). As researchers select their permit number, drop-down lists are generated to reduce the amount of data entry. The resulting database enables administrative users to query the system for trips by date and create custom reports for each ranger district. The park's research permit staff hope to further develop the check-in website to allow researchers to add information to their trip itineraries post-trip, such as the equipment left in the field and the type and amount


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Yellowstone National Park's summer bison population estimate is 3,900.

of collections made, as well as enable staff to query research activities by space and time using GIS software.

Summer 2010 Bison Population Estimate

Yellowstone National Park's summer bison population estimate is 3,900. The count is based on a series of aerial surveys conducted in June and July. This year's calf production is 15% of the population. Fifty-six percent of the bison are distributed across the northern range, while the remainder are found in the central interior herd.

The population was estimated at 3,300 bison last summer, and at 3,000 adult and yearling bison in late winter. The peak population estimate of 5,000 bison was recorded in summer 2005. The observed rate of population change this past year is within the natural range expected for wild bison. The rate at which wildlife populations increase is a result of the combined effects of reproduction and mortality, and is heavily influenced by the age structure of the population and habitat conditions encountered over the course of time.

This population estimate is used to inform adaptive management strategies under the Interagency Bison Management Plan (IBMP). Specific management actions may be modified based on expected late winter population levels as corroborated by the summer population estimate. The IBMP is a cooperative plan designed to conserve a viable, wild bison population while protecting Montana's brucellosis-free status. The cooperating agencies operating under the IBMP are the National Park Service, the US Forest Service, the Animal and Plant Health Inspection Service, the Montana Department of Livestock, the Montana Department of Fish, Wildlife and Parks, the InterTribal Buffalo Council, the Confederated Salish Kootenai Tribes, and the Nez Perce Tribe. More information on the IBMP can be found at www.ibmp.info.

Lehnertz Named Pacific West Regional Director

National Park Service Director Jonathan Jarvis named Yellowstone National Park Deputy Superintendent Christine (Chris) Lehnertz as the Service's Pacific West regional director, responsible for 3,000 employees and 58 national parks visited by more than 56 million people annually. Lehnertz will lead one of seven National Park Service regions.

Lehnertz served as deputy superintendent of Yellowstone National Park starting in 2007, where she was responsible for all aspects of human resources, budget, and natural and cultural resource management and science programs. She also had oversight of more than 100 park concessioners with $100 million in annual gross revenue and ensured that the park's large portfolio of construction and maintenance projects complied with the National Environmental Policy Act and the National Historic Preservation Act.

Lewis Receives 2010 Rachel Carson Award

Yellowstone National Park Superintendent Suzanne Lewis was honored in May 2010 by the National Audubon Society for her contributions to conservation. Lewis received the 2010 Rachel Carson Award at a ceremony held as part of the society's annual Women in Conservation Luncheon, in New York. She is the first National Park Service employee to receive the award. The National Audubon Society began recognizing outstanding women in conservation with the Rachel Carson Award in 2004. The award is named in honor of Carson, whose book *Silent Spring* drew international attention to the damage caused by pesticide use and who is credited with helping launch the modern environmental movement.

Lewis began her National Park Service career as a seasonal park ranger at Gulf Islands National Seashore in 1978. She has served in a variety of increasingly responsible positions including an international assignment to Haiti, acting superintendent at Christiansted National Historic Site and Buck Island Reef National Monument in the US Virgin Islands, superintendent of Timucuan Ecological and Historic Preserve in Florida, superintendent of Chatahoochee River National Recreation Area in Georgia, and superintendent of Glacier National Park, Montana. Lewis was appointed to Yellowstone in February 2002 and is the park's first female superintendent.

COURTESY GLENN PLUMB

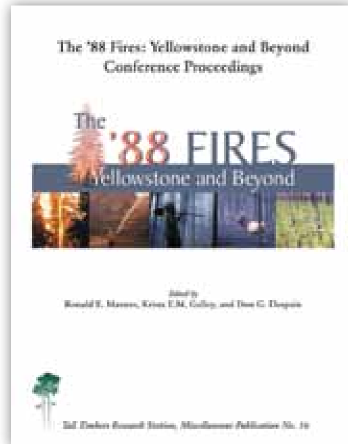
Aquatic and Wildlife Resources Branch Chief Glenn Plumb is moving on.

Plumb Accepts NPS Wildlife Program Manager Position

After 12 years at Yellowstone, Glenn Plumb will take on new duties in mid-October as the National Park Service Wildlife Program Manager located in Fort Collins, Colorado. This is a new program to address key wildlife issues across the NPS system, such as migration, population management, energy development, and climate change adaptation. At Yellowstone, Glenn served as Supervisory Wildlife Biologist, Quantitative Ecologist, Natural Resource Branch Chief, Aquatic and Wildlife Branch Chief, and most recently as Acting Chief of Yellowstone Center for Resources. In 2006, Glenn was awarded the NPS Director's Award for Professional Excellence. He also served as Chair of the US Animal Health Association Committee on Brucellosis, a member of the DOI Strategic Science Working Group for the Deepwater Horizon oil spill, and a consulting brucellosis scientist with the US State Department Bureau of International Security and Nonproliferation/Cooperative Threat Reduction.

10th Biennial Conference Registration Available

Registration for the 10th Biennial Scientific Conference on the Greater Yellowstone Ecosystem, "Questioning Greater Yellowstone's Future: Climate, Land Use, and Invasive Species," is now open. The conference will be held in Mammoth Hot Springs, Yellowstone National Park, October 11–13, 2010. Special rates are available for students, conference participants, and single day admission. A preliminary agenda, information about the keynote speakers, and other materials are available on the conference website, which can be accessed at www.greateryellowstonescience.org/gyesciconf2010. Reservations for the conference hotel are also being accepted through the website.



'88 Fires Conference Proceedings Available

In late spring, the conference proceedings for the 9th Biennial Scientific Conference on the Greater Yellowstone Ecosystem, "The '88 Fires: Yellowstone and Beyond," were published. The conference commemorated the 20th anniversary of the 1988 fires in Yellowstone and the northern Rocky Mountains. Public land managers, scientists, and partners celebrated and shared lessons learned from past and present fire management practices and scientific research that serve as a foundation for the future of fire management. Electronic copies of the proceedings composed of short and extended abstracts can be accessed at www.nps.gov/yell/naturescience/conferencearchive.htm. You may also request a hard copy by emailing yell_science@nps.gov. YS

NPS/HFC COMMISSIONED ART COLLECTION, ARTIST GIL COHEN

Shorts

DOUG MCWHIRTER

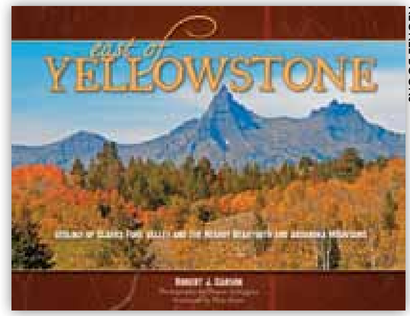
East Rosebud is the major drainage in Montana that Clarks Fork Canyon and Rock Creek sheep migrate through on their way to Yellowstone National Park.

Clarks Fork Bighorn Sheep

McWhirter, D. 2009. Clarks Fork Bighorn Sheep Study Final Report. June 2009. Wyoming Game and Fish Department. http://gf.state.wy.us/wildlife/sheep/ClarksForkSheepFinalReport_E-Mail.pdf

The bighorn sheep inhabiting the Absaroka and Beartooth Mountain Ranges near the Wyoming-Montana boundary are descendants of a native population that was never extirpated or supplemented with introduced sheep. McWhirter identified and monitored four population segments (Clarks Fork Canyon, Pilot Peak, and Yellowstone National Park in Wyoming, and Rock Creek in Montana) from December 2004 to July 2007. Data collected from 19 sheep (11 rams, 8 ewes) that were radio-collared for the project indicate linkages between the segments. Although sheep in the Yellowstone National Park segment (those residing from Mount Norris to Amphitheater Mountain) appeared to be relatively sedentary, ram movements connected all four segments and ewe movements connected the Rock Creek and Pilot Peak segments. Perhaps the most significant finding was the 60-mile, extremely circuitous migration of rams from the Clarks Fork Canyon into the Cache Creek drainage of Yellowstone National Park. Survey information obtained during the study revealed that although sheep numbers on the Rock Creek, Montana, winter ranges were lower than in past years, overall sheep numbers in the Absaroka Mountains were among the highest recorded.

—Doug McWhirter,
Wyoming Game and Fish Department



KEOKEE BOOKS

East of Yellowstone

Carson, R.J. 2010. *East of Yellowstone: Geology of Clarks Fork Valley and the Nearby Beartooth and Absaroka Mountains*. Sandpoint, ID: Keokee Books. 184 pgs., softcover, $25.00.

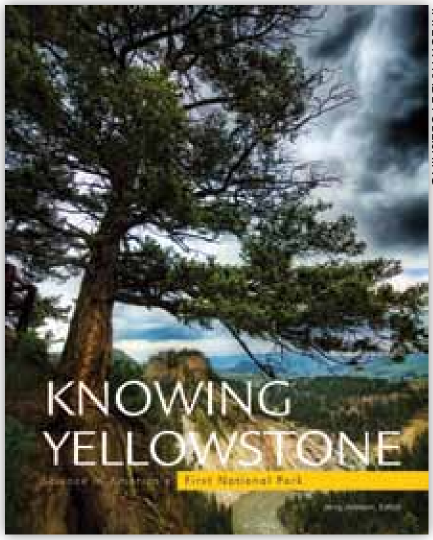
In *East of Yellowstone: Geology of Clarks Fork Valley and the Nearby Beartooth and Absaroka Mountains*, geologist and professor Bob Carson interprets the geologic story of the Clarks Fork Valley east of Yellowstone National Park, including the nearby Beartooths, Absarokas, and Bighorn Basin of Wyoming and Montana. *East of Yellowstone* includes five road logs or tours of the Beartooth and Chief Joseph highways and adjoining roads to vistas of mountains and scenic valleys. Through these tours, Carson reveals the remarkable geologic history behind the enigmatic Heart Mountain detachment, Absaroka volcanics, and Pleistocene glaciation. The book includes 10 topographic maps with trails outlined, seven color geologic maps, numerous photos, historical sketches, and tips for recreation.

—Keokee Books

Knowing Yellowstone

Johnson, J., ed. 2010. *Knowing Yellowstone: Science in America's first national park*. Lanham, MD: Taylor Trade Publishing. 240 pgs., $19.95, paperback.

Knowing Yellowstone: Science in America's First National Park tells the stories of how scientists from an array of disciplines conduct their work in and around Yellowstone National Park. The book reveals the exciting work of field research and helps readers understand how and why scientists study complex natural systems like the Greater Yellowstone Ecosystem. *Knowing Yellowstone* covers 10 disciplines from underwater geology to megafauna to social science in chapters written by leaders in their field.



TAYLOR TRADE PUBLISHING

Many of the authors will be familiar to readers of *Yellowstone Science*. Lisa Morgan and Pat Shanks provide an account of compiling the most complete underwater geologic map of Yellowstone Lake that highlights the technology and perseverance needed for such a large-scale undertaking. Scott Creel presents the science of nuanced effects of wolf reintroduction on elk in an accessible way. Alexander Zale's chapter on the wide range of capturing, tagging, and tracking fish in the region demonstrates how flexible and skilled fisheries biologists need to be as they practice their craft. All of the authors spend enormous amounts of time in the park's backcountry taking samples, tracking animals, talking to people, and collecting data. Their energy is apparent in their writing and the enthusiasm they have for their work.

Two themes emerge from this guide to fieldwork: the role of climate change and the impact it has and will have on the resources of the region, and the importance of technologies like GIS (geographic information systems) and global positioning to modern ecological science. Most of the work detailed in the book uses those complementary technologies for data collection and analysis. This book puts readers in the field with scientists in one of the great outdoor laboratories on Earth.

—Jerry Johnson

DNA Genotyping Suggests Recent Brucellosis Outbreaks in the Greater Yellowstone Area Originated from Elk

Beja-Pereira, A., B. Bricker, S. Chen, C. Almendra, P.J. White, and G. Luikart. 2009. DNA genotyping suggests that recent brucellosis outbreaks in the Greater Yellowstone area originated from elk. *Journal of Wildlife Diseases* 45(4): 1174–7.

Identifying the source of disease outbreaks is especially difficult for pathogens like *Brucella abortus* that infect multiple wildlife species. The authors, who genotyped 10 highly variable DNA markers in *B. abortus* isolates from 10 bison, 25 elk, and 23 cattle in the Greater Yellowstone Area from 1992 to 2003, found that those from cattle and elk were nearly identical but highly divergent from bison isolates, and that the genotypes from elk remained similar across time and geographic locations. The data, which suggest that elk rather than bison are most likely the origin of recent outbreaks of brucellosis in Greater Yellowstone cattle, are consistent with the fact that elk comingle with cattle more often than do the wild bison, which have been managed to prevent dispersal outside established conservation areas. The relatively high genetic divergence between elk and bison isolates also suggests that *B. abortus* might not be exchanged extensively between the two species, though additional sampling and genotyping are required to assess this issue. The study illustrates the potential for genetic markers to assess the origin and spread of disease outbreaks, which are increasing worldwide as a result of habitat fragmentation, climate change, and expansion of human and livestock populations.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A recent study suggests elk rather than bison are most likely the origin of recent outbreaks of brucellosis in GYA cattle.

YS

A grizzly bear sow with three cubs defends a carcass from wolves on Alum Creek in Hayden Valley, Yellowstone National Park, July 2010. The presence of these two Greater Yellowstone area species is a reflection of changing management practices, public values, and scientific knowledge.

Greater Yellowstone Science: Past, Present, and Future

Presented at the Greater Yellowstone Area Science Agenda Workshop, Montana State University, November 4, 2009

Paul Schullery

Even though my friend John Varley told me I was being invited to talk this evening because you guys would need something light after a day of heavy scientific lifting, I still feel very honored to get to talk to you. A day like today, listening to all of you, is exciting for me even if so much of the news about global change and exotic species seems to be lousy. But the honor for me remains. Besides, when it comes to lightness I suspect that I will, in fact, succeed beyond John's wildest expectations.

Greater Yellowstone science is fascinating. Of course many of us are convinced that we are fascinating individually, but we are even more so as a group. To make that case, I'm going to pretty much ignore the administrative and legislative history that I could have easily filled 30 minutes with, and follow a few historical threads that suggest the often unappreciated richness of science's place in Greater Yellowstone during the past 137 years. I should also assert, just in case someone here is interested in pursuing the matter, that science's historical place in Greater Yellowstone is ripe for study. The scientific side of Greater Yellowstone history deserves deep interdisciplinary examination, not only by historians but by others, including sociologists and anthropologists. Maybe even a few psychiatrists wouldn't hurt. What I would like to do tonight is give you a few examples of why I believe the subject is so worthy of scholarly and popular attention.

A few years ago a forest service friend—a scientist—and I were comparing notes on the research traditions in our respective agencies. I explained that for much of the history of the National Park Service, our agency's researchers have worked directly beneath park managers in a single chain of command. This, I suggested, led to a tradition of kneejerk skepticism among park critics and the media, who habitually branded park service science as tainted because our scientists were under the thumb of managers whose motivations were openly policy driven—and probably evil as well.

My forest service friend explained that by contrast he and his forest service science colleagues operated in an administrative environment that was bureaucratically distinct from management. This separation, he felt, gave forest service scientists a fine sense of professional purity. Church and state were clearly separated. He then explained that while this setup kept forest service scientists happily aloof from the day-to-day murkiness of real-world management, it also meant that managers just ignored them. We were awestruck at how two such different systems achieved such qualitatively similar results.


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More than 90 topical experts, agency and non-governmental scientists and managers came together to identify high-priority science needs for the next 10–20 years at the Greater Yellowstone Area Science Agenda Workshop, November 4–5, 2009.

Our little stereotyping exercise only begins to suggest the complications of science in a social and political arena as complex as Greater Yellowstone. The forest service and the park service are only two of the many institutions and agencies in Greater Yellowstone that engage in the scientific enterprise. Each of these numerous organizations has what, for want of a better term, we tend to think of as its own culture.

The scientific side of Greater Yellowstone history deserves deep interdisciplinary examination, not only by historians but by others, including sociologists and anthropologists. Maybe even a few psychiatrists wouldn't hurt.

Not surprisingly, each culture has not only generated its own style of practicing science, but its institutional direction has naturally tended to select for scientists who were most comfortable with that style. (I confess that I use the word "style" here to avoid using words like "values" and "ideals," which may distract me from getting on with my point.)

And there are plenty of styles to choose from. The histories of the park service and forest service remind us of the harsh historical reality that these cultures can diverge very fast. Until relatively recently, long-time observers of some of Yellowstone's famous controversies could track the genealogy of the various institutional positions of agencies, university departments, and advocacy groups back through three or more generations. The apparent heritability of scientific viewpoint is only one of many things that make the saga of Greater Yellowstone science so worthy of study.

About 20 years ago, when former Yellowstone Superintendent Bob Barbee, John Varley, and I were dreaming up the quarterly magazine *Yellowstone Science* and our biennial scientific conference series, one of our fondest ambitions was that these two initiatives would help awaken the scientists who live and work in this region to a heightened sense of themselves as members of a research community. Back then my abysmal failure to attract many state or forest service researchers to write for *Yellowstone Science* or to participate in our conferences made me wonder if we were a community after all. That is why after a day at a meeting like this, I can hardly express how grateful I am, and how grateful you all should be, to live in a Greater Yellowstone where a workshop like this one just seems like the obvious right thing to do. It wouldn't have been nearly so obvious just one short generation ago. Those who remember the political catastrophe of the infamous *Vision* document, whose twentieth anniversary we are pointedly *not* celebrating this year, will know what I mean.

Dark memories aside, I have arrived at the first historical thread in the saga of Greater Yellowstone science, the very old idea that there actually *is* something called Greater Yellowstone. Science in fact gave us our first clues that we needed to think big about this region.

From 1872, when Yellowstone National Park was established, until the early 1900s, the people who thought hard about the park's ultimate meaning and eventual purposes were unconstrained by much pre-exisiting regional bureacracy, which is to say that they were not much hampered by a boundary mentality. Many of the best of these thinkers didn't even live here, and were free to see the region *as* a region. These people may never have heard the word "ecology," but they routinely thought in ecosystem terms. George Bird Grinnell, the Yale-trained zoologist who was perhaps the park's most visionary and effective national defender until at least 1900, certainly lacked our terminology, but he had his own words that worked just as well. Grinnell was especially fond of using the term "reservoir" to characterize the role that the park should play in the region.

THE MURIE CENTER ARCHIVES/2010.6.1

Brothers Adolph (in the Tetons, c. 1928, a few years before his coyote study in Yellowstone) and Olaus (not pictured) Murie were well-known, influential Greater Yellowstone area scientists.

FROM *DIARY OF THE WASHBURN EXPEDITION TO THE YELLOWSTONE AND FIREHOLE RIVERS IN THE YEAR 1870* (c.1905) BY N.P. LANGFORD

Naturalist and conservationist George Bird Grinnell, an important defender of Yellowstone National Park in the late 1800s and early 1900s, was an early proponent of ecosystem thinking in Greater Yellowstone.

For example, he believed that the park's forested landscapes, left unharvested, moderated the runoff of snowmelt and precipitation, making the park a valuable servant of a host of agricultural and urban interests far downstream. Some of you will recognize that this same landscape-as-water-reservoir argument also helped protect the Adirondacks of upstate New York at that same time.

For another example, Grinnell saw the park as a reservoir of wildlife. As long as the summer ranges and calving grounds of the park were protected, the park would provide a steady, perpetual flow of game animals onto surrounding lands.

There's no overstating the extent to which the park's early champions thought beyond the boundaries. They perceived the seasonal and annual flows of natural forces up and down these long drainages. For many of them, the creation of the nation's first forest reserves adjacent to the park in the 1890s was simply a *defacto* extension of the park to further improve the efficiency of the living reservoir system that was an as-yet un-named *Greater* Yellowstone.

But ultimately, other efficiencies conflicted with this open-minded perspective. At the dawn of the twentieth century, the progressive era, so vividly symbolized by Grinnell's close friend Theodore Roosevelt, promoted what historian Samuel Hays referred to as a national gospel of efficiency, a gospel that inherently favored the quantifiability of natural resources over the less formally measured qualities of actual nature. As Gifford Pinchot's new US Forest Service, founded in 1905, took hold, the human-drawn boundaries between the park and the surrounding forests hardened. Soon the only talk of flowing resources involved repeated campaigns by agricultural interests to construct dams on many of the park's rivers to irrigate Montana wheat and Idaho potatoes.

By 1919, when the term Greater Yellowstone was first coined in print, it was already too late to honor Grinnell's ideals in a landscape of ever more impenetrable boundaries. Several decades would pass, and American attitudes toward nature would undergo dramatic changes, before the scientific and management realities of grizzly bears, elk, and fire would literally and permanently put Greater Yellowstone back on the map.

But the point is that it was science, even the fairly limited science of Gilded Age America, that launched those first tentative ideas of this thing called Greater Yellowstone, and it would be science that would finally bring Grinnell's ideal back to its current eminence.

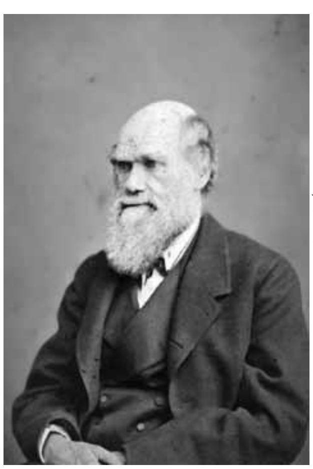
A second historical thread paralleled this one, and it is the extent to which many scientists have openly engaged in the politics of Greater Yellowstone. One of science's great and essential internal debates is over the proper role of the scientist in public dialogues over policy and management; as I mentioned earlier, scientific credibility is closely tied in the public mind to scientific neutrality. And yet from the time of Yellowstone's creation in 1872 on, generations of prominent scientists have been outspoken in advocating not only a scientific perspective on the park, and not only the preservation of Yellowstone's wildness, but also the specific policies that they believed would work best. These people amount almost to a roll call of Greater Yellowstone's most famous scientific voices, from Ferdinand Hayden and Arnold Hague, to Charles Adams and George Wright, to Adolph and Olaus Murie, to John and Frank Craighead, to a growing number of others since then. They did not always agree among themselves, but they were willing to put their professional reputations on the line for Yellowstone and, because so many of them thought and worked across boundaries, for Greater Yellowstone.

Those of you who saw Ken Burns' big film on the national parks in September must have noticed the unusual extent to which scientists were even cast as heroes. My own favorite example of such scientific advocacy made it into the film. It was National Park Service biologist George Melendez Wright's eloquent recommendation, in 1933, "that the rare predators shall be considered special charges of the national parks in proportion that they are persecuted everywhere else." And only a few years later, Aldo Leopold himself recommended the restoration of wolves to Yellowstone. Anyone who knows much about the history of land management in the American West will agree that science, at least wildlife science, has rarely gotten more socially subversive than these statements by Wright and Leopold.

But rather than quoting a bunch more historic scientists, I think you only need to hear from one—one that you may have never heard of, a geologist named Theodore Comstock. Comstock visited and studied the park at its beginning, in 1873, with the Jones Expedition, and published several foresightful papers that reached far beyond his specialty. We ought to name a mountain or a microbrewery or something for this guy.


COURTESY OF THE GEORGE WRIGHT SOCIETY

George Wright, pioneering National Park Service biologist and a leading force in the development of NPS wildlife management policy, during a survey of trumpeter swan nesting sites in Yellowstone in the early 1930s.


SMITHSONIAN INSTITUTION LIBRARIES/SIL14-D1-09, PHOTO BY ERNEST EDWARDS, LONDON

Yellowstone National Park was established during the early social and scientific turmoil of the Darwinian revolution. Since then, the impact of Darwinian thought has increasingly influenced thinking about the roles and values of national parks throughout the world.

Remember that Comstock worked and wrote in the fierce propwash of the Darwinian revolution. We can barely imagine the mood of his times. The publication of both *On the Origin of Species* and *The Descent of Man* were current events to him, and his awareness of their sudden impact on science and society is reflected in this plea for the preservation of Yellowstone's authentic wildness—a plea so modern that one of us might say it at this meeting.

> *Momentous questions are now agitating the scientific world, calling for experiment and observation which are daily becoming less possible, owing in a great measure to the obliterating influence of modern civilization. Thus it would almost seem that the present difficulties in the way of the solution of many questions, bearing upon the process of natural selection, will soon become insurmountable if some means are not employed to render more practicable the study of animals in a state of nature.*

NPS HISTORIC PHOTO COLLECTION/HPC-000345

Scientific researchers, such as members of Ferdinand Hayden's surveys, pictured here in 1872 in what would become Grand Teton National Park, have been aggressive and effective advocates of the scientific importance of the Yellowstone National Park area.

Of course Yellowstone provided those means, and Comstock, perhaps more fully than Hayden or any of the other early scientific pioneers of the region, articulated the case for the park as an unparallelled and perpetual opportunity to learn about wild nature.

But Comstock had more. In what seems to me prescience bordering on prophesy, Comstock sensed and predicted the breadth of opportunities the park would some day provide for study, in what even today still seem to be nearly fabulous realms. The first time I read this 136-year-old statement, it gave me chills.

> *There is one young but active science—microscopy,—which has as yet scarcely entered this field, but which, I firmly believe, will discover within the limits of the Park most valuable treasures. The act of Congress providing for this reservation insures the preservation of the greater portion of whatever may be available for this purpose.*
>
> *Among the most interesting objects for the microscope, will be found the colloidal and filamentous products of the hot springs, the minute vegetable and animal life of both hot and cold springs, the animal and vegetable parasites, and the numerous crystalline deposits of the hot springs and geysers.*

So with his phrase "most valuable treasures" haunting my historical consciousness, I will let Comstock speak for all of those later scientist-advocates who have fulfilled his dream so magnificently, and move along to one more historical thread in the story of Greater Yellowstone science, the least considered but maybe the most far-reaching of all.

In the early days of NASA, when the Mercury spacecraft was unveiled to a public conditioned by Hollywood's fanciful portrayals of shiny and graceful rocket ships, the reaction was predictably negative. People thought this Mercury thing looked clumsy, like a garbage can, and, I suppose, a little too much like a coffin. But John Yardley, the McDonnell Aircraft engineer who had overseen the creation of the Mercury capsule, had all the answer anyone needed. He said, "Pretty is what works."

Certainly the idea that beauty can be a product of function is not new. For millennia we have admired finely made devices, whether a watchwork or a weapon, in which something's function was at least in part a result of its being beautifully made—a quality that was easily translated in our minds to being, just, beautiful. If you want a magnificent illustration of this historical reality, go down the street to the American Computer Museum—you should go there anyway, because it's a fascinating place—and spend a few minutes staring at their replica of the ancient Antikythera mechanism.

But long before the rise of the modern scientific sensibility, the beauty of the natural world—the very Creation itself—was often perceived as a function of its imagined mechanical perfection, and of course of the beautiful wisdom of the Creator. But the application of this notion, that pretty is what works, and that what works could be pretty by *virtue* of how well it works … well, the application of that notion to ecological process still had something historically fresh about it, and something revolutionary, when it was applied in the wild setting of Yellowstone and the other national parks.

It has taken American society and American government more than a century, but we have come to realize how profoundly right Comstock was, that the highest value that a park has for us, whether we are scientists or artists or just regular visitors, is in the authenticity of its wildness—in the rare opportunity it gives us to learn and be awed by the way that nature makes its own decisions. And here is the delightful surprise of a new social and even aesthetic role for science. Science, by providing a yardstick to the wildness and consequent authenticity of a landscape, in effect gives us permission to admire things we used to be shocked by. It exposes us to a new, broader, and far richer idea of beauty.

We have had to overcome a lot of cultural, emotional, and religious conditioning to get here. But once that perceptual door was opened and we stepped through to the broader view, we were overwhelmed by the extravagantly perfect beauty we now choose to find in Yellowstone's wildness—from firestorms to debris flows to predation to winterkill to the unexpected ecological elegance of a buffalo chip.

What an ironic and amazing development—that science, so valued for its dispassion and supposed freedom from the subjective, should serve us as the only sure guide to the most emotional end of the spectrum of experiences we find in Yellowstone. Science empowered us to discard the refined artificiality that characterized earlier notions of the beauty of nature. Science said to us, if pretty is what works, then Yellowstone is indeed beautiful. Those of us who have embraced this ideal of wild authenticity as the guiding principle by which we should judge the success of our management of places like Yellowstone are now largely dependent upon science to lead us to wonder and beauty. I like to think that this would make Theodore Comstock very happy.

Let me wrap this up by invoking all this history in the cause of the subject of this meeting. Today we are both burdened and invigorated by a powerful sense of crisis, and I can tell you that in the history of the national parks, crisis is the highest form of peril. Crisis loosens *all* the cannons. Crisis by its very nature, and by the tone of its times, stirs panic and generates a vague but mighty need for urgent action if not desperate measures. Crisis does these things because the wise and crafty among us also recognize that crisis is a rarified form of opportunity, when all stakeholders proclaim that their standing agendas are precisely the answer.

But crisis is almost a steady state here. Surely, 136 years ago, when Theodore Comstock said that "Momentous questions are now agitating the scientific world," it was with a precisely accurate sense of the great crisis of his time. In some respects, Yellowstone has always made us feel, as historian Aubrey Haines put it in describing the park's management situation 40 years ago, that we stand "at a crossroad, faced by fearful decisions." There are always crossroads, always fearful decisions.

In that spirit, I would like to offer a few of the sweeping generalities that historians are so fond of, to characterize how Yellowstone has usually gone about its business at these crossroads, and perhaps even to suggest how we, today—though we are of course much smarter now, right?—must still operate.

First, pretty much every generation of us since Comstock's time has contained a majority of people, even among the scientists, who were absolutely convinced that they knew all they needed to know in order to do right by Yellowstone.

Second, they were always wrong. This isn't to say that they always did the wrong thing. But it is to say that their confidence in doing whatever they did was rarely as warranted as they imagined. One of the most important contributions science has made to management dialogues around here in the past 30 years is to elevate the admission of uncertainty as a credible management stance. This workshop is all about uncertainty, and that's another reason it is hard to imagine it having happened very long ago.

Today we are both burdened and invigorated by a powerful sense of crisis, and I can tell you that in the history of the national parks, crisis is the highest form of peril.

Third, again and again, in our traditional confidence that nothing short of our own bold actions could "fix" whatever, on any given day, we felt was most importantly wrong with Yellowstone, we have sold nature short, underestimating its power, its resilience, its complexity, and its capacity to surprise us with unimagined consequences of our well-intentioned attempts to care for it.

Fourth, again and again, when the urge to step in and take Yellowstone's wildness in hand has pressed us hard and yet we have restrained ourselves, and have stood back and kept our hands off things, we have always learned more than we would have learned had we yielded to the temptation to meddle and tinker. And by the way, I am beginning to think nature was trying to do that we were so afraid of.

And last, the rate at which we are still peeling away the layers of Yellowstone's wild character, and still coming to terms with the demands that its authenticity makes on us, can leave no question that there are more,

One of the most important contributions science has made to management dialogues around here in the past thirty years is to elevate the admission of uncertainty as a credible management stance.

that this may be the most important lesson of the so-called "natural-regulation" era of ungulate management in the park over the past forty years. We now know infinitely, *pricelessly* more about the function of this wildland ecosystem than we would know if we'd spent those same forty years continuing to manipulate, suppress, harvest, herd, and otherwise engineer whatever probably many more, of Theodore Comstock's "most valuable treasures" still out there—still unrecognized—and still potentially vulnerable to the collateral consequences of our best intentions.

I don't intend the above generalities to advocate any exact position. I for one am inexpressibly grateful that we meddled enough to restore wolves, and have in other ways stepped in now and then when wisdom and opportunity provided what seemed at the moment like adequate justification. Sometimes maybe we do know what we're doing, and we do get it right. I mean only to point out certain powerful tendencies we have, and to remind us to be careful out there.

Science finds itself in a historic and extraordinary position here. Managers and the public have never before depended upon scientists so much, not only for direction on how best to ride out each new crisis, but even for guidance in how best to find the fulfillment that Yellowstone offers each of us in such individual and personal ways. Yellowstone and science are now full partners. The stakes are as high as they get. As my generation used to say, the whole world is watching.

And personally, I just can't wait to hear what you're going to tell them.

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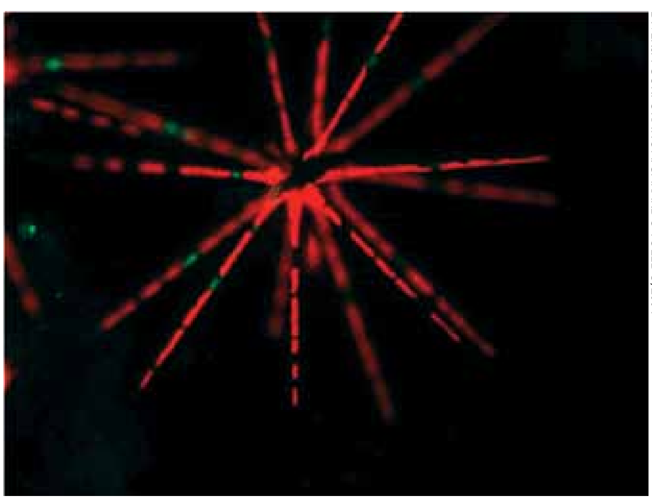
NPS/CHRISTIE HENDRIX

The culture of science has itself evolved during its long Yellowstone career, perhaps most notably in the diversity of researchers. Here, paleoecological researcher Cathy Whitlock examines a sediment core from a Yellowstone pond.



DIVERSA CORPORATION/GARARDO TOLEDO, 2004

The diatom *Asterionella formos,* a common species in many Greater Yellowstone subalpine lakes, is among the uncounted "valuable treasures" that Theodore Comstock predicted we would eventually discover here. This diatom from Yellowstone Lake was placed in culture at Diversa Corporation, San Diego, California. The red depicts the silica wall and the green are the chloroplasts.

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A Science Agenda for the Greater Yellowstone Area

Responding to landscape impacts from climate change, land use change, and invasive species

Tom Olliff, Glenn Plumb, Jeffrey Kershner, Cathy Whitlock, Andy Hansen, Molly Cross, and Scott Bischke

This paper presents a science agenda to support ecosystem management in the Greater Yellowstone area (GYA) over the next 10–20 years. The authors represent the planning committee of a November 2009 workshop at Montana State University entitled "Climate Change, Invasive Species, and Land Use Change as Drivers of Ecological Change in the Greater Yellowstone Area: A Workshop to Identify Priority Science and Implementation Strategies." The science agenda presented here reflects the input of approximately 40 invited land managers and subject area experts and approximately 50 other experts and interested-party observers at a workshop endorsed by the Greater Yellowstone Coordinating Committee.

This science agenda is intended to be a living framework that captures the state of knowledge in late 2009 with flexibility to incorporate continuing research and new information to support adaptive management. In general, a science agenda seeks to identify critical information gaps, steer the research community toward management needs, guide future science funding and permitting, and help managers understand science priorities that underpin management efforts. This science agenda focuses on three key drivers: climate change, land use change, and invasive species. We suggest that these are long-term issues for the GYA, and they also are consistent with the science framework of the National Ecological Observatory Network (NEON), a National Science Foundation project to collect data from across the United States on the impacts of climate change, land use change, and invasive species on natural resources and biodiversity. A transect from the Yellowstone northern range to Bozeman, Montana, has been identified as the core site for long-term NEON science in the Northern Rockies (NEON 2009). These drivers are acting independently and synergistically to alter North America, including the landscape of the GYA. Within the GYA we expect these changes to amplify in scope and ecological relevance over the next 20 years. If we are to manage resources effectively in the GYA, an informed understanding of how these drivers influence GYA wildlands will be critical.

Brief description of the GYA

The GYA covers roughly 18 million acres in three states (Wyoming, Montana, Idaho). The region is often described as the largest intact ecosystem in the lower 48 states, with Yellowstone and Grand Teton national parks at its core. Some 75% of this land area is in public ownership, including national parks, national forests, national wildlife refuges, and Bureau of Land Management land. One of the

SCOTT BISCHKE

Approximately 90 land managers and experts attended the November 2009 "Climate Change, Invasive Species, and Land Use Change as Drivers of Ecological Change in the Greater Yellowstone Area: A Workshop to Identify Priority Science and Implementation Strategies" at Montana State University.

important and unique components of the GYA is long-standing land-management partnerships. For example, the Greater Yellowstone Coordinating Committee was formed in 1964 with a Memorandum of Understanding (MOU) between the National Park Service and the Forest Service. By 2002, the partnership expanded to include the US Fish and Wildlife Service. Various Greater Yellowstone Coordinating Committee subcommittees, comprised of federal, state, and non-governmental organization staff, carry out the ongoing coordination of management activities in the GYA, including subcommittees for Aquatic Invasive Species, Clean Air, Fire Management, Fisheries, Hydrology, Recreation Visitor Use, Sustainable Operations, Weeds, and Whitebark Pine. Greater Yellowstone Coordinating Committee priorities include climate change, invasive species, and landscape integrity. Another example of a long-standing partnership in the GYA is the Interagency Grizzly Bear Study Team, which has been in place since 1983 to oversee conservation of the Yellowstone grizzly bear population. The Interagency Grizzly Bear Study Team operates under the guidance of the Yellowstone Grizzly Coordinating Committee, which includes representatives from the National Park Service, Forest Service, the US Fish and Wildlife Service, the Bureau of Land Management, and the US Geological Survey; state wildlife agencies from Montana, Idaho, and Wyoming; representatives of local governments from Idaho, Wyoming, and Montana; and representatives from the Shoshone Bannock and Eastern Shoshone tribes. These partnerships have provided valuable opportunities for coordinating resource management within the GYA.

The need for an ecosystem-level science agenda

In recent years, attention on ecological stressors in the GYA has shifted from local impacts associated with recreational use and land use practices to more regional issues associated with changing land use patterns and invasive species. In addition, recent scientific information suggests that climate change may have significant effects on the GYA. These larger-scale stressors are expected to impact both ecosystem dynamics and services in ways that are hard to predict based on our current understanding (Hansen and DeFries 2007; Bartlein et al. 1997; Shafer et al. 2001). Over the coming century, these changes may significantly alter the ecosystems we see today and lead to major disruptions of habitats and species (IPCC 2007; McWethy et al., forthcoming; Ashton 2010). Such potential changes present a profound challenge for natural resource managers in the GYA (Baron et al. 2009).

Increasing human population growth is likely to constrain both the movements of species and organisms and the adaptation strategies of managers (Heller and Zavaleta 2009). Since 1970, the human population in the 22 counties that compose the GYA has increased an average of 55% and the number of rural homes in that area has increased 350% (Hernandez 2004). Land use around the parks and wilderness areas in the GYA affects ecological function in many ways, including (1) changing ecosystem size, with

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Gallatin County (the Gallatin Valley south of Bozeman shown here) is located within the Greater Yellowstone area and is Montana's fastest growing county. Its growth rate is in the top 3% of all counties in the United States. Since 1990, Gallatin County's population has grown by 73%; its annual growth rate has accelerated since 2000. While the populations of cities in the county grew by 98% since 1970, the population in rural areas outside of towns has grown by 239%. (Data from the Sonoran Institute; www.sonoraninstitute.org.)

Nonnative lake trout (*Salvelinus namaycush*) were first documented in Yellowstone Lake during the summer of 1994. Lake trout are efficient predators that have been associated with substantial declines of native Yellowstone cutthroat trout (*Oncorhynchus clarki bouvieri*; smaller fish in photo removed from stomachs of lake trout). The National Park Service operates a lake trout suppression program to curtail negative consequences to Yellowstone cutthroat trout and the Yellowstone Lake ecosystem.


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implications for minimum dynamic area, species-area effects, and trophic structure; (2) altering flow of materials and disturbances into and out of reserves; (3) altering crucial habitats for seasonal and migration movements and population source/sink dynamics; and (4) increasing negative human impacts through poaching, exotic species invasion and spread, and disease (Hansen and DeFries 2007).

Some invasive species, including plants, aquatic species, and wildlife pathogens, are likely to thrive under the conditions brought on by climate change and land use change, and bring impacts of their own. Broadly, one of the first-order casualties of invasive species will likely be changes in native biodiversity (Gude et al. 2007; Bartlein et al. 1997). For example, introduced blister rust (and native mountain pine beetle) have killed more than half a million whitebark pine trees in the GYA (Forest Service 2008). Aquatic nuisance species such as New Zealand mudsnails are spreading into GYA waters (McMahon et al. 2009) along with introduced pathogens such as whirling disease (Koel et al. 2006). Bivalves such as zebra and quagga mussels may also spread into GYA waters (IEAB 2010). Exotic lake trout have taken over Yellowstone Lake and caused dramatic declines in Yellowstone cutthroat trout (Varley and Schullery 1995; Gresswell 2009). Terrestrial systems have also suffered from invasions of spotted knapweed, nonnative thistle, and other plants that are threatening rangelands used by domestic and wild ungulates (Olliff et al. 2001). Future projections show yellow starthistle, cheatgrass, and spotted knapweed increasing their range in the GYA (Bradley et al. 2009).

Developing the agenda

This GYA science agenda is based on discussion and debate during the November 2009 workshop that reviewed the current understanding of how climate change, land use change, and invasive species are expected to drive GYA ecology over


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In August 2008, the National Park Service convened a scientific review panel to evaluate the park's lake trout suppression program and provide direction for future suppression and recovery activities. The review panel consisted of government, academic, and non-profit scientists. After an intensive, three-day review, Dr. Robert Gresswell of the US Geological Survey delivered the findings and recommendations to National Park Service personnel. Efforts such as this improve communication among stakeholders and assure that managers have the best available scientific information available to make decisions.

the next 20 years, and translated that state of knowledge into guidelines for near-term ecological research needed to manage GYA wildlands. In preparation for the workshop, we surveyed managers on their concerns regarding ecosystem management in the face of climate and land use change and invasion of nonnative species, and compiled an annotated bibliography on the three drivers and their current and potential impact on the GYA. At the workshop, plenary talks were followed by concurrent breakout sessions where three agency managers met with five to seven scientists to discuss each driver, the current issues, and the state of our knowledge, and to project consequences into the future. Interchange among breakout groups, other experts, and interested observers occurred during several combined sessions (fig. 1).

GYA science agenda: The central elements

Collaboration is the first fundamental element of the GYA science agenda. The GYA is uniquely organized for a viable, long-term, integrated approach to ecosystem management, as multiple, long-standing, collaborative partnerships exist between federal, state, tribal, and local government agencies, non-government organizations, and the general public. These existing collaborations will be cross-linked within the Great Northern Landscape Conservation Cooperative (LCC) recently mandated under Department of Interior Secretarial Order 3289 (Secretarial Order 3289). The goals of the Great Northern LCC align with this science agenda: LCCs seek to inform integrated resource management actions addressing climate change and other stressors within and across landscapes based on management-science partnerships. Thus the goal of the LCC program matches the goal of the GYA science agenda—to link science and conservation delivery. Similarly, each of the Greater Yellowstone Coordinating Committee partner agency strategic plans mandate collaborating across large landscapes and using the best available science to build a strong foundation for assessing climate change and its impacts, and continuing to improve the scientific basis for a unified approach to managing ecosystems (National Park Service, forthcoming; US Fish and Wildlife Service 2009; Forest Service 2010). By becoming integrated into the LCC program and linked to the respective agency strategic plans, the GYA science agenda will be immediately linked to the four key aspects of a successful program: mandate, funding, leadership, and communication.

Relevance is the second fundamental element of the GYA science agenda. We use the term relevance to mean the explicit linking of scientific knowledge to management action through an adaptive management framework. Adaptive management links management action to monitoring where the results from that monitoring are used to validate or potentially change the management action (Walters and

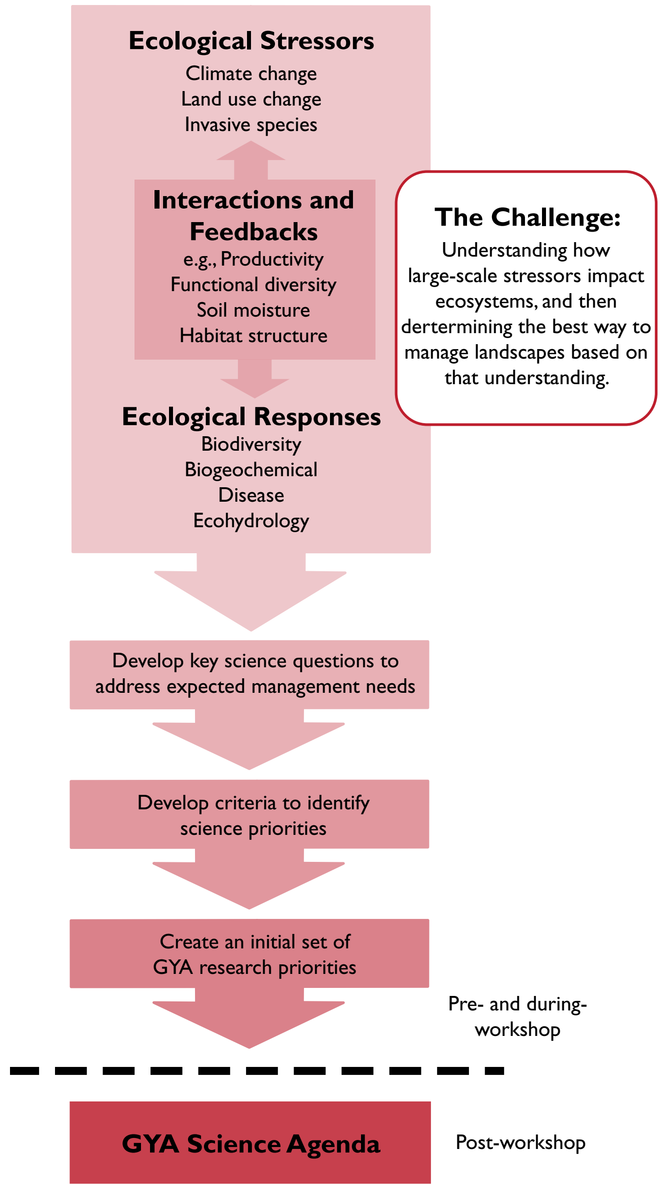

Figure 1. Conceptual model for development of the Greater Yellowstone area science agenda.

Holling 1990; Glick and Stein 2010). Scientists can help managers understand the linkage between management actions and outcomes by designing monitoring efforts that measure the outcomes. Monitoring and evaluation provide cross-over points for interaction between managers and scientists. The evaluation period in particular provides a venue for managers to petition scientists for more information, and for scientists to redesign data collection schemes based on the information learned to date. The key is to continue baseline inventory and long-term monitoring programs at timescales that allow for meaningful interpretation.

Synthesizing existing and new data into concise formats and actionable reports, including utilizing new information technologies, is needed to make information available to all user groups, but particularly managers making decisions. Concise information products need to be specifically tailored to meet managers' needs and integrate across topics of climate change, land use change, and invasive species. Additionally, it is critical to expand education and outreach efforts with the interested public through informal and formal education and interpretation programs.

Recognizing that an endless array of academically interesting science questions is possible, we developed criteria for deriving science priorities. These criteria helped us evaluate science relevancy to management decision making intended to protect the public trust. Our criteria for evaluating key science questions were:

(1) Does the research meet an immediate need of managers?
(2) Does the research provide forecasts that help managers deal with uncertainties and surprises?
(3) Does the research improve understanding of basic principles of interactions between human and natural systems?
(4) Does the research improve basic understanding of impacts of key drivers on key natural processes?

Using these criteria to qualitatively filter these issues, we developed a suite of GYA science priorities that were identified for each driver and then a set of questions that integrated multiple drivers (see sidebar).


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Rapid climate and associated ecosystem transitions in the Rocky Mountains have occurred in the past and will likely occur in the future. Projections include a higher frequency of large fires, longer fire seasons, and an increased area of the western US burned by fire.


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Sarcoptic mange (or "scabies") is an infectious skin disease caused by a mite. It was intentionally introduced in the western United States in the early 1900s as a biological control of wolf and coyote populations, and has been present in Greater Yellowstone coyotes ever since. It appeared in wolves outside of Yellowstone National Park in the early 2000s and now affects wolves inside the park.

The final step is to identify the highest priority science questions by key drivers. We anticipate working closely with members of the Great Northern LCC and other conservation partners to develop a framework for conservation action in the near future. This framework will help us prioritize the most important questions and allow for key research to be initiated. We anticipate that we will customize the framework for the GYA to take advantage of local opportunities for funding and research collaboration.

Linking science with management

There have been several other attempts to link scientific analysis with adaptive management related to climate change. These efforts have identified steps to prioritize resource values (e.g., species, habitats, ecosystems); assess resources for their vulnerability to climate change and other landscape stressors, determine which are likely to be most at risk and which are more likely to persist; identify and evaluate an array of management options based on technical, financial, and legal considerations; select management strategies to implement; and monitor the activities and outcomes in order to feed into a regular cycle of evaluation, correction, and revision (Glick and Stein 2010) and others (Cross et al., forthcoming; Chapin et al. 2010).

A model for linking science to management that builds from these frameworks will be presented in a follow-up

Key Questions of the Science Agenda

Synergistic questions

1. What has been the variability in climate (temperature, precipitation, and snow dynamics) and land use (rural home and agricultural water use) in the past and what are the projected trajectories for future decades?
2. How will projected interactions among climate change, land use change, and/or invasive species impact ecosystem function and connectivity at different spatial and temporal scales?
3. What changes in disturbance regimes can be expected under projected changes in climate, land use, and invasive species prevalence?
4. What are the cascading impacts to ecosystems, communities, and species across different trophic levels resulting from projected climate change and land use change?
5. How will climate change, land use change, and invasive species affect sensitive cultural resources, including cultural landscapes, ethnographic resources, national historic landmarks, national historic districts, and important archeological sites?
6. How are land-use and climate change altering the spatial and temporal distribution of primary productivity and what are the consequences for herbivore populations?
7. How do humans act as vectors of invasive species spread and does exurban development promote expansion of invasive species into wildlands?
8. What types of invasive organisms, diseases, and disturbance synergies are most likely under different scenarios of changing climate and land use?
9. What is the role of social science in informing management decisions and communication about climate change, land use change, and invasive species?

Climate change questions

10. How will climate change (drought, temperature, snowpack, soil moisture, flow degree and timing, and invasive species) impact cold water ecosystems?
11. How are surface water, ground water, and the timing and volume of runoff influenced by climate variability and change and what are the likely patterns of these under future climate scenarios?
12. What species, habitat, and ecosystem types are especially sensitive to climate change?
13. How will the species in fragile alpine communities (e.g., whitebark pine and pika) be impacted by expected climate-related changes in fire, insects, temperature, and moisture regimes?
14. How resilient are Greater Yellowstone area ecosystems to climate change and are there thresholds in climate change leading to new states in ecological systems?
15. What improvements are needed in the current climate station network of the Greater Yellowstone area to fill gaps in station coverage, improve quality control, and enhance suitability for describing variability and trends in climate?

Land use change questions

16. In what ways and to what extent are human activities outside protected areas (e.g., national parks or designated wilderness areas) altering ecological processes and biodiversity inside protected areas?
17. What specific linkage areas are necessary to improve connectivity for wide-ranging species such as wolverine, lynx, wolves, and grizzly bears?
18. How do changes in the structure and function of protected ecosystems and the surrounding landscape feedback to change human attitudes and trajectories of development?
19. How can development (e.g., exurban, energy, recreational) be managed to minimize impacts on natural process (e.g., wildlife ecology, fire)?

JENNIFER WHIPPLE

How will fragile alpine communities be impacted by expected climate-related changes?

20. What processes (e.g., economics, perceptions of crowding) will limit growth in amenity communities?
21. How do changes in land use and land cover associated with consumption of natural resources (grazing, mining, logging, energy development) impact natural processes within and outside protected areas? What are the ecological ramifications of shifting from extractive land uses to residential uses?
22. How do social/political processes operate to change biological processes through management decisions? How do changes in human demographics and values shape the operation of these decision-making processes?
23. How do changes in landscape hydrology in areas surrounding Yellowstone National Park influence thermal features within the park?

JENNIFER WHIPPLE

What will Greater Yellowstone area rangelands look like in future climate scenarios?

Invasive species questions

24. What will be the rate of spread of priority invasive species (plant, animal, and pathogen) already present in the Greater Yellowstone area over space and time?
25. How quickly will invasive species (plant, animal, and pathogen) that are not currently present in the Greater Yellowstone area spread to this area?
26. What are the drivers (ecological processes and species traits) of spread of invasive species?
27. What terrestrial landscapes and waters are most vulnerable to new invasions of exotic species?
28. What are the ecological impacts of invasive species in the Greater Yellowstone area?
29. What is the current understanding of the role of invasive species in the systems where they occur and what methods best prevent and control them?

These science questions prompt the following resource management issues:

- How will managers develop capacities required to utilize the state of knowledge of changing climate, land use, and invasive species to mitigate their impacts via targeted or integrated management policies?
- What, if any, resource management approaches can build resilient ecosystems or mitigate the likelihood of extreme stressor-caused disturbance events?
- How can managers use improved understanding of human dimensions (e.g., values, expectations, behavior, and economics) to engage and influence human behavior to positive effect?
- How can managers utilize current knowledge to assess risks via tools such as scenario planning and vulnerability analyses?
- How can managers work with scientists to develop and use reliable forecasting models that provide the best possible representation of expected future conditions while recognizing uncertainty?
- How can managers develop integrated and standardized baselines of ecological data obtained from active monitoring programs so that it usefully informs management?
- What steps are needed to institutionalize monitoring programs, standardized field protocols, and data analysis activities, and what strategies are needed to provide the sustained workforce and infrastructure necessary for long-term repetitive monitoring, inventory, and analyses?
- How can managers maintain necessary funding and resources to ensure that long-term, repetitive programs such as invasive species containment are adequately carried out?
- How can managers institutionalize science infrastructure, collaboration, and delivery through a formal long-term consortium of scientists, managers, and public dedicated to high priority topics?

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How will alpine vegetation communities shift as climate changes?

article in *Yellowstone Science*, including guidelines to link scientific tools such as research studies, scenario planning, vulnerability assessments, and long-term monitoring with management approaches and adaptive management into an integrated resource management program.

Recent reports useful to managers

Since the November 2009 workshop, several synthesis reports have been initiated or completed, including syntheses of observed and projected changes in climate variables and ecological response to climate change covering most of the Great Northern LCC, including the GYA (McWethy et al., forthcoming; Ashton 2010) and a similar synthesis specific to the Shoshone National Forest (Rice et al., forthcoming). Other scientific reports that will be useful to managers include a broad scale vulnerability assessment of potential effects associated with climate change on native trout (Haak et al., forthcoming) and the report from a scenario planning workshop on climate change impacts on wolverines and grizzly bears in the northern US Rockies (Cross and Serhveen 2010).

Summary

The GYA science agenda presented herein was developed to assist scientific and management communities in addressing issues associated with three large-landscape stressors—climate change, land use change, and invasive species—that are expected to impact the region over the next 20 years and beyond. The agenda is presented as a living document, to be informed as the state of knowledge grows. An exciting opportunity for review and growth will occur at the 10th Biennial Scientific Conference on the Greater Yellowstone Ecosystem, "Questioning Greater Yellowstone's Future: Climate, Land Use, and Invasive Species" in October 2010 at Yellowstone National Park (http://www.greateryellowstonescience.org/gyesciconf2010).

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Note: This document represents the work and views of the authors and does not necessarily imply endorsement by the agencies or organizations who provided financial support for this work or with which the authors are affiliated.

Acknowledgements

The authors would like to thank all attendees to the November 2009 workshop, and in particular those who served as science or management experts during plenary presentations and breakout groups, including Kit Batten, Jim Capurso, Randy Carpenter, Sue Consolo-Murphy, Bob Crabtree, Molly Cross, Paul Cross, Mary Erickson, Dan Fagre, Doris Fischer, Steve Gray, Justin Gude, Sue Heald, Tom Hobbs, Steve Hostetler, Steve Kallin, Chris Lehnertz, Bruce Maxwell, Ken McDonald, Kevin McKelvey, Kelly McCloskey, Bill Murdock, Ray Rasker, David Schimel, Chris Servheen, Sophie St. Hilaire, Tom Stohlgren, Dan Tinker, Greg Watson, Joe Weigand, Bill West, and Jack Williams. This article greatly benefitted from editing by Mary Ann Franke.

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Grizzly Bears and Snowmobile Use

A Summary of Monitoring a Grizzly Den on Togwotee Pass

Sarah J. Hegg, Kerry Murphy, and Dan Bjornlie

During winter 2009–2010, a grizzly bear was observed digging a den in the Squaw Basin area of Togwotee Pass, providing a unique opportunity to monitor a grizzly bear den and the bear's reaction to snowmobile use. Togwotee Pass is located on the Bridger-Teton National Forest, in the southern part of the Absaroka mountain range in northwestern Wyoming. This majestic mountain range forms a part of the southern and eastern border of Yellowstone National Park. Squaw Basin is an open meadow area, approximately 500 meters (1,640 ft) from State Highway 26/287 and 1,300 meters (4,265 ft) from the popular Continental Divide snowmobile trail. The Togwotee Pass area is well known by snowmobile recreationists and there are almost 402 kilometers (250 mi) of groomed snowmobile trails in the area. With the exception of designated Wilderness areas and a handful of ungulate winter ranges that require humans to stay on designated trails, much of the terrain on Togwotee Pass is open to off-trail snowmobile use. Squaw Basin is one of those popular places for snowmobilers to freely explore large open meadows and hillsides.

Much of the snowmobile activity in the Greater Yellowstone Ecosystem occurs on the same federal lands that are also home to the Yellowstone grizzly bear population. In order to properly manage federal lands, wildlife biologists have tried to analyze the possible effects of snowmobiling on the bears of the Greater Yellowstone Ecosystem. Studies have found that bears are potentially sensitive to disturbance by roads, human habitation, and industrial activity (Linnell et al. 2000). Also, grizzly bears may prefer den sites in remote areas with little human use or activity within 1–2 kilometers (0.62–1.24 mi) (Goldstein et al. 2010; Craighead and Craighead 1972). While these studies may seem to point to a possible sensitivity by bears to other general disturbances, very little is known specifically about a bear's reaction to snowmobiles. Due to the scarcity of information, the US Fish and Wildlife Service recommends monitoring known grizzly bear dens in snowmobile recreation areas.

Methods

In December 2009, the Interagency Grizzly Bear Study Team notified the Bridger-Teton National Forest of the Squaw Basin den. It was occupied when it was first reported by hunters in November and it was observed from a distance by Wyoming Game and Fish Department biologists

Camera set-up used to monitor snowmobile and grizzly bear activity at a den site on Togwotee Pass, Bridger-Teton National Forest, January–April 2010. Camera #1 on the left and Camera #2 on the right. The camera site is located approximately 175 meters north of the den.

SARAH HEGG

Photo of the hillside supporting the grizzly bear den and snowmobile activity near Togwotee Pass, Bridger-Teton National Forest, taken from the camera site on January 19, 2010. The collapsed breathing hole that was observed on January 12, 2010 is circled.

throughout the next several months. In January 2010, two RECONYX® cameras were deployed on a rocky outcrop approximately 175 meters (574 ft) north of the den to remotely monitor bear and snowmobile activity in the area. The cameras were positioned to obtain a panoramic view of the den, encompassing an area of approximately 5 hectares.

The RECONYX® cameras were programmed to take pictures every 5 minutes during daylight hours. Due to their distance from the den, the cameras were not triggered by movement on the hillside that supported the den. During January through April the camera site was visited every 1–2 weeks, during which visual observations were made and memory cards were collected.

Observations and track counts were gathered using a variety of procedures. Most of the general observations were taken from the camera site, using both binoculars and plain sight. The snowmobile track counts were made using the RECONYX® photos. The photos were viewed individually and a new track was counted when it became visible. The tracks were counted in two categories. One category was for tracks that drove directly over the den area, defined as within a 25-square-meter (83 ft^2) area of the den entrance. The other category counted any tracks that could be seen around the hillside that supported the den, including those directly over the den.

Some discrepancies were found between the number of snowmobile tracks captured by the two cameras. Due to glare from the sun and snow, and camera lenses being occasionally covered by drifting snow, each camera captured close but slightly different track numbers. For consistency, only the track numbers counted by Camera #1 were used in the graphs and statistics reported in the following sections.

Results

The den was first reported to Wyoming Game and Fish Department biologists in early November 2009. The den was then monitored from Highway 26/287 by the Wyoming

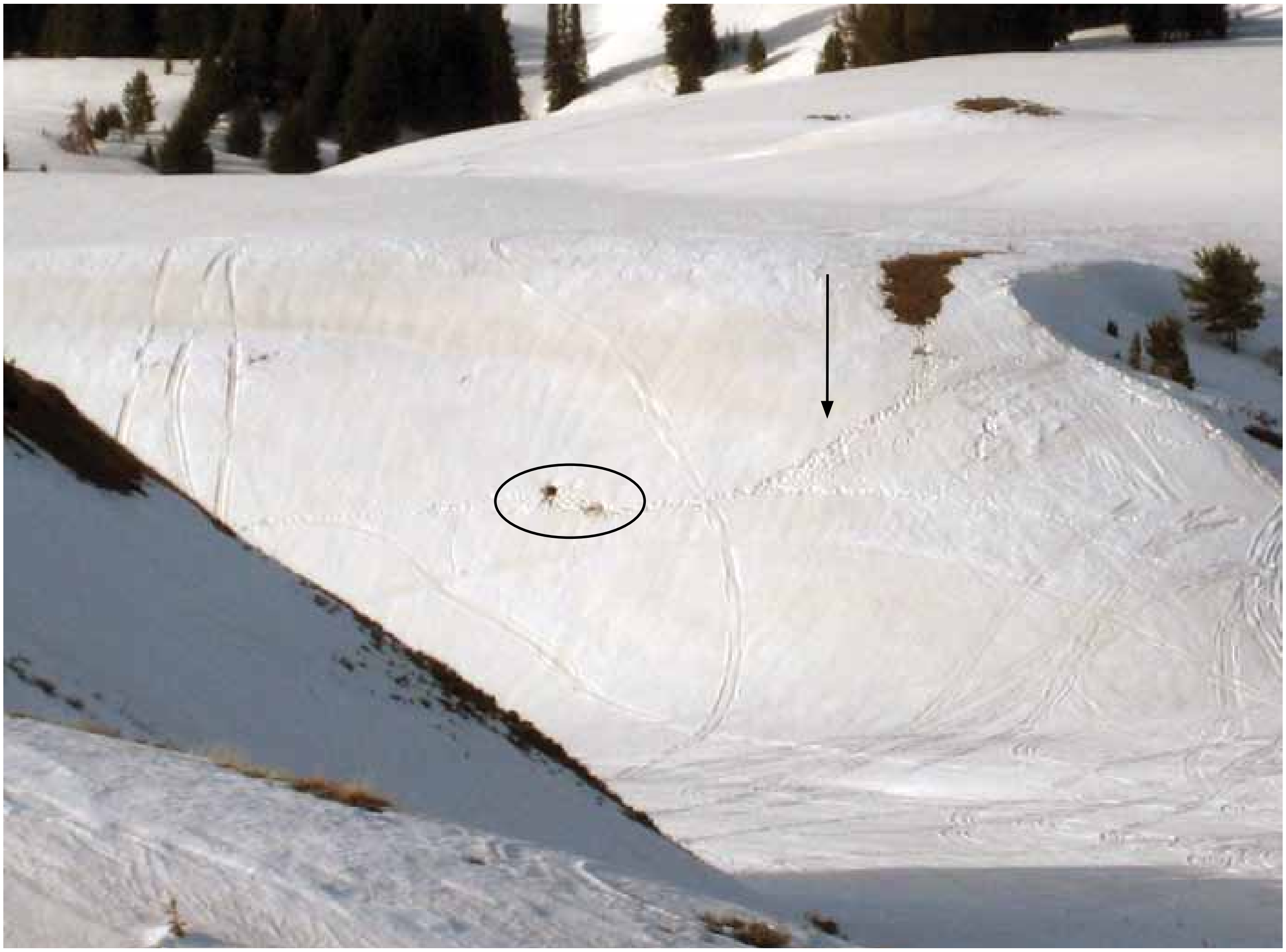

Photo of the hillside supporting the grizzly bear den near Togwotee Pass, taken from Highway 26/287 on April 21, 2010, a few days after bear emergence, showing the entrance hole and both bear and snowmobile tracks. The den entrance is circled and bear tracks are marked with an arrow.

Game and Fish Department several times thereafter through December 2009. The Wyoming Game and Fish Department found that the den entrance was covered by snow on December 3, 2009. A few kite-skiing tracks were observed near the den in early November and again in early December. No snowmobiles were observed near the den until the end of December, although there was some snowmobile use reported in the general Squaw Basin area during those months.

On January 12, 2010, the RECONYX® cameras were installed and monitoring with photos began. On that same day, a hole was first observed over the den entrance. This was presumed to have been caused by snow collapsing into the den hole when a snowmobile user drove directly over the den. It was the first sign of den presence since it was initially covered with snow in early December. The den entrance was subsequently covered by snow after an ensuing winter storm and there was no other sign of den occupation until bear emergence in April.

We visited the camera site on Monday, April 19, to recover photos and make visual observations of the den site. The RECONYX® photos revealed that the den entrance was first exposed by the bear at 4:36 PM on Sunday, April 18. At 2:00 PM on Tuesday, April 20, we observed a sow with one cub of the year 10 meters (32 ft) from the den entrance, prompting the Buffalo District Ranger to initiate an emergency closure of the area surrounding the den to help ensure public safety and bear security. On Wednesday, April 21 at 1:00 PM, the sow and cub were observed leaving the den area, moving west across a large (approximately 50 hectares) treeless area toward conifer cover 1 kilometer from the den.

At 9:00 AM on Thursday, April 22, we located the family's tracks leaving the den and followed them to the treed area. We also followed the tracks back to the den area where three bed sites were found on an east-facing hillside approximately 130 meters (426 ft) west of the den. We collected hair from those bed sites and sent them to the Interagency Grizzly Bear Study Team for DNA analysis. This may

LYNN WELLS

The grizzly sow and cub of the year emerge from the den on April 19, 2010.

provide individual bear identification and lineage of the bear when included in the full Greater Yellowstone Ecosystem grizzly bear DNA database.

We monitored the den site intermittently from the highway for six days following emergence. There was no sign of the bears' return to the den area, despite ample fresh snow that would clearly indicate use of the site by the family. The closure was then lifted and the cameras removed.

Snowmobile use occurred in the general vicinity of Squaw Basin meadow (approximately a 370 hectares), the den hillside itself (approximately 2.5 hectares), as well as at the den entrance (figs. 1 and 2). All recreation use observed was by snowmobiles, with the exception of one snow-kite skier. Snowmobile use increased at the end of December and continued throughout the rest of the winter. There was an increase in use on weekends—65% of tracks occurred on weekend days versus weekdays. April 12 was the last time a snowmobile was observed on the den hillside—six days before bear emergence. The average number of new tracks per week was 11.5, ranging from a minimum of 0 to a maximum of 23. The total number of tracks directly over the den area for the entire winter was 48.

Discussion

The denning period is a vulnerable time for bears. On average, lactating females lose 30%–40% of their body weight during the winter (Schwartz et al. 2003). Studies on black bears have shown that body weight can decrease an additional 3%–20% if dens are abandoned (Tietje and Ruff 1980). Of the potential reactions to disturbance, the abandonment of a den by a sow with a neonatal cub carries the highest energy cost (Linnell et al. 2000), since it exposes the cub to many risks and greatly decreases its chance for survival. Therefore, females with cubs should be expected to withstand the greatest levels of disturbance without abandonment (Cherry 2001), and it may be expected that maternal females may tolerate snowmobile activity, even directly on top of the den.

Our observations suggest tolerance by some bears to disturbance from both highway and snowmobile traffic. The sow and her cub experienced high levels of disturbance by snowmobiles during the winter—an average of 11.5 snowmobile tracks on the den hillside per week. Although significant snowmobile use likely did not occur until mid-late

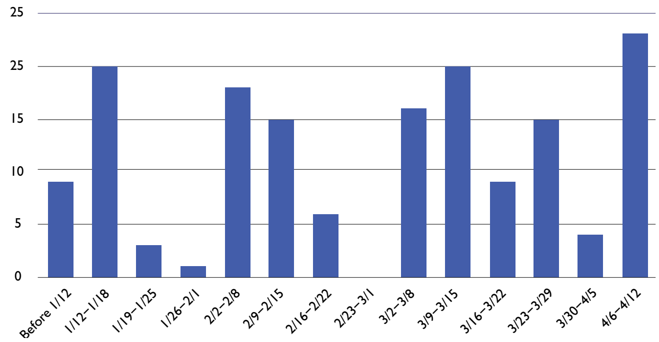

Figure 1. The weekly number of total snowmobile tracks observed within a 2.5 hectare area around the grizzly bear den at Togwotee Pass, including tracks directly over the den entrance. The number of snowmobile machines associated with the weekly counts was not estimated.

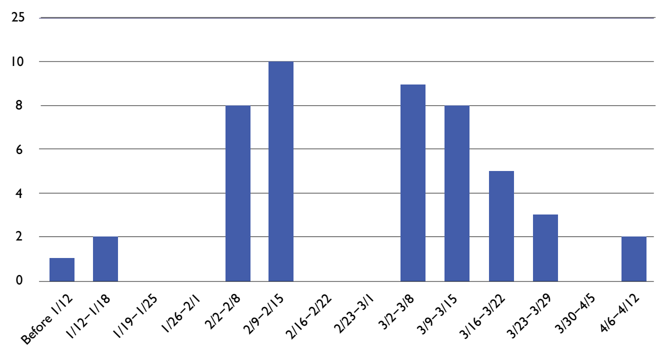

Figure 2. The weekly number of snowmobile tracks observed within 25 square meters of the den entrance, Togwotee Pass.

December, when the sow had already selected the site and built the den, the highway was in use at the time the den was selected and dug by the sow. Bears may be more likely to abandon dens if disturbed shortly after entry rather than in mid-winter (Craighead and Craighead 1972; Linnell et al. 2000).

While the sow did not abandon the den, lesser responses to disturbances, such as increased heart rate, waking and movement in the den, among others, are possible and also have the potential to increase energy costs (Linnell et al. 2000). The presence or absence of these responses could not be determined by this monitoring.

One factor contributing to the successful over-wintering may be that the snow covering the den may have significantly diminished the sound and vibrations from snowmobiles and the highway. Studies with polar bears in Alaska have found dry arctic snow to be a good sound insulator (Blix and Lentfer 1992).

After emergence, the amount of time spent by grizzly bears in the vicinity of the dens is variable (Judd et al. 1983). However, it is not uncommon, particularly for sows with cubs of the year, to spend several weeks in the vicinity of the den after emergence (Craighead and Craighead 1972). Haroldson et al. (2002) found that females with cubs often stay within 3 kilometers (1.8 mi) of the den until late May. This den was apparently abandoned within about 24 hours of emergence. At the time of the bears' emergence there was no known snowmobile use in the nearby area for the 24 hours they remained close to the den. Therefore, we were not able to assess any potential reactions to snowmobile use close by the den. Disturbances by traffic along the highway may have contributed to an apparent early departure from the den area. While this sow and cub may have abandoned the den site proper, it is possible they remained within a 3 kilometers (1.8 mi) radius.

A considerable amount of glare on the camera lens resulted from the sun and snow. During most cloudless days, this glare was strong enough to completely block photos of activity on the hillside for significant lengths of time. Drifting snow also periodically covered the camera and/or lens. This happened with both cameras, although it was more frequent with Camera #2, which was located in the corner of a large rock outcrop which may have contributed to the drifting snow. These difficulties likely explained the discrepancies in track numbers observed between the two cameras.

Management implications

This example suggests tolerance by a bear to large amounts of snowmobile use and disturbance during her denning period. However, as noted by other researchers (Craighead and Craighead 1972; Mace and Waller 1997; Haroldson et al. 2002), perhaps the greatest potential for negative consequences of direct disturbance for females with newborn cubs is directly after emergence. This case does not amend that hypothesis; the sow selected the site long before snowmobile use occurred, and having a cub of the year present

SARAH HEGG

The den area directly after den excavation, November 2009.

KERRY MURPHY

Author Sarah Hegg following the tracks of the sow and cub on April 22, 2010, after they left the den vicinity.

would have greatly increased the potential costs of moving the den site. Monitoring dens in high disturbance situations and taking cautionary measures after emergence is important to protect bears and better understand their reactions to human activity. However, because grizzly bears rarely reuse a den site, particularly one dug into a hillside (Judd et al. 1986), providing extended area protections in a situation such as this is likely unnecessary. As the grizzly bear population in the Greater Yellowstone Ecosystem increases, conflicts with recreationists may also increase. Observations such as this can be referenced to evaluate anthropogenic effects on grizzly bears and future research and management actions.

Acknowledgements

Thanks to Kerry Murphy for his patient mentorship. Thanks to the Bridger-Teton National Forest Buffalo Ranger District staff, specifically Wade Undem and Rick Taylor, for their assistance in monitoring the den. Thanks also to Gordon Ash, Tom Hill, Jim Ramirez, Ray Spencer, and Mike Boyce for their quick response in implementing the closure and assisting den monitoring post-emergence. Dan Bjornlie and Dan Thompson (WGFD) helped provide the remote cameras and set up the monitoring site. Thank you to Mark Haroldson of the Interagency Grizzly Bear Study Team for his valuable advice and counsel. Thanks to Lynn Wells for the useful and entertaining photos.

COURTESY SARAH HEGG

Sarah Hegg has worked in wilderness recreation and wildlife biology for the Forest Service for the last seven years in New Mexico and Wyoming, along with various other wildlife research projects in the southern GYA. She is currently a biological technician working for Grand Teton National Park on a whitebark pine regeneration study. Sarah attended the College of St. Benedict in St. Joseph, Minnesota, from which she received a BA in Natural Science and Ecology. **Kerry Murphy** has worked with a variety of state, tribal, and federal agencies as a technician and wildlife biologist, and with numerous large and medium-sized carnivores in both a research and management context, including cougars, black bears, bobcats, Canada lynx, wolverines, and gray wolves. Kerry served as an endangered species and mid-sized carnivore biologist with the National Park Service in Yellowstone National Park from 1998 to 2009. Kerry is currently a wildlife biologist for the Bridger-Teton National Forest in Jackson, Wyoming. In addition to the ecology of carnivores, Kerry has a broad interest in wildlife population and habitat management. **Dan Bjornlie** is a bear biologist for the Wyoming Game and Fish Department.

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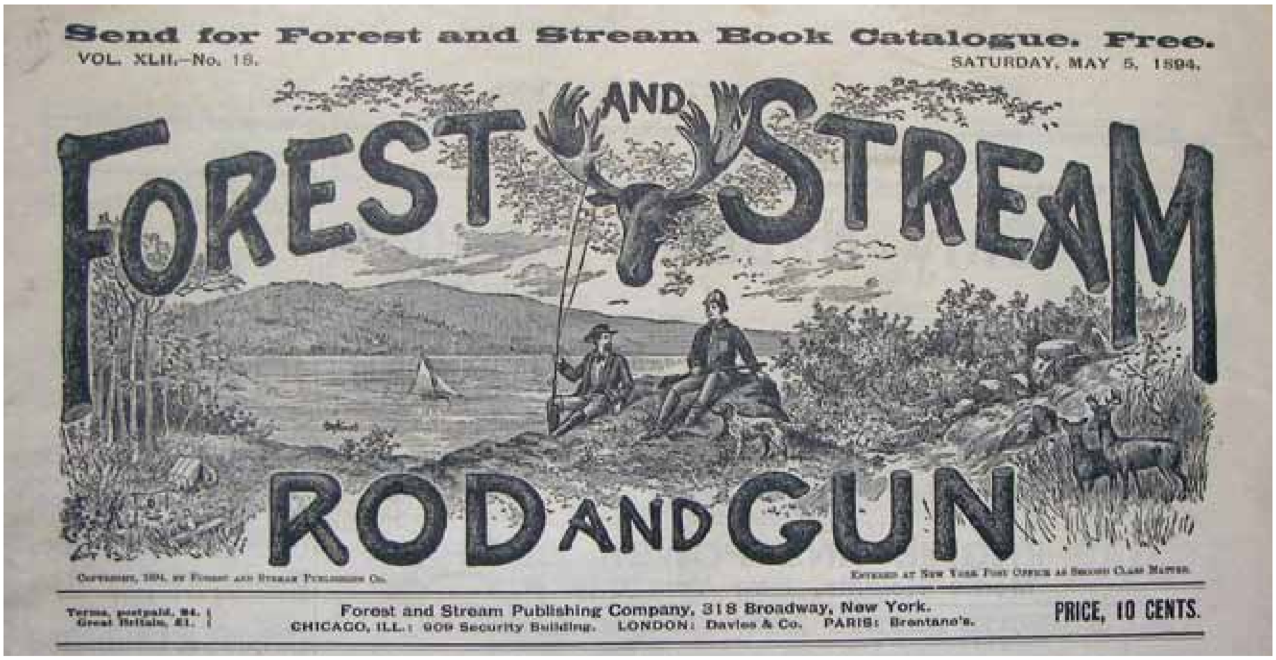

Forest and Stream, founded in 1873 and edited for many years by George Bird Grinnell, published hundreds of notes and articles on Yellowstone issues during the next 60 years, routinely campaigning for protection of Greater Yellowstone's migratory wildlife.

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The production of *Yellowstone Science* is made possible, in part, by a generous grant to the Yellowstone Park Foundation from Canon U.S.A., Inc., through *Eyes on Yellowstone* is made possible by Canon. This program represents the largest corporate donation for wildlife conservation in the park.

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