Ancient Corridors: The Trapper's Point Story of the Prehistoric Path of the Pronghorn

Meredith Taylor

Wyoming Outdoor Council, 6360 Hwy 26, Dubois, WY 82513 (307-455-2161, metaylor@wyoming.com)

Abstract

"Ancient Corridors" is the Trapper's Point story of the pronghorn antelope and the prehistoric American Indians dependent on hunting them in the longest big game migration corridor in the lower 48 United States. The archeological record suggests seasonal hunting more than 7,000 years ago at the Trapper's Point "bottleneck" —a narrow route through the hourglass-shaped migration route along this corridor west of Pinedale, Wyoming. Ancient hunters and animals traveled from Grand Teton National Park through the Trapper's Point bottleneck as they migrated to winter in the sagebrush steppe of the upper Green River Basin. The pronghorn migration and early human occupation of Greater Yellowstone were documented in the 1992 archeological excavation of Trapper's Point. Humans and wildlife have been interacting for at least 12,000 years in Wyoming, and prehistoric hunters would have adapted to pronghorn migration patterns. As hunters became familiar with game movements, migration landscapes, and intercept points, they established key hunting sites, such as archeologists found at Trapper's Point. The interaction between pronghorn and humans along this migration corridor continues to this day, but the route is now impacted by human encroachment in the form of fences, roads, housing, and mineral development that have all narrowed and may eventually block the bottleneck. In areas of low human population, such as Wyoming, pronghorn antelope still succeed as one of the remaining New World long-distance migrators. However, according to a recent study by the Wildlife Conservation Society, there is reason for concern in the upper Green River Basin: few remaining long-distance migrations (LDMs) have good long-term prognoses if current land management practices continue. In the interest of protecting this LDM, conservationists recommend that this longest big game migration corridor in the continental U.S. be made the world's first National Migration Corridor.

The Trapper's Point story is about *Antilocapra americanus*—the American pronghorn, which dates back more than 20 million years. Inhabiting the sagebrush plains from Canada to Mexico, there once were at least 40 million pronghorn, the fastest land mammal in North America. At the time when Lewis and Clark came West two centuries ago, pronghorn were allegedly as abundant as bison, but historians claim that a century later they were reduced by habitat fragmentation and overhunting to fewer than 5,000 in Wyoming. Now, with proper habitat management and hunting regulations, they have recovered; they outnumber people in Wyoming, with a population of almost 500,000.

Recent research has shown that pronghorn travel about 160 miles each way on the longest migration route in the lower 48 United States. The pronghorn migration corridor addressed in this paper passes through the southern Greater Yellowstone Ecosystem (GYE). Research by the Wildlife Conservation Society shows that more than 75% of the historic migration corridors in the GYE have already been lost to habitat fragmentation, so it is especially important that the pronghorn are still able to travel along this longest big game migration route today.

Since the last ice age, wildlife have followed their ancient migration paths each year. The 1,500–2,000 pronghorn from the portion of the Sublette herd unit that migrate along this long distance migration (LDM) corridor each year still use the same route from their winter range on the Red Desert and Little Colorado Desert (Wyoming) up the Pinedale Mesa to Trapper's Point through the Green River Basin. Only about 200–300 actually get through to Grand Teton National Park, according to radiotelemetry surveys.

In 1898, Dr. Frank Dunham submitted a proposal to *Recreation* magazine to protect this prehistoric migration route for the tens of thousands of pronghorn, elk, mule deer, and moose that, according to eyewitness accounts, migrated through each spring and fall. This historic proposal documented the need for habitat protection for all migratory big game.

The Trapper's Point map (Figure 1) shows the prehistoric path of the pronghorn north along this ancient corridor as they funneled through this natural geographic bottleneck at the Cora Y junction. As the animals negotiated this exceptionally narrow bottleneck, early American Indian hunters may have hidden behind sagebrush blinds to hunt them as the pronghorn migrated north each spring. In 1992, the Office of the Wyoming State Archaeologist surveyed Trapper's Point in preparation for the reconstruction of U.S. Highway 191. In that excavation, archeologists discovered three layers estimated to be 4,690–7,880 years old by radiocarbon dating. The site revealed 87,000 pieces of stone artifacts, 86,000 pieces of bone artifacts, 400 bone tools, 300 projectile points, and 27 adult and 3 fetal pronghorn skeletons. The size of the pronghorn fetal bones indicated that pronghorn migrated through Trapper's Point in late March–April. Lithic tools, including chert and obsidian found from Rock Springs to Jackson, Wyoming, indicated that these native hunters followed the pronghorn from the Red Desert to Grand Teton National Park. This route has also been called the People's Trail.

Figure 1. The Trapper's Point bottleneck (at arrow).

The archeological survey also revealed how Early Archaic hunters strategized to use the seasonal spring/fall migration route through the naturally narrow geographic bottleneck. The sheer numbers of bones found led archeologists to conclude that prehistoric hunters may have corraled the pronghorn and killed them with atlatls or other projectile weapons, then butchered the meat on site. Petroglyphs found south of the area may have been carved by the same native peoples.

Today, both pronghorn and mule deer migrate along the prehistoric route at this bottleneck that has now become another obstruction along a difficult route. The Trapper's Point bottleneck, once 1.5 miles wide, has now been reduced to less than 0.75 mile wide by roads, fences, and development along U.S. Highway 191, where thousands of pronghorn and mule deer migrate bi-annually. Like pieces of a puzzle, the land is chopped up into a checkerboard of different ownership patterns where the animals must cross land managed by the Bureau of Land Management, the Bridger-Teton National Forest, the state of Wyoming, and private individuals. In addition, the high natural gas potential demonstrated in the Pinedale Mesa and Green River Basin is an increasing threat to the pronghorn winter range and migration corridor on the Pinedale Mesa.

As the pronghorn leave the bottleneck, they stage on the ridges north of Trapper's Point at Cora Butte. The pronghorn encounter yet another bottleneck at the Bridger-Teton National Forest boundary, now called the Funnel, where they literally wind down the driveways between summer homes. Once they have skirted snowbanks along the upper Green River, they reach Mosquito Lake Flats. There the pronghorn break trail across snow-covered meadows to small bare patches where they can forage. They then cross a huge expanse of open space at Union Pass and the upper Green River on their way to their summer range in the high country, and continue north over the triple hydrographic divide at Union Pass that separates the headwaters of the Green, Snake, and Wind rivers. These rolling slopes offer pronghorn a high-altitude summer range of rich sagebrush grasslands, but many (200–300 annually) continue over the Green River Divide and north down the Gros Ventre.

The route down the Gros Ventre is a well-established, ancient trail. The pronghorn move down Bacon Creek on the Gros Ventre drainage, but soon the open space becomes an obstacle course of dozens of fences and roads. Another bottleneck occurs on the Gros Ventre at the Red Cliffs, where pronghorn literally go single-file along the riverbed and the sagebrush slopes above Slide Lake. They continue down until they reach their goal in Grand Teton

National Park, the northernmost terminus of the migration route, where they will have their fawns. Recent Wildlife Conservation Society research has shown poor fawn survival and reduced recruitment here; a doe/fawn study is underway to determine the cause of the mortality.

In Greater Yellowstone is one of the last intact ecosystems in the temperate zones of Earth. In order to ensure that the connectivity of these migration route linkages along this ancient corridor continue to function in the future, conservationists are coordinating efforts to designate a National Migration Corridor so that together we can keep our native history and wildlife heritage alive. The National Migration Corridor Protection Proposal would be the first designated migration corridor in the world; maintain Ancient Corridors protection for the longest big game migration route in the continental U.S.; keep migration bottlenecks open for connectivity; protect the ecological integrity of Greater Yellowstone Ecosystem; and preserve the American Indian history and wildlife heritage of the West. Where else could this visionary proposal be better accomplished than in Greater Yellowstone, where Wyoming is home to the first national park, the first national forest, and the first national monument?

At the end of the day, the question remains, "What can we do to help protect this longest migration corridor in the lower 48 states, the second longest in North America only after the Porcupine caribou herd, to ensure connectivity in perpetuity?" The National Migration Corridor is a vision for the future.

References

Bennet, L. 1998. *Wildlife and ecological conditions in Sublette County, Wyoming: a historical and contemporary perspective*. Laramie, Wyo.: Ultra Petroleum, Inc., and Wyoming Cooperative Fish and Wildlife Research Unit.

Berger, J. 2003. Is it acceptable to let a species go extinct in a national park? *Conservation Biology* 17:1451–1454.

Berger, J. 2004. Can we save the last of the great long-distance migrations? *Wild Earth* (Fall/Winter).

Blair, N. 1987. *The history of wildlife management in Wyoming*. Cheyenne, Wyo.: Wyoming Game and Fish Department.

Clark, T. W., and Harvey, A. 1989. *Rare, sensitive, and threatened species of the Greater Yellowstone Ecosystem*. Jackson, Wyo.: Northern Rockies Conservation Cooperative.

Dorn, R. 1986. *The Wyoming landscape, 1805–78*. Cheyenne, Wyo.: Mountain West Publishing.

Dunham, F. 1898. Proposal for a winter game preserve on the Red Desert. *Recreation* IX (October):271.

Hecox, R. D. n/d. *Memories of Kendall Valley*. Self-published.

Knight, D. H. 1994. *Mountains and plains: the ecology of Wyoming landscapes*. New Haven: Yale University Press.

Larson, M. 1996. *Archaeological research issues in southwest Wyoming*. Technical Report No. 2. Laramie, Wyo.: University of Wyoming Department of Anthropology.

Larson, T. A. 1978. *History of Wyoming*. Lincoln: University of Nebraska Press.

Miller, J. C., and S. Kornfeld. 1996. *Excavations of 48sW4141 Dodge Bottom Interpretive Road*. (Sweetwater County, Wyoming). Technical Report No. 13. Laramie, Wyo.: University of Wyoming Department of Anthropology.

Sanders, P. H. 2000. Trappers Point. *Wyoming Wildlife* (May).

Sawyer, H., and D. McWhirter. 2000. The long trail. *Wyoming Wildlife* (May).

Sawyer, H., and F. Lindzey. 2000. *Jackson Hole pronghorn study*. Laramie, Wyo.: Wyoming Cooperative Fish and Wildlife Research Unit.

Seedskadee National Wildlife Refuge. 1995. *A historical perspective*. Washington, D.C.: U.S. Government Printing Office.

Seedskadee National Wildlife Refuge. 2000. Comprehensive conservation plan. Washington, D.C.: U.S. Fish and Wildlife Service.

Sublette County Guild. 1985. *Seeds Ke-Dee reflections: historical lore of Wyoming's Green River Valley*. Laramie, Wyo.: Modern Printing.

Sublette County Guild. 1998. *Seeds-Ke-Dee revisited, land of blue granite and silver sage. historical folklore of Wyoming's Green River Valley*. Sioux Falls, S.D.: Pine Hill Press, Inc.

Federal Agencies in the Greater Yellowstone Ecosystem

Jack Ward Thomas

Former Chief, U.S. Forest Service

A. Starker Leopold Lecture, October 18, 2005

Jack Ward Thomas holds a BS in Wildlife Biology from Texas A&M University, an MS in Wildlife Science from West Virginia University, and an MF and PhD in Forestry from the University of Massachusetts. He has been honored as a Distinguished Alumni by each of those institutions. He worked 10 years for the Texas Parks and Wildlife Department (as both a management and research biologist) and 30 years for the U.S. Forest Service (27 years as a research scientist and 3 years as chief). He retired as the Boone and Crockett Professor of Conservation at the University of Montana, where he taught for seven years, in spring 2006. He has authored or co-authored more than 400 publications spread across a number of specialty areas, including ecology, conservation biology, forestry, range management, threatened species management, ethics, philosophy, economics, fish and wildlife management, and natural resource planning. He has received numerous awards, including the Aldo Leopold Medal from The Wildlife Society, the Award for Distinguished Service from the Department of Agriculture, Fellow of the Society of American Foresters, the Gulf Oil Conservation Award, Distinguished Achievement Award of the Society for Conservation Biology, and honorary doctorates from Lewis and Clark College and Lakehead University (Canada).

Just how this address will turn out is something of a mystery—even to me. I arrived from Europe at the Missoula, Montana, airport this morning at 10:30. At this point I have slept three hours out of the last 36. My wife, Kathleen, prevailed upon my stalwart graduate student, Alex Sienkiewicz, to drive me down here from Missoula. And during intermittent moments of consciousness, I wrote my speech on the way. So I would ask each of you to cross your fingers and let's all hope it turns out all right.

I was sound asleep when we arrived in the parking lot just outside this room. A day and a half ago I was salmon fishing and stalking red deer in Scotland. At the end of the hunt we were saying goodbye to our hosts when Lord Wigan laughed and asked if I had ever considered that God might be a salmon or an elk. I was dreaming about that when I was awakened by a huge bull elk bugling and giving me an intent look. I came wide awake in a hurry.

Well, any time I make a talk that involves folks from a national park, I try to establish a bit of rapport with a story from my days as Chief of the U.S. Forest Service (USFS). All federal land management agencies run what public relations staffers call "tracking polls" that are intended to reveal public opinion on one question or another. The folks who did that sort of work in the headquarters of the USFS showed up in my office for their regular monthly meeting [one day, and] the team leader started off with the old saw, "Chief, I have the summary from our latest tracking poll, and there is good news and bad news. Which do you want to hear first?" I opted for the good news.

He continued, "The U.S. Forest Service is the most highly respected agency in the federal government." I was elated with that wonderful news and cautiously asked for the bad news. He went on, "The bad news is that the public doesn't know the difference between the National Park Service and the forest service."

Now, when I have a chance to talk about Yellowstone National Park (YNP) and about the National Park Service (NPS), to some extent I base my comments on my experiences involving Yellowstone and its employees. I was with the National Academy of Sciences team that was here during the big fires that caused the huge and ongoing changes in how both federal scientists and administrators in all federal land management agencies think about wildfires and their "management." The "management" of that fire was more about backing up and praying for rain [than anything else]! I have lived long enough as a natural resources management professional to see the humor in the myths that grow up quickly around such dramatic events. For example, I remember the accusations that the NPS was "letting Yellowstone burn." The firefighters, in most cases, were wisely backing up as fast as they could go. That was a fire that nobody—no how, no way—was going to "control" until circumstances of weather and exhaustion of fuel allowed that to happen. Just being there as an observer was an enlightening, interesting, and educational experience. It gave me a chance to become acquainted, and develop respect and admiration for, many of Yellowstone's personnel.

My next close association with Yellowstone was a different matter and left a bitter taste in my mouth that still lingers. That bad taste emanates from the fiasco that swirled around the proposed New World Mine that took place in 1996. A Canadian mining company acquired the mining rights to some USFS land in a drainage off of—not adjacent to—the eastern edge of Yellowstone. As was their right, the mining company announced their intention to resume mining in a drainage that had been ecologically devastated by mining in the early twentieth century, and from which there had been only slight recovery. The USFS, as was required by law, partnered with the State of Montana to prepare the environmental impact statements on the mining company's proposed alternatives. The work was reaching its final stages when, out of the blue and with no consultation or discussion with the USFS, Yellowstone Superintendent Michael V. Finley accused the USFS of rigging the outcome of the environmental impact statements. That statement, made without warning or consultation, made headlines all over the country. Without investigation or contact with the USFS or the State of Montana, some of the powers in the Clinton administration took Finley's statement at face value. When I called my friend, NPS Director Roger Kennedy, he was as shocked and irritated as I was. Clearly, Finley was a fair-haired boy with the administration, and they would entertain no discussion of this—if nothing else—breach of protocol. The mining company, in my opinion, was pursuing a "can't lose" strategy: mine the mine or mine the U.S. Treasury. They were now set up to do the latter, which they ultimately did.

I checked things out and concluded that the USFS/State of Montana effort relative to the preparation of the required environmental impact statements was being properly conducted, as required by law. However, just to be sure, I had the USFS contract with the best private environmental impact outfit in North America for a review and critique of the ongoing process.

However, in the meantime, the press and environmental activists grabbed onto Finley's statement and painted him as a great hero standing alone against the evil mining company and the USFS. Finley, along with some allies of the environmentalist persuasion who should have known better, had managed to paint a picture in the public's mind of a pristine watershed that was about to be torn to shreds on the very boundary of Yellowstone National Park, which was downstream of the coming devastation. None of that was true. But it provided a political platform for President Clinton to establish his bona fides with the environmentalist camp. Without consultation with the USFS, or attaining a thorough understanding of what that agency was required by law to do, the administration bought Finley's fairy tale.

In the meantime, the consulting firm I had engaged delivered its assessment of the USFS/State of Montana's environmental impact statement relative to the matter. Their conclusion was not only that the effort was proper and thorough; it was among the very best they had ever examined. Katie McGinty, Director of the Council on Environmental Quality, was scheduled to testify before a congressional committee the very next day and tell them how the administration, tipped off by Finley's courageous stand against the USFS's "flawed" efforts at an environmental impact statement, intended to "save Yellowstone" by trading off national forest lands in exchange for mining rights. That decision also had been made without consultation with the USFS.

I informed her about the consulting firm's report. She was not appreciative. She had forgotten all about the ongoing evaluation. I sent her the report via messenger, and she immediately cancelled her scheduled appearance. I think she considered what I had done to be treacherous, though she had been informed of the ongoing review.

That summer, President Clinton and his family vacationed near Yellowstone, and the president, in a ceremony in the park, announced that the U.S. Government would buy out the New World Mine—that is, the mining company would mine the Treasury instead of the mine. The platform was filled with dignitaries—none of whom were from the USFS, upon whose lands the New World Mine would have been located. I, along with the regional forester, forest supervisor, and others, was ordered to attend the ceremony—in uniform, no less. We were seated in the peanut gallery.

In order for the president to keep his word without increasing federal expenditures, some political operative came up with the really swell idea of swapping some National Forest System lands near YNP for the mining rights. That was, simply, too damned much for me to swallow. I was simultaneously aggravated by an order to fire five of my top staff for what I thought were clearly political reasons. It was time for me to step down. However, I made arrangements to make several speeches over the next several months—really the same speech to several different audiences. Foremost among the audiences was a meeting of the Outdoor Writers and the North American Wildlife and Natural Resources Conference in Washington, D.C., in March 1997. With the secretaries of agriculture and interior in attendance, I delivered what, in retrospect, I consider the best and most heartfelt speech of my career. The speech focused on the equally sacred trust of the national forests relative to the national parks. I bore down on the dangers of establishing a precedent of using public lands as chips in political wheeling and dealing. The crowd came to its feet in loud and sustained applause and cheering. The secretaries of agriculture and interior and other political appointees standing in the back of the hall got the message. The New World Mine was bought out using Land and Water Conservation funds.

I did enjoy, for my three years in Washington as Chief of the USFS, a close personal and professional relationship with NPS Director Dr. Roger Kennedy. He was, and is, a scholar and a gentleman. I spent many hours in the Kennedy's home, especially in the days immediately after my wife died. We spent many hours discussing public land issues and the relationships between national forests and national parks.

Sally Fairfax, a social scientist at the University of California–Berkeley, recently published an article in the *Journal of Forestry* suggesting that the USFS, NPS, and the Bureau of Land Management (BLM) be combined in the Department of Interior. Her rationale was that the missions of the three agencies had more or less evolved to be centered around protection of environmental values (preservation) and recreation.

Such is not a new concept. Secretary of Interior Harold Ickes made the same determined pitch during the administration of Franklin D. Roosevelt in the late 1930s. His thrust was defeated, largely by the actions of the USFS chief and top staff—which, understandably, shortened their careers. Likely, they were not surprised. Ickes retaliated by engineering massive transfers of land from the USFS to the NPS. President Jimmy Carter's government reorganization proposals in the 1980s included some aspects of the same plan, and it failed again.

Why did those efforts fail? Agencies have constituencies, and those constituencies may, from time to time, consider the agency with less than total enthusiasm. However, the old adage, "the devil you know is better than the devil you don't know" applied, and those constituencies have consistently raised their voices—and power—against consolidation. So historically, at least, the Department of Interior has been seen as the one more focused on preservation of the public lands as opposed to conservation ("wise use") of lands under their jurisdiction, the BLM being the exception. The Department of Agriculture was the "use" agency when it came to public lands. Gifford Pinchot, the first chief of the USFS, had once headed the forestry operations in the Department of Interior, which he considered to be corrupt at that time. He worked long and hard to have the forest reserves, and all forestry operations, transferred to the Department of Agriculture. Pinchot, I think correctly for that moment in history, did not believe that large withdrawals of public lands from the public domain to form the U.S. Forest Reserves would stand if the lands were not actively managed to produce goods and services in a sustainable fashion.

I think it is just as likely that Pinchot wanted to establish the USFS in the Department of Agriculture because, he reasoned, the secretary of agriculture would be focused on production of agricultural commodities (e.g., cotton, corn, and livestock), and would have not have the expertise or interest to guide the USFS. That guidance would be left to the chief of the USFS. And that was largely true until some 20 years ago. Today, the primary spokesman for the USFS is not the chief of the USFS, but the undersecretary of agriculture. What does that mean, and what does it portend? Time will tell if that condition persists after the current administration leaves power.

It is well to recall the conflicts during the early years of the USFS (1905–1910) between John Muir, the preservation guru, and Gifford Pinchot, the "wise use" guru. Even today, it is possible to visit the offices of those involved in the ongoing saga of the public land management game—those in government and those in lobbying groups—and see pictures of Pinchot hanging on the wall of those interested in active land management and pictures of Muir on the walls of the preservationists. When I was chief of the USFS, I ordered that pictures of Muir, [Aldo] Leopold, [Arthur] Carhart, and [Bob] Marshall be hung in the "Hall of USFS Heroes." So far as I know, they hang there still. I thought there was a need for and room for both focuses, and both sets of heroes, on the public's lands.

There are differences in mission between the federal land management agencies. The mission for the USFS was set out in its Organic Act of 1897. It called for the management of the forest reserves for three purposes: protection of the forest reserves, production of a sustained flow of water, and provision of a flow of timber for the use of the American people. That mission was not modified until the passage of the Multiple Use Sustained Yield Act of 1960, which added livestock grazing, fish and wildlife, and recreation to the mandate.

In 1905, the forest reserves were transferred from the Department of Interior to the Department of Agriculture. Gifford Pinchot was appointed the first chief of the USFS. He had maneuvered for this change and this appointment for more than a decade. The chance came when his friend Theodore Roosevelt became president with the assassination of President McKinley.

Pinchot firmly established direction for the USFS when, early on, he wrote a letter for Secretary of Agriculture [James] Wilson to send to the chief of the USFS. That letter told the new chief how and for what the new agency would be managed. That direction still stands after 100 years. Sometimes it pays to know history, as such knowledge can provide a playbook for use in the political games of today—and tomorrow. In 1993, I had the opportunity to write a letter for President Clinton to send to me describing how we were going to deal with ecosystem management on public lands in the Pacific Northwest. Those instructions still stand.

The NPS, of course, has had its share of mixed messages over the last century. The primary confusion has been over achieving a politically correct balance between the mixed, and sometimes incompatible, messages of preservation and satisfying increasing recreational use.

Pinchot's USFS wanted to increase the amount of lands in the National Forest System. In order to do that, it was essential to assure local people, and their politically elected officials, that these lands were not to be "locked up," but were to be actively managed to provide goods and services in an equitable fashion. For Pinchot, that dictated application of "practical forestry" (forestry that would make money and be sustainable) and the regulation of livestock grazing in a fashion that was equitable and would help repair damaged range conditions. In doing so, Chief Pinchot had to take on both the "timber barons" and the "cattle barons," not to mention the miners. They were formidable opponents that he considered to be future allies.

Wanting into the business of "practical forestry" and actually achieving that objective turned out to be two very different things. The USFS, by and large, did not have control of the most productive forest lands. In fact, many of the national forests were composed of what might be called marginal timberlands, which made it difficult for the USFS to make money in the "practical forestry" business. And the USFS was competing against a very powerful timber industry not constrained by any lofty ideas of actually practicing sustainable forestry. Worse yet, that industry did not want any competition from "cheap government timber" and, by and large, they made sure that such did not happen until 1929. The Great Depression began in 1929 and, as a result, there was very little demand for wood products. Demand picked up during World War II (1939–1945), but the "cost plus 10%" contracts being passed out to private timber companies kept the USFS largely on the sidelines relative to timber production.

The USFS, during the period 1910–1945, concentrated on bringing grazing under control, building roads and trails into the vastness of the National Forest System to facilitate management (largely efforts at fire control), and fighting wildland fires. The idea was to protect the forests from fires until, at some future date, the nation would need the wood and turn to the National Forest System as a source. And, sure enough, when World War II ended in late 1945, the moment finally came when the timber from the National Forest System was in high demand at prices that made "practical forestry" a reality. There was a pent-up demand for housing that had been building since the onset of the Great Depression in 1929 and had lasted through the end of 1945—a hiatus of 16 years in home- and other construction. The timber supply from much of the private lands had been expended during the war years. The nation turned to the National Forest System and the USFS to supply much of the skyrocketing demand for timber and other wood products. Timber cut from the National Forest System increased continuously from less than 2 billion board feet/year in 1945 to some 13 billion board feet/year in 1990. Then there was a collision with a changing public will and the environmental laws passed in the period of the 1960s and 1970s.

Beginning in the 1970s, there was a gradual shift relative to the way fire was considered in the forested landscape. The "10:00 AM fire policy," which called for the extinguishing of any wildfire on the national forests by 10 AM on the day after its discovery was put in place in 1911 and was now being questioned on both ecological and economic grounds.

By 1990, timber yields from the national forests began to drop due to a public backlash against "industrial-strength forestry" which included broad-scale application of pesticides, road densities exceeding four miles per square mile, even-aged timber management involving clear cutting, planting of monocultures of single species of trees, and harvesting of trees at "economic maturity." "Old growth" had essentially disappeared from private lands and was being rapidly logged on USFS and BLM lands. The attitude toward fire in the forest was also changing. Fire became more and more recognized as a natural part of the ecology of forests. This was taking place at the same time that fuel loadings, due to 80 years of increasingly effective wildfire suppression efforts, were increasing on both national forest and national park lands. Managers began to wonder how to incorporate fire into forest management.

The new approaches were complicated by several factors. First was the simple fact that forests come in a variety of ownerships—federal, state, other government, and private. Though these landowners had different management objectives, wildfires do not respect property lines. To make matters worse, homes were and are, and at an increasing rate, being built in locations where they are susceptible to being destroyed by wildfires in adjacent forests.

It is common today to hear and read castigation of the federal land managers of yesterday for their attitudes toward wildfire—and even for their success in, to some extent, controlling wildfires. We tend to forget that their intention, in the case of the USFS at least, was to preserve the forests in their care until the wood could be harvested and used to benefit the American people. No one could have foreseen the shift in public attitudes that would dramatically alter the management of public lands more toward preservation and away from active management for the production of wood. The early forest managers thought of the green trees in the forest as products in a warehouse to be accessed and utilized at some future date. It seemed only prudent to keep the warehouse from going up in flames. It is hard to argue against that logic, given the knowledge of the time. Now, during a period when we have decided that burning up such a warehouse, for some reason or other, has its good points, the original concept appears stupid to some. Is it? Was it?

We are beginning to learn that living with wildfire, including its intentional use in forest and range management, is much easier in theory than it is in the overall political and economic sense. The NPS's fire managers had the great misfortune to be responsible for the first large-scale "controlled burn" that became so "uncontrolled" as to have burned up a significant portion of a town: Los Alamos [New Mexico]. But if the truth be known, anyone who has dealt with controlled burning could view that scene, shudder, and mouth the worn words, "There, but for the grace of God, go I." My prediction is that in the end, we will find that [policies of] "controlled fire" and "let-it-burn" will have much less application than some visualize at the moment. That is particularly true when we consider the increasingly mixed ownerships as one large timber company after another gets out of the timber business and sells to or becomes a real estate investment trust—i.e., land developer.

Global warming is now accepted—by scientists, at least—as a reality. The National Academy of Sciences has concluded that the phenomenon is responsible for increases in the number, size, and extent of wildfires in North America. There are, to be sure, holdouts in industries that will be adversely influenced by any attempt to deal with the situation, and they hold more influence in the political arena than scientists. But they will be overwhelmed by developing evidence. Such is merely a matter of time and, now, cascading evidence.

Beginning in the 1920s, the NPS became the USFS's primary competitor for allocations of land out of the public domain and for the purchase of land for inclusion in the federal estate. The NPS has a founding father, and icon, that matches the USFS's Gifford Pinchot. Things began to change for NPS with the arrival of Stephen T. Mather as director. He was just as charismatic, just as ego-driven, just as shrewd, just as ambitious, and just as focused as Pinchot. But Mather's focus was on land preservation as opposed to Pinchot's (and his successors') doctrine of wise use. Mather's objective was to build a national system of parks. Given that the USFS had a significant head start in acquiring lands from the public domain, and that the agency had "cherry-picked" the best, most beautiful, and most productive of the lands available, what was Mather to do? The answer was simple. Mather would, on a selective basis, raid the National Forest System for the lands he wanted for national parks. And he was to prove to be a most successful pirate, from the view of the USFS. In the view of the preservation community, he was a most successful crusader for keeping vast stretches of wild lands forever protected in their pristine state. That was, frankly, a little hokey, and not in keeping with ecological realities, but it sold, and it still sells.

The USFS mandate was too narrow to allow a successful defense of the lands desired by Mather and [his] associates. The USFS's narrow mandate to protect the forest and assure water flows and a supply of timber for the American people left the NPS to seize the mission of protection of natural landscapes, provide havens for plants and wildlife, and provide pleasuring grounds for the American people. Clearly, those mandates are to some degree contradictory, and are increasingly so. But, as some would say, whatever works. And it did work. Director Mather and his successors were every bit as successful in their quest for what they thought was the best future for the public lands of the United States as Gifford Pinchot and his successors were in terms of the National Forest System. But, understandably enough, [Mather was] viewed with animosity and suspicion; acceptance required a painful adjustment for the USFS. Those "raids" stimulated the USFS to bring forth the Multiple Use Sustained Yield Act of 1960. Passage leveled the playing field between the NPS and the USFS. NPS success in raiding the National Forest System for new park lands essentially stopped.

Now, I fast-forward to the end of World War II in 1945. The USFS entered what some, especially those enamored by the production of goods from federal lands, consider its glory years. The nation had been overwhelmingly successful in World War II, vanquishing Germany and the Empire of Japan in a two-front war. Millions of GIs were coming back from the war, many of whom had suffered through the Great Depression. Those veterans, most drafted into military service, had not gone into combat on a rotation basis; they went overseas and did not come home until victory was achieved. Casualties were not in the thousands or tens of thousands, but in the hundreds of thousands. The nation had two feelings about those returning veterans: (1) they were owed a tremendous debt, and (2) unless they were appropriately recognized, rewarded, and appreciated, and quickly reintegrated into a society that had changed much in their absence, political and social unrest was possible or even likely.

In a stroke of genius, Congress passed, and President Truman signed, the most successful social legislation in the history of the United States: the G.I. Bill. That bill made two promises to returning veterans. First, through guaranteed low-interest loans, it became possible for veterans to own a home (keep in mind that essentially, there had been no homes built in the United States since the onset of the Great Depression in 1929). Second, it was made possible—through stipends and tuition payment—for veterans to enhance their education in ways ranging from vocational training to university education. Home ownership became common for middle- and lower-class Americans, and the new surge in an educated work force set off prosperity never before known.

And as far as the NPS was concerned, there was a huge surge in outdoor recreation. The war was over. The economy was booming. Cars were rolling off the assembly lines and into garages and onto driveways. Gasoline, which had been rationed, was readily available at low prices. Recreation, particularly outdoor recreation, was booming.

The USFS provided a great deal of the wood that fueled the housing boom. Examination of newspapers and magazines for the period 1946–1980 reveals story after story extolling the virtues of the agency's performance. The USFS was the agency that "could do the job," "the Marine Corps of the civil service," "the only agency that pays its way," and so on. Budgets climbed, personnel numbers increased, and applause was common. These were heady times for the USFS. The USFS, in 1960, finally got the mandate it wanted to deal with range, fish and wildlife, and recreation. Now, they could beat off additional raids for lands from the NPS—and they did.

The 1960s and 1970s gave rise to both the modern environmental movement and a plethora of environmental laws. These laws had markedly delayed effects, as it was about 10 years after their passage before they were commonly used as the basis for legal actions against federal agencies. In the meantime, the timber cut on the national forests was inching up to 13 billion board feet/year. And it was becoming clear, through experience and research results, that if the USFS was to continue "practical (money-making) forestry," it must be done through the avenue of even-aged management, with its built-in efficiencies of road construction and maintenance, harvesting, stand regeneration (natural or planted), and stand tending.

The USFS was still suffering from a hangover from the Progressive Era, under which it was anticipated that the technological elite, when given responsibility and authority, would make the best decisions, and then execute those decisions so as to maximize the greatest good for the greatest number for the longest time. The Progressive Era was long gone, yet the USFS and several other federal agencies, such as the Bureau of Reclamation and the Army Corps of Engineers, proceeded as if that were not so. The USFS was faced with increasing public backlash and, now, there were environmental laws that could be used to force attention to the public will.

There was nothing wrong with the research relative to even-aged timber management. It worked quite well if the manager's objective was the maximization of wood production per unit of area. Otherwise, it has some rather nasty, if short-term, attributes—one being that from the time of cutting for a decade or two afterward, the result is just plain ugly. Only a forester can see the beauty of a clear-cut in its infancy. Then, to make matters even worse, silviculturalists commonly laid out the cutting units in 40-acre squares that were clearly visible marching up the hillsides with the roads, while granting motorized access of timber managers and recreationists into the backcountry, which was adding up to an economic and environmental liability. Then, in Montana, the ugly factor was multiplied by terracing hillsides within clear-cut areas to maximize "water capture" and speed tree growth. That was referred to as "ugly squared." It didn't matter to the public, the owners of the national forests, that these practices might have been quite effective for their intended purpose: maximization of wood production. The USFS pressed ahead.

When I went to work for the USFS in Morgantown, West Virginia, in 1966, I was quickly embroiled in research relative to the reaction of wildlife and hunters to even-aged timber management. White-tailed deer, turkeys, and ruffed grouse responded positively, but hunters, most decidedly, did not. A retired shoemaker in Gauley, West Virginia, was working part-time as the head of the Chamber of Commerce for that small town. He and a number of his constituents were aficionados of turkey hunting, and were appalled by the clear-cutting of hardwood forests. By happenstance, he was also an influential member of the West Virginia Chapter of the Izaak Walton League. When he and his friends protested to the USFS about clear-cutting, they were, at least in their minds, paternalistically brushed off, with the implication that such matters should be left to the experts—by definition, the USFS.

The Izaak Walton League went to federal court and charged the USFS with violating the USFS Organic Act of 1897, which specified that any trees cut for commercial purposes on national forests had to be "mature" and individually marked for cutting. The USFS maintained that in spite of what the law said, they were the experts, and times had changed relative to knowledge about the most appropriate silvicultural treatments; therefore, they had the right and obligation to proceed with forest management as they deemed appropriate. The judge ruled that the USFS was in clear violation of a clearly written statute. Further, the judge said the law might be antiquated, but it was the law until modified. Ergo, the USFS would cease and desist so far as clear-cutting was concerned.

Meanwhile, out in Montana, a committee of forestry professors from the University of Montana came forth with the Bolle Report (named for Arnold Bolle, the chairman and dean of the school's School of Forestry), which took the USFS to task for the clear-cutting and terracing in the Bitterroot National Forest. It was a second staggering punch for the USFS's timber management program.

Congress jumped into the fray and sought clarifications from the applicable laws (primarily, the simple instructions in the Organic Act) that guided management of the National Forest System. Two primary pieces of legislation vied for consideration in the Senate. The first was the so-called "Randolph Bill," named for its sponsor, Senator Jennings Randolph of West Virginia. That proposed legislation, written with assistance from the developing and growing environmental community, was very prescriptive in nature as to what the USFS could and could not do in forest management. The USFS saw the Randolph Bill as a significant encroachment on the managerial prerogatives of its professionals, and worked with Senator Hubert Humphrey of Minnesota on an alternative. That alternative restored managerial flexibility to the USFS and mandated that the agency should prepare 10-year management plans—whereby, at least in theory, appropriations could be controlled or, at least, strongly influenced.

Senator Humphrey's legislation prevailed as the National Forest Management Act of 1976. In retrospect, it might have been better if the agency had held its collective nose and swallowed the Randolph Bill. The old caution comes to mind, "Be careful what you ask for; you may just get it."

The USFS also maneuvered to get the Forest and Rangeland Renewable Resources Planning Act of 1974, which directed the agency to do three things: assess all the potential actions of the federal land management agencies; assess the best alternatives for the expenditure of federal funds; and prepare plans for the most efficient use of federal funds in federal land management. As a sideline, it is interesting to note the act also provided for the following (emphasis added): "an analysis of the potential effects of ***global climate change*** on the condition of renewable resources on the forests and rangelands of the United States; and an analysis of the rural and urban forestry opportunities to mitigate the buildup of atmospheric carbon dioxide and to reduce the risk of ***global climate change***." Congress recognized and acknowledged, 32 years ago, that global warming was a reality.

The USFS's intent in guiding the preparation and passage of the act was to put the agency in the driver's seat relative not only to the multiple-use management of the national forests, but also to other federal lands, as well. The Multiple Use Sustained Yield Act of 1960 gave the USFS license to expand its mission to include timber, water, recreation, range, fish and wildlife, and minerals. The National Forest Management Act of 1976 restored managerial flexibility and required national forest planning. The Forest and Rangelands Renewable Resources Planning Act of 1974 directed the USFS to assess the best alternatives for expenditures on all the public lands. It was, in concept, brilliant from the standpoint of the USFS. The USFS now had a wide-ranging mission, a direction to carry out, national forest by national forest, on a 10-year basis. And the USFS could, on a regular basis, assess and point out to Congress the best opportunities for effective additional spending on the federal estate.

It was a brilliant bureaucratic maneuver, but it didn't work in practice. The USFS seemed to have missed the point that Congress does what Congress does in terms of allocations of federal dollars, more in light of political expediency than in terms of what is logical or efficient. As former house speaker Tip O'Neill of Massachusetts once said, "Everything is political, and all politics are local."

Then, to drive the last nail in the coffin of the independence of federal land management agencies, the Equal Access to Justice Act arrived on the scene, and things were never the same. This act allowed citizens to "sue the Crown" if they thought any entity of the Executive Branch violated the laws under which it operated. And in the event of a victory by the plaintiff, the government was to pay all of the plaintiff's costs. The land management agencies were now vulnerable to lawsuits under a number of federal statutes if their actions were believed to be in non-compliance. Not only could citizens sue a government agency and have their expenses paid in the case of victory, there also was no penalty involved in a loss, outside of sunk costs. Compliance with the Endangered Species Act, National Environmental Policy Act, and the National Forest Management Act were the source of most such lawsuits.

During the period 1945–1990, the USFS, in general, seemed quite insensitive to the concerns of the NPS relative to the management of national forests adjacent to national parks. In fact, some of those actions went beyond the bounds of insensitivity to "in your face" management actions. The one such action that leaps to were clear cuts on a park's [Yellowstone's] boundary delineated by straight lines that could be seen from outer space. Such was, in retrospect, as stupid as it was insensitive. If the intent was to draw a clear contrast between federal land management agency missions and actions, it was certainly achieved.

By the 1960s, two differing constituencies were developing around the USFS and the BLM relative to the NPS. The NPS received support from the "greenies—" folks of the protectionist/preservationist branch of the conservation community. Greenies were little-courted by the land management agencies prior to 1960, but by 1980, the greenies were a force to be reckoned with. So the NPS got the support of the greenies; the USFS was supported by conservationists of the old school, that is, those who believed in "wise use" (with emphasis on "use"). This group included those involved in active forest management, livestock grazing, mining, commercialized recreation, outfitting, and hunting and fishing. Many gave active support to both agencies with full appreciation of their differing missions. But in general, the body politic that was interested in natural resources began to fracture along the green/brown line.

The Endangered Species Act of 1973, a decade after its passage, emerged as a turning point in how public lands of all kinds were to be managed. One of the species and places that received immediate attention under the Endangered Species Act was the grizzly bear, with the Yellowstone ecosystem (Yellowstone National Park and surrounding national forests) being the focus of this attention. There was an initial focus on what became known as "charismatic megafauna," and [the grizzly bear] was, and is, a sterling example. Wolves were soon added to the mix in the Yellowstone ecosystem.

But there was a new star emerging in the ongoing saga—or is it a tragedy—of application of the Endangered Species Act. It was a cryptic little known species of owl—the northern spotted owl—that would produce the biggest conflict relative to public land management of the last half of the twentieth century.

I was appointed director of the USFS's Range and Wildlife Laboratory in La Grande, Oregon, in 1972. In those days, federal agencies, at the end of the fiscal year, had to deal with what was internally referred to as "year-end money—" budgeted dollars that were left unspent at the end of the fiscal year after all the obligations had been paid. Any money that was unspent was returned to the U.S. Treasury (and it was likely that the next year's budget was reduced by the unspent amount). The director of the Northwest Forest and Range Experiment Station called me out of the blue and announced that I was to be assigned some year-end funds. He wanted me to contract for some research with the U.S. Fish and Wildlife Service Cooperative Research Unit at Oregon State University, thereby healing over some irritations that had been festering for a few years. This healing was to be accomplished by means of a couple of small research grants to the unit to carry out research of mutual interest. So I called my friend Howard Wight, who was the co-op unit leader, and told him the good news. I asked him to have a half-dozen young graduate students who were scratching for research support present me their proposals. If warranted, I could support a couple of studies.

A week or so later, I journeyed to Corvallis [Oregon] to listen to the presentations. All of the six presenters did an excellent job, and all of the proposed studies were within the parameters of research that I could legitimately fund. So I put the onus on Professor Wight, and told him he could pick the studies to be undertaken. Howard's first pick was a study proposed by Eric Forsman to determine the habitat associations of the northern spotted owl. I don't remember the second. But I do remember whispering to Howard Wight, "Howard, that's O.K. with me, but what's the bag limit on the damned things?" Our profession of wildlife management, in those days, focused almost entirely on species that were hunted or were predators of species that were hunted.

Nobody laughed, save for maybe the greenies, when Forsman's study indicated that the primary habitat of the northern spotted owl was old-growth forests—the very same old-growth forests that had been essentially eliminated from private lands and reduced by more than 80% on public lands through logging. Forsman's initial report triggered a number of other studies that added to understanding of the ecology of the northern spotted owl and it s habitats.

Those of the hardcore environmentalist persuasion saw an opportunity to significantly reduce the rate of cutting of old growth, particularly on public lands. Here was a relatively slow-breeding bird with a large home range that is dependent on old-growth forests that were being steadily logged and simultaneously fragmented in the process. This added up to a "perfect storm" relative to, first, the owl's listing as "threatened," and, then, dramatic reductions in the harvest of old-growth forest from public lands. They did not take long to exploit that opportunity. As one of their leaders later remarked, "If the northern spotted owl had not existed, we would have had to invent it."

All of this added up to a mega-voltage jolt to the federal agencies involved. The USFS went through two iterations of plans to provide habitat for the northern spotted owl while continuing to cut old-growth forests at a rapid pace. But the economic/political consequences of these plans on timber harvest and jobs in the timber industry were just too tough to face, and the efforts failed. Finally, the handwriting was clear on the wall: the northern spotted owl would be listed by the U.S. Fish and Wildlife Service (USFWS) as "threatened," and it would be necessary to cobble together a recovery plan as required by the Endangered Species Act. In the meantime, logging of old growth would be held in abeyance. The four federal agency heads concerned (F. Dale Robertson of the USFS, Cyrus Jamison of the BLM, John Turner of the USFWS, and James Ridenour of the NPS) created a team (the Interagency Scientific Committee, or ISC) to create, within six months, a plan for the management of the northern spotted owl. Clearly, the four agencies would have to cooperate if a political meltdown was to be avoided. I was assigned the team leader and given carte blanche to pick the scientists who would make up the team and make the necessary expenditures. The team was to include scientists from all four of the agencies, the California and Oregon departments of wildlife, private industry, and academia.

Whatever federal land management agencies were to do relative to cutting old-growth had little direct effect on the NPS. To this point the NPS had been standing around watching as the USFS, BLM, and USFWS were sweating blood. But now, the NPS had been drawn into a game they preferred to avoid. Boundaries between agencies were crumbling—just a little.

In the meantime, President George H. W. Bush attended the Rio summit in South America relative to the worldwide environment. He needed to make some dramatic announcement that would show the leadership of the United States relative to the environment, and his staff was coming up short. A call was made to the chief of the USFS asking for a statement that was heavy with meaning, yet nebulous enough to afford some wiggle room if and when push came to shove at some time in the future. They suggested "ecosystem management" to the president's aides, and they grabbed onto it. From today's vantage point, I am not so sure that what they had in mind at the time was what we consider ecosystem management today, but nonetheless, the commitment was made. So the management plan for the northern spotted owl was based on principles of ecosystem management, and lands of the USFS, NPS, BLM, and USFWS were all in the pot.

Similar things were happening elsewhere in the United States with different triggers. But it was the northern spotted owl that made the news. And no wonder, for no matter which way the struggle turned out, there would be 30,000–40,000 jobs lost, damaged or disappearing communities, and severe social disruption. Politicians do not appreciate such scenarios.

In desperation, the Bush administration essentially put the ISC and their work on public trial in Portland, Oregon. This was accomplished using the provisions of the Endangered Species Act (ESA). The ESA allows for the institution of an Endangered Species Committee, all political appointees of the president, to determine if the consequences of attempting to save a species are simply too great. The ISC, and the results of their work, survived unscathed when, in a humiliating defeat for the administration, all the members of the Endangered Species Committee, save for Secretary of Interior Manuel Lujan, upheld the work and recommendations of the ISC.

My first night home after the trial, the phone rang in the middle of the night. I was sound asleep and groped around for a moment or two before encountering the telephone. "This is Jack Thomas." The caller, who had obviously been drinking, asked, "Are you the spotted owl guy?" His words were more than a bit on the slurred side. "Well, I'm going to burn down your house, blow up your car, kill your dog. . . ."

When he paused for breath, I said, "Now, wait just a minute! Look, Mister, I have rules that govern my reactions in a situation like this, and with which I must comply. I simply cannot accept death threats at home. I would like to make an exception in this case, but I can't do it. I can only accept death threats at the office between 8:00 and 12:00 on Mondays, Wednesdays, and Fridays. My number is 406-273-3040." All I could hear was heavy breathing. I said, "Let me repeat that number." I could visualize the drunk writing down the number. I repeated it slowly and distinctly. Needless to say, I had bodyguards off and on for a while.

While there were ongoing drops in timber harvests across the entire United States, the most severe, with the greatest political backlash and the most public involvement, took place in the Pacific Northwest with the spotlight on the northern spotted owl. But similar patterns were developing on national forests across the United States. The timber cut from national forests dropped from some 13 billion board feet/year in the late 1980s to some 2 billion board feet/year in 2000, where it has hovered since.

In late 2005, I was in Washington, D.C., to attend the ceremonies celebrating the hundredth anniversary of the establishment of the USFS. As a result, I had occasion to visit with the undersecretary of agriculture about the USFS. He had served as the chief of staff for the Senate Committee on Natural Resources during my tenure as chief of the forest service. Before that, he had been head of a lobbying outfit for the timber industry. We had known each other for many years, and were friends in spite of some significant disagreements over the years. He was a hired gun, and a very good one. He fed the Republican members of the Natural Resources Committee questions intended to beat me up over declining timber harvests on the national forests. The committee insisted that we were simply not doing our job relative to timber harvests, that is, the USFS was not "getting out the cut." My response was, always, that Congress made the laws and the USFS carried out budget directions under the laws.

I said, "Mark, what's happening? You and the Republicans (presidency, House, and Senate) have been in charge for almost six years, and the timber cut from the national forests per year hasn't changed appreciably." He just smiled. Ah, the games that people play.

Where do we stand today relative to management of federal lands? Things have not really changed very much since the departure of the Clinton administration and the advent of the George W. Bush administration, except for the continuation of declining budgets relative to inflation and erosion in employee numbers. No big changes seem to be looming on the horizon. There does seem to be an increasing recognition that the federal land management agencies must increase their cooperation. Who could disagree with that?

I don't think, for example, that the NPS, with any semblance of a straight face, can continue to cling to the wreckage of the failed policy of "natural regulation." Migratory elk, deer, and buffalo that move in and out of national parks continue to make that concept a fairy tale. Any discussion of natural regulation as a land management policy should begin with the words, "Once upon a time. . . ."

A new cooperative era of management of federal lands is, or at least should be, dawning. It will be increasingly necessary to fully appreciate what is entailed when we talk about "ecosystem management" or such places as the "Greater Yellowstone Ecosystem." That will require the abandonment of fairy tales and a longing for circumstances that no longer exist and, most likely, can never exist again. The most-intact ecosystems that exist, or will exist, in the United States exist where large blocks of federal land, regardless of the agency in charge of the pieces, exist. If ecosystem management has any place and any chance to be successful, it is in those places. That will require increased attention to what might be called "conservation across boundaries."

I know that USFS Chief Dale Bosworth spoke to you earlier. I think that in the circumstances of the moment, he is doing a most excellent job. He, and the rest of the USFS leadership, knows that a new day has emerged requiring new approaches to address the oldest of human problems: how to live well in this world and maintain its ability to support life—our life form included—forever. Such will require accelerated learning and adaptation—adaptive management of the most astute sort. What an incredible challenge.

Chief Bosworth puts it this way—he has a way of making the complex simple and understandable—in exploiting our environment, what we leave is more important than what we take. There is both keen perception and wisdom in that message. When USFS personnel are working in and around YNP in the Greater Yellowstone Ecosystem, or in other areas around national parks, that adage of what we leave being the most important factor in our management is even more important. Clearly, it is doubtful that we will see a new, straight-edged clearcut along a national park boundary in the future. That, at least, is some progress. But more is required. The aesthetic quality of roads, roadsides, and watersheds leading into the parks is being more carefully addressed. Plans for dealing with population numbers of migratory ungulates should be more in touch with reality, with shared responsibility for actions and consequences. New thinking, and increasingly cooperative approaches, to dealing with fire—wildfire and managed fires—across boundaries is well underway. Demands for coordinated management will continue to increase.

There is one immediate issue in the management of national forests to which USFS and NPS personnel, and the constituencies of both agencies, should ensure maximum attention and maximum exposure. Near the end of the Clinton administration, all "roadless areas" of 5,000 or more acres were placed off-limits to the construction of new roads. Many of those areas are adjacent to and complementary to national parks. That rule was negated by the George W. Bush administration. The states have been asked to recommend, on a case-by-case basis, which of those areas should remain in roadless status and which should be considered for road construction. As a pretty good old wildlife biologist—certainly old—I can not think of any benefits to fish and wildlife of road construction; ditto water quality. Will the quality of the national parks adjacent to such roadless areas be enhanced by a change in their land use allocation?

So was Dr. Fairfax right? Is it time to simply amalgamate the three federal land management agencies?

There is a myth in the USFS that maintains that the agency's first chief, Gifford Pinchot, left a sealed letter in the middle drawer of his (and successive chiefs') desk with detailed instructions of the course of action to be taken if there were ever a serious effort to meld the federal land management agencies into the Department of Interior. I have had dozens of inquiries over the years as to whether such a letter actually exists. My first reply is that "If I tell you, I will have to have you killed." Joking aside, so far as I know, no such letter exists—at least, I could never find it.

If that letter exists, it wouldn't mean much today. Too much water has gone under the bridge. Times change, and managers of the federal lands must change with them. Pinchot said that the national forests should be managed for "the greatest good of the greatest number for the longest time." He thought he knew what that meant for the national forests in his time. But he also knew and appreciated that new knowledge and new circumstances would require change in focus and day-to-day operations. There is no going back, and who would really want to? Increased cooperation and coordination between federal land management and regulatory agencies will be the order of the days to come. And once past the pain of change, such will be challenging, exciting, taxing, and maybe even fun.

I started this rambling talk with that story about the good news and the bad news—that the USFS is the most respected agency in government but the public can't tell the difference between the two agencies. With that in mind, I would suggest that the two agencies are increasingly less different than in the past. But they are also not the same; they are siblings born of Theodore Roosevelt and the Boone and Crockett Club, but not twins.

Matters relative to natural resource management never stay the same for long. Let me use timber as a surrogate for all natural resource products. Timber yields from federal lands are down 80% over a 15-year period. During that same period, the number of large timber holdings has declined to two or three, with the remainder sold into real estate investment trusts. Mills have closed by the hundreds.

But if you go to the lumberyard, wood products are plentiful, and at more-or-less reasonable prices. Where did the wood come from? Where will it come from in the future? What are the ecological consequences?

That wood is coming, and will come for the foreseeable future, from "elsewhere." In most cases, it is a good bet that elsewhere does not have the same environmental laws nor the cutting-edge expertise to do the same level of environmentally sensitive forestry that is, or can be, practiced in the United States. Yet we use more and more wood in toto and per capita than any other nation in the world. Upon consideration, such circumstances legitimately could be classed as morally bankrupt. And along with the importation of such huge amounts of wood, we increase our already soaring balance of trade deficits; such could be labeled as fiscally irresponsible. Then, to top things off, we export the jobs that are associated with growing, tending, harvesting, transporting, manufacturing, and distributing wood products. Such exports are largely from rural areas, where good-paying jobs are in short supply. That could be called socially callous. Decisions relative to how we manage our natural resources have consequences—both locally and worldwide.

Circumstances can change quickly. September 11, 2001, brought us a war on terror. Stock markets plunged and have recovered, but just barely, and are bouncing along sideways. Energy prices have, and likely will continue to, soar. Balance-of-trade deficits are spiraling upward, and budget deficits stretch ahead as far as the eye can see. Adjustments will be required, including how we deal with natural resources. We will, sooner or later, discover, and then come to grips with the fact, that we can't buy everything we want from somebody else with a dollar that is dropping in value as debts and balance-of-payment deficits increase inexorably. We will, sooner or later, have to resume producing more of what we use, while—on the flip side—conserving as much as we can.

The struggle for appropriate management of natural resources is always present; failure results in destitution. Conservation is always of paramount importance. For most of us in this room, it is our calling—a noble and worthwhile calling. I will retire at the end of this year after 50 years as a professional conservationist in various roles: 10 years with the Texas Parks and Wildlife Department, 27 years as a USFS research scientist, 3 years as chief of the USFS, and 10 years as professor at the University of Montana. I cherish the teaching part, because I could pontificate endlessly and, in the end, not have to be responsible for what I said and did. But that is not quite true, because those students who listened and learned are going forth to continue the struggle—I hope a little better prepared for what they learned.

An interviewer asked me a while back if I'd do it all over again—the 50 years as a professional conservationist. I didn't have to ponder. I answered, "In a heartbeat!"

Analysis of 1988 Post-Fire Forest Conditions in Yellowstone National Park from the 2002 Forest Inventory and Analysis of Wyoming

Michael T. Thompson

U.S. Forest Service, Rocky Mountain Research Station, Forest Inventory and Analysis, Ogden Forestry Sciences Lab, 507 25th Street, Ogden, UT 84401 (801-625-5374, mtthompson@fs.fed.us)

Jock Blackard

Same address (801-625-5394, jablackard@fs.fed.us)

Abstract

In the summer of 1988, during the driest period in Yellowstone National Park's history, large-scale fires burned more than one-third of the park's area. The 2002 inventory of Wyoming's forest conducted by the U.S. Forest Service's Forest Inventory and Analysis (FIA) program marked the first comprehensive forest inventory of Yellowstone National Park. Information was collected on each FIA sample that identified sample plots with evidence of burn in 1988. This information allows for summaries and statistical analysis of current forest conditions in Yellowstone that had evidence of fire in 1988. Forest area attributes such as forest type, stand size, stand age, stand density index, and basal area class are presented in this paper. Tree-level attributes such as species, numbers of trees, diameter class distribution, growth, and mortality are also presented. FIA's estimate of the amount of forest area that burned in 1988, based on the 2002 plot burn history, is 803,000 acres. The most dramatic effect is the heavily skewed age class distribution toward the youngest age class. Sixty-four percent of the burned area is currently classified as a lodgepole pine forest type, and another 19% is non-stocked. Spruce-fir types account for 7% of the burned area; the remaining 10% is comprised of aspen, Douglas-fir, Engelmann spruce, whitebark pine, and limber pine types. More than 58% of the burned area is classified as a sapling/seedling stand size class, 18% is sawtimber stands, and 5% is poletimber stands.

Introduction

In the summer of 1988, the driest recorded period in the history of Yellowstone National Park, large-scale fires burned more than one-third of the park's area. The fires created a unique forest ecosystem that has been extensively studied in subsequent years to evaluate how forests and wildlife recover from severe disturbance. Ecological succession, spatial heterogeneity, herbaceous production, and effect on mammal populations are some examples of studies conducted on the areas burned in 1988.

The U.S. Forest Service's Forest Inventory and Analysis (FIA) program recently completed a comprehensive forest inventory for the state of Wyoming that included Yellowstone National Park. The data from this inventory included information about those sample plots that had evidence of burn in 1988. The forest inventory estimates from sample plots that burned in 1988 provide an opportunity to examine forest area attributes, population estimates of live trees, and stand dynamics from a broad-scale perspective about 11 years after the fires occurred.

Methods

FIA's extensive, sample-based inventory includes a systematic grid of permanently established field plots across all lands in the interior West. The FIA program uses a mapped, fixed-plot design as part of its national core sampling protocols (Hahn et al. 1995). Each ground plot contains a cluster of four points spaced 120 feet apart. Each point is surrounded by a 24-foot, fixed-radius subplot where trees 5.0 inches diameter at breast height (d.b.h.) and larger are measured. All four subplots total approximately 1/6 of an acre. Each subplot contains a 6.8-foot, fixed-radius microplot where saplings (1.0–4.9 inches d.b.h.) and seedlings are measured. All four microplots total approximately 1/75 of an acre.

To divide the forest into various domains of interest for analytical purposes, the tree data recorded on these plots is properly associated with the area classifications. To accomplish this, plots are mapped by condition class. Field crews assign an arbitrary number (usually 1) to the first condition class encountered on a plot. This number is then defined by a series of predetermined discrete variables attached to it: land use, forest type, stand size, regeneration status, tree density, stand origin, ownership group, and disturbance history. Additional conditions are identified if a distinct change occurs in any of the condition-class variables on the plot.

Sometimes a plot straddles two or more distinct condition classes. Boundaries between condition classes can bisect the subplots, or they can be located between the subplots. Microplots are mapped in a similar fashion. Thus, for each ground plot, the microplot and subplot area in each condition class is known, as are the location and condition class of every tree tallied.

Fieldwork began in Wyoming in 1998, and was completed in 2003. Most of Yellowstone National Park was inventoried in 1999. The most recent inventory of Wyoming marks the first wall-to-wall coverage inventory of Yellowstone National Park. Previous forest inventories did not install sample plots on reserved public land. For each inventory plot that sampled forest land, field crews recorded evidence of fire and the year in which it occurred. Figure 1 illustrates those inventory plots that sampled forest land with evidence of burn in 1988, overlaid with ancillary coverage of the 1988 burned area. Figure 2 illustrates those inventory plots that sampled forest land with no evidence of fire in 1988. A total of 132 inventory plots had evidence of burn in 1988, and a total of 131 inventory plots had no evidence of burn in 1988.

Forest area

Forest Inventory and Analysis estimated the total land area (excluding census water) in Yellowstone National Park to be 2.0 million acres. Eighty percent of the total land area was classified as forest land. About 803,000 acres were estimated to have evidence of fire in 1988; 795,000 acres were estimated to have no evidence of fire in 1988.

Forest type is a classification of forest area based on the predominant tree species in a stand. It affects wildlife habitat, timber supply, and other forest eco-

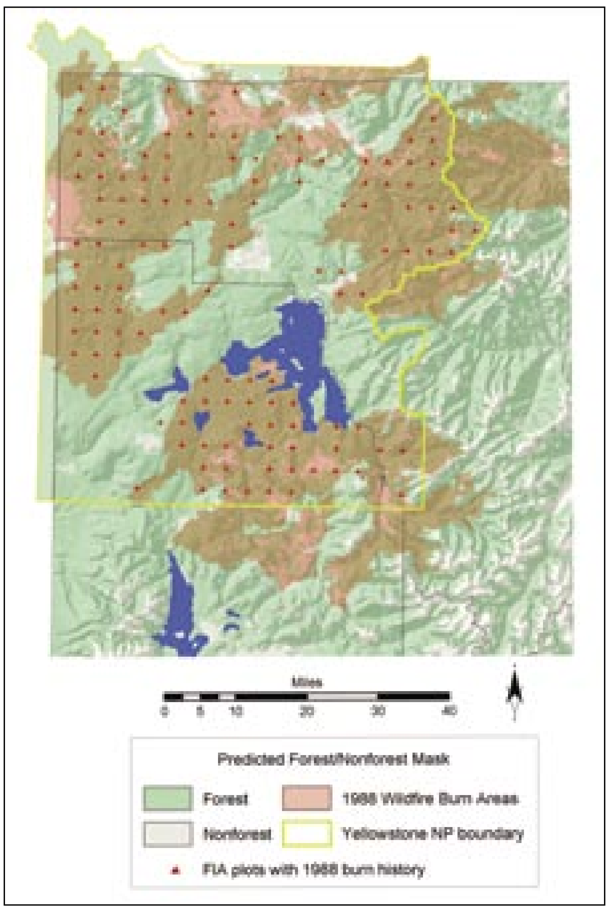


Figure 1. Forest inventory plots that sampled forest land with evidence of fire in 1988, Yellowstone National Park, in Wyoming, 2002.

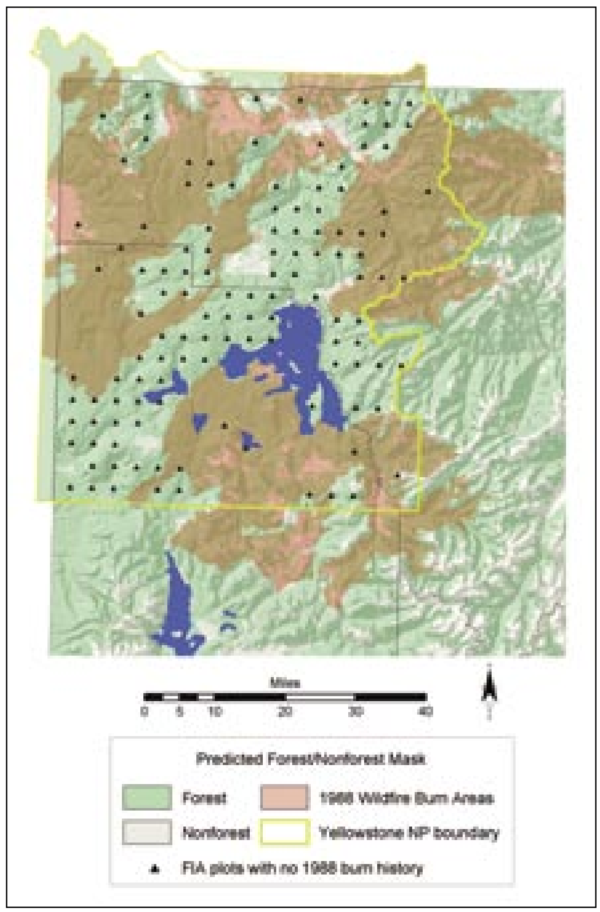


Figure 2. Forest inventory plots that sampled forest land with no evidence of fire in 1988, Yellowstone National Park, Wyoming, 2002.

system goods and services. Lodgepole pine occupies the largest amount of forest area burned in 1988, at 64% (513,000 acres) (Figure 3). Second in abundance is non-stocked timberland at 19% (149,000 acres). Non-stocked timberland refers to land that is less than 10% “stocked” (covered) with live trees but has the potential to support live tree cover at or above 10%. Third, the spruce-fir type accounts for 7% of the burned area, followed by aspen forest types at 3%.

Comparisons of forest inventory estimates on burned and unburned forest land illustrate some striking differences in forest cover type in Yellowstone National Park. Figure 4 compares the area burned in 1988 against the area with no evidence of burn in 1988 by major forest type. Lodgepole pine predominates on the unburned area at 55% (441,000 acres). There is significantly less non-stocked timberland on the unburned area compared to the burned area, where non-stocked timberland accounts for 20,000 acres, or 3%. Spruce-fir, Englemann spruce, and whitebark pine types on the unburned area are more than double that recorded on the burned area. Also noteworthy is the absence of aspen forest types recorded on the unburned area.

The most significant impact of the 1988 fires from a macro-forest land condition perspective is the effect on stand-age class. Stand age is a computed variable using only those ages of trees within a computed stand-size class and weighted by trees per acre. If a computed stand-size class is non-stocked, the age class is defined as non-stocked/unclassified. Figure 5 shows 50-year stand age classes for the burned and unburned areas. Fifty-seven percent of the burned forest area is concentrated in stands less than 50 years of age, and nearly 77% of the burned stands classified as lodgepole pine forest type are less than 50 years of age. Most of these young stands, especially lodgepole pine, are newly regenerated stands that reestablished following the 1988 stand-replacing fires. In contrast, only 13% of the unburned forest area in Yellowstone National Park is in stands of 50 years and younger. The forest area in the unburned area is more normally distributed than the burned area, with the majority (50%) in stands 100–200 years old.

Several studies suggest that all forest types across all stand ages were affected by the 1988 fires (Christensen et al. 1989). Initially the public and some ecologists assumed that the 1988 fires would result in a uniform landscape of exclusively even-aged stands similar to what would be expected following a large,

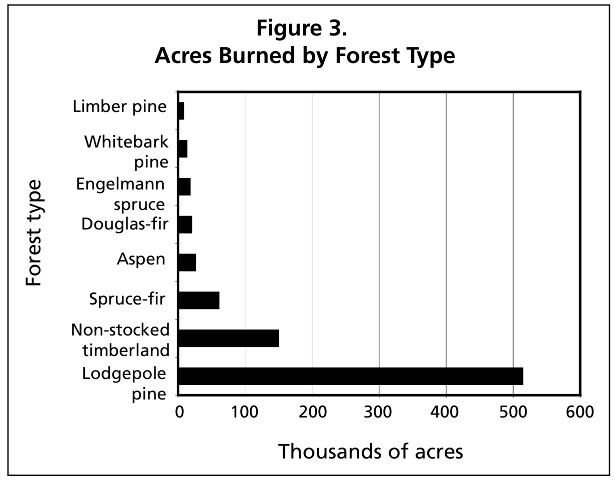


Figure 3. Area of forest land with evidence of burn in 1988 by forest type, Yellowstone National Park, Wyoming, 2002.

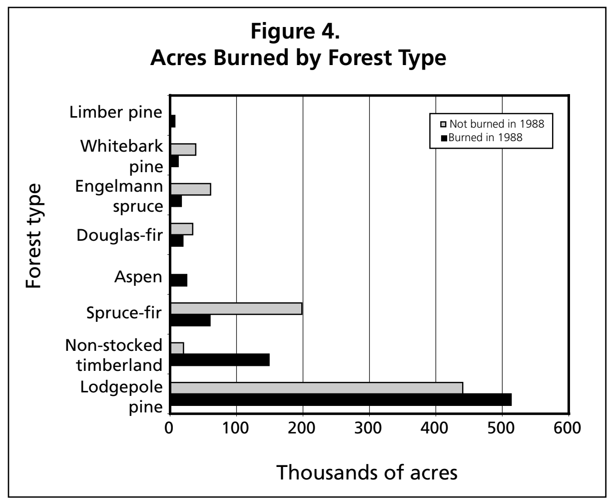


Figure 4. Area of forest land by forest type and 1988 burn status, Yellowstone National Park, Wyoming, 2002.

Figure 5. Area of forest land by stand-age class and 1988 burn status, Yellowstone National Park, Wyoming, 2002.

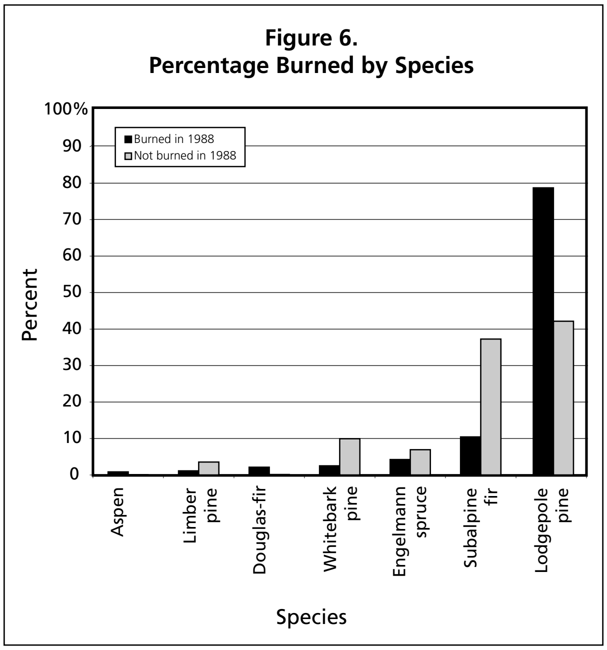


Figure 6. Distribution of all live trees by 1988 burn status, Yellowstone National Park, Wyoming, 2002.

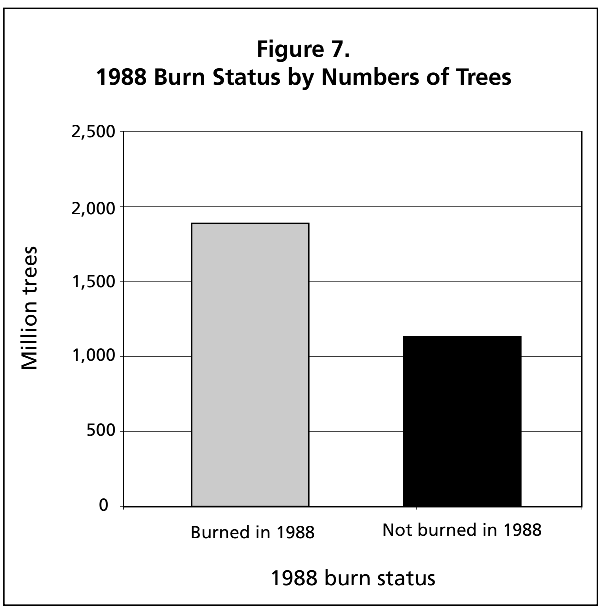


Figure 7. Number of live lodgepole pine seedlings on forest land classified as lodgepole pine forest type by 1988 burn status, Yellowstone National Park, Wyoming, 2002.

human-caused disturbance such as clear cutting followed by natural or artificial regeneration. However, the fires actually created a spatially complex mosaic of unburned and burned patches as the result of a wide range of burn severities (Turner et al. 2003). Within the burned area, the amount and spatial distribution of the forest area classified as non-stocked/unclassified suggest that the fires created patches of marginally stocked forest land. These non-stocked forest conditions are widely distributed spatially in the burned areas and are not concentrated in any one geographic location. The large numbers of these forest areas with low live-tree density are probably the result of patch size, burn severity, and pre-fire cone serotiny. Small patches, low intensity of surface burns, and small percentages of pre-fire stand serotiny (measured by percentage of lodgepole pine trees bearing serotinous cones) are strongly correlated with post-fire lodgepole pine seedling density (Turner et al. 2003).

Numbers of live trees

Forest Inventory and Analysis generates population-level estimates of numbers of live and dead trees. These estimates are used for species diversity measurements, timber supply studies, old-growth analysis, and stand density assessments. On the forest area burned in 1988, the estimate of all live trees, including seedlings, is 2.6 billion trees. Lodgepole pine accounts for 79% of all live trees on the burned area, at 2.0 billion trees. Next in abundance is subalpine fir at 10%, followed by Englemann spruce at 4%, whitebark pine at 2%, Douglas-fir at 2%, and limber pine at 1%. Lodgepole pine also predominates on the unburned area, at 1.4 billion trees or 42% of the live tree total. Subalpine fir is second in abundance at 37%, followed by whitebark pine at 10%, Engelmann spruce at 7%, and limber pine at 4%. Figure 6 illustrates the distribution of all live trees on the burned and unburned forest areas.

Lodgepole pine regenerated well in most forest areas following the 1988 fires. Figure 7 compares the estimate of live lodgepole pine seedlings on forest areas classified as lodgepole pine between the burned and unburned areas. Figure 8 compares the estimate of live lodgepole pine trees on lodgepole pine stands between the burned and unburned areas. These illustrations indicate the significant differences in number of lodgepole pine stems by diameter class and also underscore the slow-growing nature of lodgepole pines in the subalpine plateau. Most lodgepole pine stands that burned in 1988 still remain in the seedling/sapling stage despite 11 years between the date of the fires and date of inventory.

The 1988 post-fire dynamics of aspen were surprising to many ecologists who discovered seedling regeneration in areas where aspen did not previously exist. From a broad-scale perspective, aspen is a minor component in Yellowstone National Park, accounting for less than 1% of the live tree population. However, there is a striking difference in the estimate of live aspen stems between the burned and unburned areas. The number of live aspen trees on the burned areas totals 22 million trees, all of which are in the seedling and sapling size class. This figure is more than 22 times the number of live aspen trees in the non-burned areas, where the estimate of live aspen trees is 965,000 trees (Figure 9). Turner et al. (2003) also found that aspen regenerated successfully throughout the burned forests and well beyond the pre-fire range of aspen.

Summary

The 1988 Yellowstone fires produced spatially complex patterns of succession in what a casual observer might consider a homogeneous landscape dominated by lodgepole pine. The large proportion of non-stocked forest conditions on the burned area are areas with low stand density where gradual recruitment may or may not continue. The heavily skewed stand age distribution on the burned areas is a classic macro-scale example of stand structure following a major stand-replacing disturbance. Aspen appears not only to have established itself successfully following the fires, but also to be appearing in areas where it previously did not exist.

Estimates from FIA inventories are broad-scale in nature. These estimates of forest area and numbers of trees in Yellowstone National Park are coarse compared to many of the site-specific studies conducted after the 1988 fires. However, FIA can be used to verify many of these studies conducted at a much finer scale. The difference between population estimates of live aspen stems on the burned and unburned areas is an example of how FIA inventories may be used to verify the findings of other studies.

The FIA program of the U.S. Forest Service is rapidly implementing an annual inventory system that features a nationally consistent plot configuration; a nationally consistent sample design; integration with the ground sampling component of the Forest Health Monitoring program; a complete, statewide, systematic, annual sample of each state; and new reporting requirements. These new systems will be implemented in future inventories of Wyoming, and will greatly enhance the timeliness, quality, and usefulness of estimates on unique ecosystems such as Yellowstone National Park.

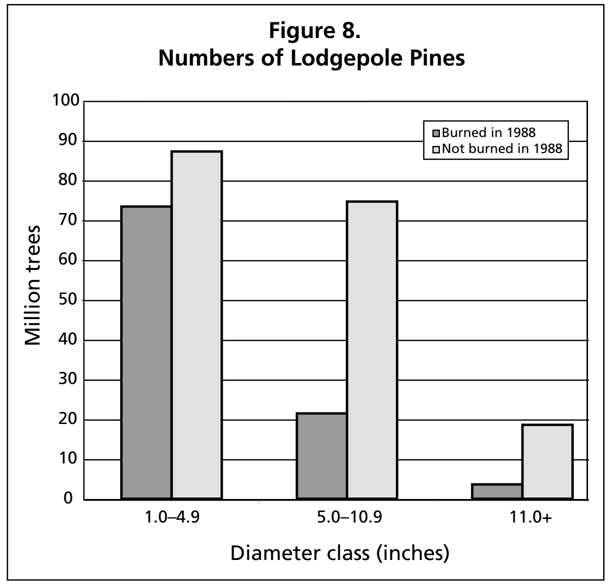


Figure 8. Number of live lodgepole pine trees 1.0 inches in diameter at breast height and larger on forest land classified as lodgepole pine forest type by 1988 burn status, Yellowstone National Park, Wyoming, 2002.

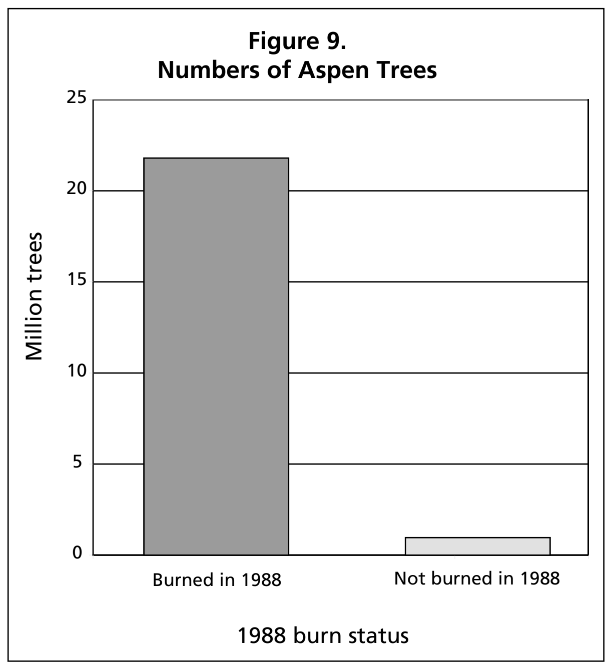


Figure 9. Number of live aspen trees on forest land by 1988 burn status, Yellowstone National Park, Wyoming, 2002.

References

Christensen, N. L., J. K. Agee, P. F. Brussard, J. Hughes, D. K. Knight, J. M. Minshall, J. M. Peek, S. J. Pyne, F. J. Swanson, S. Wells, J. W. Thomas, S. E. Williams, and H. A. Wright. 1989. Interpreting the Yellowstone fires of 1988. *BioScience* (39):678–685.

Hahn, J. T., C. D. MacLean, S. L. Arner, and W. A. Bechtold. 1995. Procedures to handle inventory cluster plots that straddle two or more conditions. *Forest Science Monograph* (31):12–25.

Turner, M. G., W. H. Romme, and D. B. Tinker. 2003. Surprises and lessons from the 1988 Yellowstone fires. *Frontiers in Ecology and the Environment* 1(7):351–358.

Wildlife at a Crossroads: Energy Development in Western Wyoming

Janice L. Thomson

The Wilderenss Society, 1424 4th Ave., Suite 816, Seattle, WA 98101 (206-624-6430, jthomson@twsnw.org)

Tim S. Schaub

HyPerspectives, 2048 Analysis Drive, C, Bozeman, MT 59718 (406-556-9880, schaub@hyperspectives.net)

Nada Wolff Culver

The Wilderness Society, 1660 Wynkoop Street, Suite 850, Denver, CO 80202 (303-650-5818, nada_culver@tws.org)

Peter C. Aengst

The Wilderness Society, 503 W. Mendenhall, Bozeman, MT 59715 (406-586-1600, peter_aengst@tws.org)

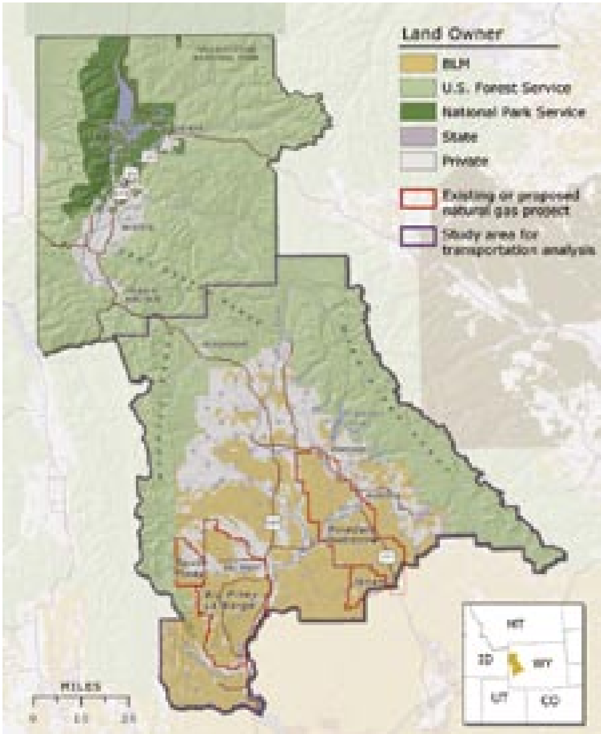
Abstract

The Upper Green River Basin of Wyoming supports the largest block of publicly owned winter range in the Greater Yellowstone Ecosystem (GYE) and some of the fastest-growing natural gas developments in the West. The Bureau of Land Management has the opportunity, in an ongoing management plan revision, to maintain the ecological integrity of winter range, a critical link for wildlife that migrate across national forest, national park, state, and private lands in the GYE. A landscape analysis of the transportation network was conducted to assess the spatial impacts of energy development on pronghorn, mule deer, elk, and greater sage grouse habitat. Landscape fragmentation metrics were measured for the entire landscape, for gas fields, and within species habitat boundaries. A comparison of the results with biological field literature describing road and energy impacts on wildlife suggests that impacts are significant. For example, 80% of pronghorn crucial winter range has route densities higher than a 1-mi/mi^2 threshold, which has been shown to cause adverse effects on pronghorn. In addition, all sage grouse leks are within three miles of a route—a distance from surface disturbance that is recommended for seasonal closures to preserve breeding functions. Specific transportation and energy development management recommendations were crafted based on the findings. A few examples include (1) closure and reclamation of routes to increase core area to more than 1,542 feet from a route in mule deer crucial winter range, (2) reduction of transportation route densities to less than 1 mi/mi^2 within elk crucial winter range, and (3) ensuring directional drilling and cluster development to minimize habitat fragmentation.

Introduction

The Upper Green River Valley, in western Wyoming, contains a prime example of the vital and threatened sagebrush ecosystem of the western United States (Knick et al. 2003; WYG&F 2004). Sagebrush steppe and grassland habitats in the lower elevations of the valley are surrounded by the forested slopes of the Wyoming Range to the west, the Wind River Range to the east, and the Gros Ventre Range to the north. Much of the valley falls within the Bureau of Land Management (BLM)'s 4.8-million-acre Pinedale Resource Management Area (RMA) (Figure 1).

The Upper Green River Valley contains crucial habitat for big game species including pronghorn (*Antelocarpa americana*) (Figure 2), mule deer (*Odocoileous hemionus*) (Figure 3), elk (*Cervus elaphus*) (Figure 4), bighorn sheep (*Ovis canadensis*), and moose (*Alces alces*). Wyoming has by far the greatest concentration of pronghorn of any North American state or province, and the Green River Valley holds the highest concentration of this animal in Wyoming (BLM 2000). More than 100,000 big game animals winter in the Upper Green River Valley (Berger 2004a), the largest block of publicly owned winter range for big game in the 19-million-



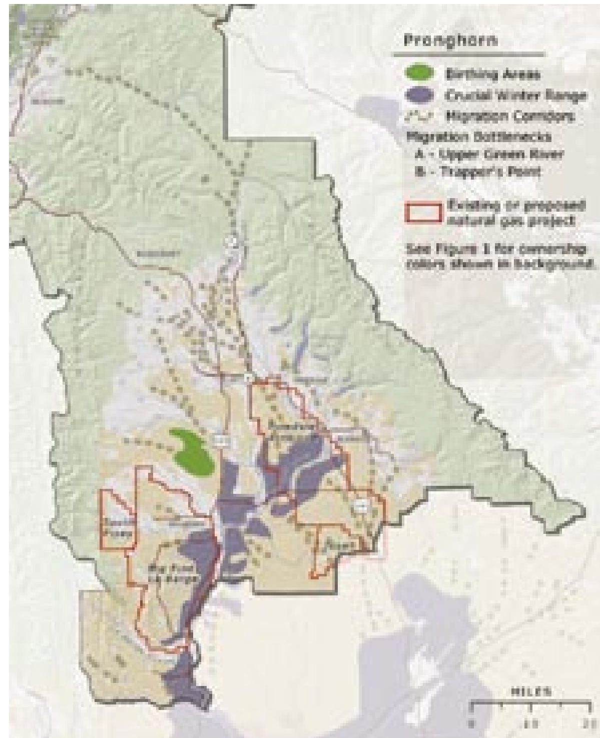


Figure 1 (left). Surface ownership within the Pinedale Resource Management Area.

Figure 2 (right). Pronghorn in the Pinedale Resource Management Area: migration routes, crucial winter range, and birthing areas. More than 170,000 acres of the Pinedale RMA have been designated as pronghorn crucial winter range by the Wyoming Game and Fish Department. More than 125,000 acres of that winter range fall on BLM lands. Another 23,000 acres of the RMA are designated as birthing areas, of which 22,000 acres fall on BLM lands.

acre Greater Yellowstone Ecosystem. The valley also contains birthing areas used by pronghorn and mule deer.

The Upper Green River Valley contains important big game migration routes. Round-trip migration distances documented in the valley range from 62 miles for moose and 137 miles for elk to 186 miles for mule deer and 311 miles for pronghorn (Berger 2004b). The annual journey of herds of mule deer and pronghorn from Grand Teton National Park and nearby national forest lands to snow-free areas of the Upper Green River Valley containing crucial winter forage represents North America's longest big game migration outside the Arctic (Sawyer and Lindzey 2000; Berger 2004a). Archeological evidence indicates that the pronghorn migration has continued uninterrupted for more than 6,000 years (Sawyer and Lindzey 2000). Berger (2004a) has proposed formally designating a national migration corridor to acknowledge and protect this unique phenomenon.

The Pinedale RMA also contains one of the largest populations of greater sage grouse (*Centrocercus urophasianus*) in the western United States (Braun 1998). This species has recently declined throughout western North America, and in Wyoming, in particular (Braun 1998; Connelly and Braun 1997). The BLM has demonstrated its concern for the species by establishing a National Sage Grouse Habitat Conservation Strategy, a comprehensive approach to the management of sage grouse habitat on public lands.

Because sagebrush is slow to regenerate following disturbance, conservation of sagebrush habitat is critical for the success of sage grouse (Knick et al. 2003). Sage grouse are a meaningful indicator of the ecological health of sagebrush steppe habitat because they depend on sagebrush throughout their life processes. During the winter months, for example, sage grouse are totally dependent on sagebrush for food and cover (Lyon 2000). The Pinedale RMA provides important winter habitat for sage grouse, with wind-scoured slopes and ridgetops that ensure year-round sagebrush exposure. The Pinedale RMA also contains important complexes of sage grouse breeding habitat, the availability of which limits populations of sage grouse in many areas (WYG&F 2004). Sage grouse habitat and lek courtship and mating locations in the Pinedale RMA are shown in Figure 5.

In addition to its importance for wildlife species,

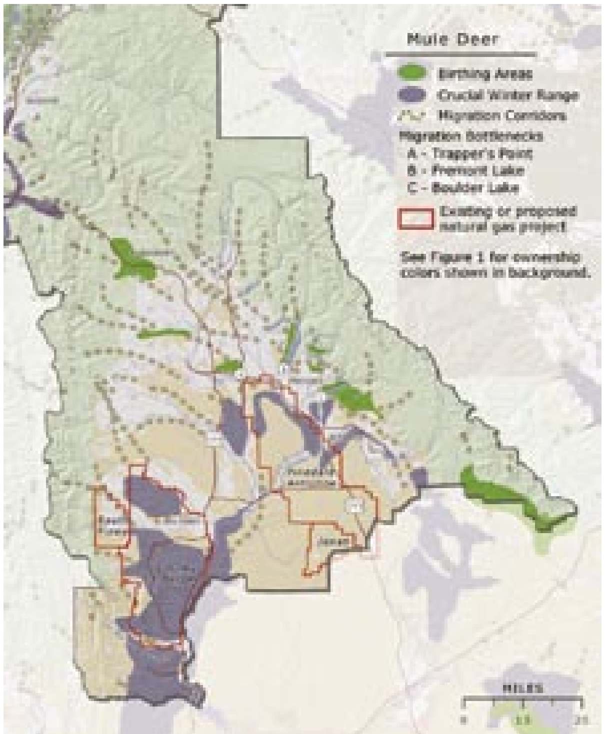


Figure 3 (left). Mule deer in the Pinedale Resource Management Area: migration routes, crucial winter range, and birthing areas. Nearly 350,000 acres of the Pinedale RMA have been designated as mule deer crucial winter range by the Wyoming Game and Fish Department. More than 200,000 acres of crucial winter range fall on BLM lands. More than 80,000 acres in the RMA serve as birthing areas, with 14,000 of those acres on BLM lands.

Figure 4 (right). Elk in the Pinedale Resource Management Area: migration routes, crucial winter range, and birthing areas. More than 198,000 acres of the Pinedale RMA have been designated as elk crucial winter range by the Wyoming Game and Fish Department. More than 105,000 acres of that winter range fall on BLM lands. Another 354,000 acres of the RMA are designated as birthing areas, of which 62,000 acres fall on BLM lands.

the sagebrush ecosystem in Wyoming also supports the region's cultural heritage; scientific research; hiking, hunting, and other recreational pursuits; and the local economy. Notably, wildlife-associated spending is Wyoming's second-largest source of income, bringing in $500 million annually (WYG&F 2004).

However, the same Upper Green River Valley lands that provide this outstanding wildlife habitat and important cultural values also contain some of the largest and most productive onshore natural gas fields in the nation. With escalating pressures to develop domestic energy supplies, oil and gas production in southwestern Wyoming has grown rapidly. More than 8,500 well sites have already been drilled on public lands in the region, and another 10,000–15,000 are forecast over the next decade (Berger 2004a). In fact, energy production in the Pinedale RMA is further accelerating due to Executive Order 13212, which requires federal agencies to expedite permitting and other reviews for approval of energy development projects (Berger 2003).

Substantial infrastructure and human activity are associated with energy development in the Pinedale RMA. For example, the environmental impact statement (EIS) for the Pinedale Anticline Natural Gas Project (BLM 2000) projects that up to 276 miles of roads will be built or upgraded during development of the Pinedale Anticline Field. The EIS estimates traffic at 702 round-trips per well over the 80-day drilling and construction phase, followed by 100 trips per year during the production life of the well, or 168 trips per day for the entire field of 500 wells. Similarly, the Jonah II Natural Gas Project EIS projects up to 180 miles of new or upgraded access roads, with 421 round-trips per well during construction and another 739 trips over each well's production life (or a total of 521,900 trips for the 450-well field over its 20-year life) (BLM 1998). The road mileage for the Jonah Field is expected to increase substantially under a new development plan in preparation at the time this report went to press.

Surface ownership of the lands in the Pinedale RMA is held by a variety of entities. The higher-elevation lands are primarily managed by the U.S. Forest

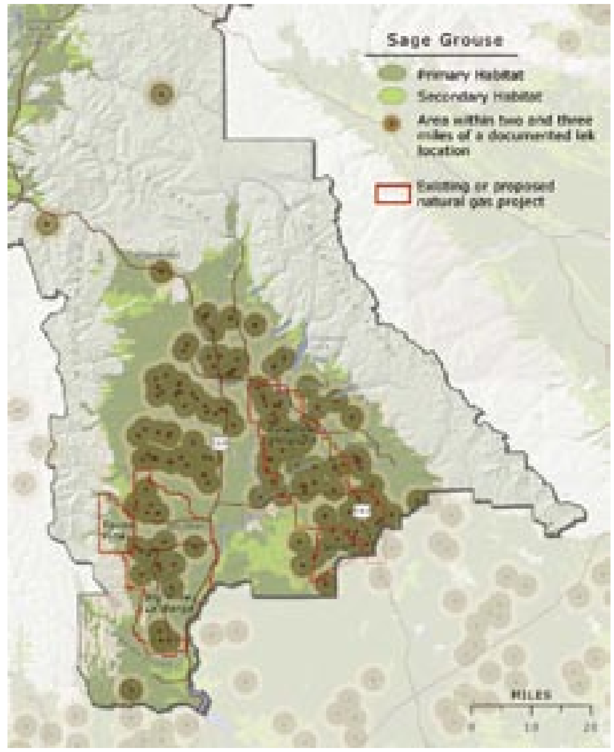


Figure 5. Sage grouse in the Pinedale Resource Management Area: habitat and leks. The Pinedale RMA includes more than 1.5 million acres of primary sage grouse habitat and about 200,000 acres of secondary habitat. Forty-nine of the 151 documented lek locations in the area fall within the Pinedale Anticline and Jonah gas field boundaries. In addition, more than 470,000 acres of BLM land in the area are within two miles of a lek, and 595,000 acres of BLM land are within three miles of a lek.

Service (USFS), while the lower-elevation areas are a patchwork of BLM and private ownership, with limited state holdings. However, across surface ownerships, the BLM controls substantial portions of the subsurface mineral rights and the development of oil and gas resources in the Pinedale RMA.

The BLM has a responsibility to manage the landscape for wildlife, energy development, and many other purposes. The agency is in the process of revising its Resource Management Plan (RMP) for the Pinedale RMA, which will set the terms for management over the next 15 to 20 years. The planning process will require the BLM to assess various alternatives for management and use of the public lands within the Pinedale RMA, and is guided by the BLM's obligations under the Federal Land Policy and Management Act (FLPMA) and the National Environmental Policy Act (NEPA).

FLPMA requires the BLM to "manage the public lands under principles of multiple use and sustained yield" in a manner that will "minimize adverse impacts on the natural, environmental, scientific, cultural, and other resources and values (including fish and wildlife habitat) of the public lands involved" (43 USC §1732). In developing management plans, the BLM must take into account physical, biological, economic, and other sciences; give priority to the designation and protection of Areas of Critical Environmental Concern (ACEC); and give consideration "to the relative values of the resources and not necessarily to the combination of uses that will give the greatest economic return" (43 USC §1712; 43 CFR §1601.0-5(f)). NEPA dictates that the BLM take a "hard look" at the environmental consequences of a proposed action, and the requisite environmental analysis "must be appropriate to the action in question" (42 USC §4321 et seq; *Metcalf v. Daley,* 214 F.3d 1135, 1151 (9th Cir. 2000); *Robertson v. Methow Valley Citizens Council,* 490 U.S. 332, 348 (1989)). The impacts and effects that the BLM is required to assess include "ecological (such as the effects on natural resources and on the components, structures, and functioning of affected ecosystems), aesthetic, historic, cultural, economic, social, or health, whether direct, indirect, or cumulative" (40 CFR §1508.8).

Oil and gas development in the Upper Green River Valley could threaten wildlife populations by fragmenting and causing disturbance in the crucial winter habitat, birthing areas, and migration corridors of big game species, and in the winter habitat, lekking areas, nesting sites, and rearing areas for sage grouse. For example, compromising winter habitat for big game in the valley could affect ungulate populations in five surrounding western Wyoming mountain ranges (Sawyer et al. 2004). Migration corridors are also vulnerable, particularly at "pinch points" where physiographic constrictions force herds through relatively narrow corridors (Berger 2004a). Loss of habitat continuity due to human activity along migration routes would severely restrict the seasonal movements necessary to maintain healthy big game populations (Sawyer and Lindzey 2000; 2001). In addition, unguided energy development would further depress declining sage grouse populations throughout the West. Prudent management that limits habitat fragmentation and disturbances from human activity along roads could give the species an opportunity to maintain, if not increase, its numbers. However, the direct and indirect impacts of energy development on wildlife are poorly understood (Sawyer and Lindzey 2004). Continued research and monitoring by wildlife management agencies, the BLM, and biologists at other institutions will be critical to designing a sustainable wildlife management strategy for the Pinedale RMA.

This report documents the intensity, extent, and spatial arrangement of wildlife impacts of the transportation network associated with oil and gas development in the Pinedale RMA. While the direct impacts from oil and gas drilling may be limited to the physical footprint of roads and well pads, the complex web of these structures across the landscape causes much broader, indirect effects on habitat quality and connectivity. Thus, a full understanding of the impact of oil and gas development on the region's wildlife requires an assessment of the spatial distribution of roads and other transportation routes (in both the areas subject to BLM management and the areas outside the agency's jurisdiction), combined with the latest wildlife research on the effects of roads and other infrastructure on specific wildlife species.

The methods and results of this report represent one of the major topics of information needed to design future management strategies in the Pinedale RMA. This report details a recommended process for assessing the ecological impact of roads on big game and sage grouse, shows the feasibility of performing such an analysis as part of the Pinedale RMP revision, and demonstrates the importance of using the results in evaluating management alternatives.

The Pinedale RMA was selected for this spatial evaluation of the impacts of energy development on wildlife because of its abundant and actively studied wildlife populations, its highly developed oil and gas fields, and the ongoing public planning process that will set the terms for energy development over the next 15–20 years. The analysis used to create this report, and the results generated, can be used by the BLM in revising the Pinedale RMP, in designating or limiting areas for further development, and in determining those areas where transportation routes should be closed or subject to limited use. The methods also serve as an example for other energy development sites.

Methods

Study area

This study focuses on the impact of roads and other transportation routes on wildlife in the lower-elevation areas of the Pinedale RMA that encompass most BLM surface ownership. The study area is roughly the southern half of the Pinedale RMA, which includes what residents and land managers consider the Upper Green River Valley. The study area accounts for about 2.9 million acres of BLM, USFS, state, and private lands within the 4.8-million-acre Pinedale RMA. It encompasses the portion of the Pinedale RMA within Lincoln, Sublette, and Fremont counties. The full Pinedale RMA, the study area boundaries, and surface ownership patterns within the Pinedale RMA are shown in Figure 1. The acreage of surface lands by ownership type within the study area is shown in Table 1.

The BLM has subsurface management authority, and thus authority over energy development, over 1.2 million acres of the study area. This includes the 992,370 acres that the agency manages at the surface, as well as additional "split estate" lands managed by state or private entities at the surface and by the BLM for subsurface energy development. Gas fields evaluated in this study include Jonah, Pinedale Anticline, and South Piney. These three gas fields are the current focus of industry development. They are either recently permitted or, in the case of South Piney, soon to be permitted.

Table 1. Acreage and percentage of the landscape within the four major land ownership categories in the study area.

	U.S. Forest Service	BLM	Private	State
Area in acres	1,252,815	922,370	609,134	86,501
Percent of study area	44%	32%	21%	3%

Data collection

Data representing the transportation network in the Pinedale RMA were obtained from the BLM Pinedale Field Office. This dataset is an updated version of the Topologically Integrated Geographic Encoding and Referencing (TIGER) data for transportation routes from the U.S. Census Bureau road dataset and includes additional routes digitized by Geographic Information System (GIS) staff at the BLM. Significant edits were made to the BLM dataset to remove duplicate records. The BLM is in the process of updating the dataset. Because this dataset includes roads and some, but not all, additional transportation routes that may not legally be considered "roads," we will use the more inclusive term "routes" or "transportation routes" when discussing this dataset (see sidebar, "Defining a Road.") Though the agency has digitized some user-created two-tracks and other routes, this dataset has not been completed, and thus our analysis represents a conservative assessment of the actual transportation network. Additional administrative data were collected from the Pinedale BLM Field Office, including the field office boundary, surface ownership boundaries, and gas field development area boundaries.

All data for big game species originated from the Wyoming Game & Fish Department (WYG&F). Winter range boundaries were used directly as supplied by WYG&F. Big game birthing areas and migration routes were updated with guidance from a local wildlife biologist with experience in the Pinedale area. The locations of occupied sage grouse leks were collected by WYG&F, and predicted distribution of sage grouse habitat originated from the Wyoming Gap Analysis Project, an interagency mapping effort. While these data layers were the best available at the time this work was conducted, WYG&F will continue to refine many of the habitat boundaries. The statistics documenting the impacts of transportation routes and habitat fragmentation on specific wildlife species that were used to guide our spatial analysis were collected from the scientific literature and will be cited throughout this document.

Defining a "road"

In this report, the terms "routes" and "transportation routes" refer to all linear features used by motorized vehicles, including "roads." However, the term "road" holds a precise legal definition with important management implications. Many but not all routes in the BLM's transportation dataset used in this analysis meet the definition of a road.

Within the Pinedale RMA, roads must meet criteria established in Title 43, Part 19.2(e) of the Code of Federal Regulations: "an improved road that is suitable for public travel by means of four-wheeled, motorized vehicles intended primarily for highway use." In addition, the legal definition of a road, according to the U.S. Department of the Interior, is derived from the definition of "roadless" in the legislative history of FLPMA: "roads which have been improved and maintained by mechanical means to insure relatively regular and continuous use. A way maintained solely by the passage of vehicles does not constitute a road" (H.R. Rep. No. 94-1163 at 17 (1976)).

Habitat fragmentation metrics

Fragmentation of habitat affects the ecological composition, structure, and functions of a landscape. Habitat fragmentation has been defined as the "creation of a complex mosaic of spatial and successional habitats from formerly contiguous habitat" (Lehmkuhl and Ruggiero 1991). Although fragmentation can be difficult to measure, we have chosen three landscape metrics to show the degree of fragmentation and the condition of the landscape, and applied them to available data regarding the distribution of wildlife and habitat. The metrics below were calculated for the entire landscape, as well as for areas within specific surface ownership types, gas fields, and critical wildlife habitat areas. Wildlife habitat boundaries were also used to calculate some basic habitat acreage figures and, for sage grouse, acreages within two and three miles of leks.

Route density. Route density is a measure of the number of miles of transportation routes per unit area, and is a common metric in quantitative assessments of ecological impacts of development from a landscape perspective. The density calculation involves measuring the length of linear transportation features in a given sub-area at regular intervals. For this analysis, the BLM transportation dataset was used to construct a "continuous" measure of route density across the Pinedale RMA. A sample spacing of 1,500 feet was used to measure route length within a 4-mi^2 circular sub-area. The result is a grid of density measurements where the value in each 1,500 × 1,500-foot cell is the total length of all routes in the nearest 4 mi^2, divided by 4 mi^2. Route density distribution curves were plotted to document the percent of the landscape with route densities greater than or equal to any given route density value. Density measurements are reported as miles of routes per square mile (mi/mi^2).

Core area. In order to characterize the degree of habitat fragmentation, the distribution of unroaded areas, or core areas, was measured for the entire Pinedale RMA. Core areas are defined as land beyond a given distance, or effect zone (Forman 1999), from transportation routes. Different wildlife species respond to disturbances related to a transportation network at varying distances. Thus, the size distribution of core areas was determined for effect zones of 100 ft, 500 ft, ¼ mile, ½ mile, and 1 mile from all routes in our dataset. A map of core areas was then plotted for one of these effect zones, 500 ft.

Distance to route. Wildlife-related restrictions on road or infrastructure construction and use are commonly given in terms of the distance by which the feature or activity must be separated from a given wildlife habitat of interest. Measuring the amount of land within a given distance to a transportation route (or route effect zone) is the reverse of measuring core areas. These two habitat fragmentation metrics complement one another and will be discussed together in later sections. To illustrate the amount of land that lies within various distances from transportation routes in the Pinedale RMA, we generated cumulative distance-to-route distribution curves for specific surface ownership types, gas fields, and wildlife habitat areas.

Other considerations. Note that all measures of habitat fragmentation in this report are conservative, because they do not take into account all of the undocumented routes visible in digital air photos of the landscape (Weller et al. 2002), other human infrastructure (e.g., well pads, pumping stations, pipelines, power lines) or natural breaks in the landscape (e.g., steep topography, rivers or washes, breaks in vegetation types). Actual infrastructure densities are likely higher, and core area sizes and distances to routes lower, than those captured in this analysis.

In addition, the varying speeds and volumes of traffic on different roads were not taken into account, because these attributes were not available for the BLM route dataset. These factors do affect wildlife, and are reflected in recommendations in this report. Similarly, seasonal access restrictions were not addressed in the analysis, because this information was not in the GIS data and because of imperfect enforcement of and exemptions granted to restrictions. For example, WYG&F has noted, "Seasonal stipulations are only effective if actually applied on the ground. To date, these stipulations have been inconsistently applied among BLM resource areas. Exceptions are routinely granted by some BLM resource areas, at times under what our Department believes are inappropriate circumstances" (WYG&F 2004). Specific access restrictions are suggested in the recommendations section.

Results

Route density analysis

Route densities vary considerably within the Pinedale RMA (Figure 6). A few key statistics characterize the differences in route densities across various land ownership types. The distribution of route densities is similar for state, private, and BLM lands, but route densities are markedly lower on USFS lands (Figure 7). Eighty percent of BLM lands have route densities of more than 1 mi/mi^2, and 36% of BLM lands have route densities of more than 2 mi/mi^2. By contrast, only 17% of USFS lands have route densities of more than 1 mi/mi^2.

Route densities within the crucial winter ranges of different ungulate species vary (Figure 8). For example, 66% of elk crucial winter range has route densities of more than 1 mi/mi^2. In addition, 80% of pronghorn and 89% of mule deer crucial winter range has route densities of more than 1 mi/mi^2.

The size and permit year of the Jonah, Pinedale Anticline, and proposed South Piney natural

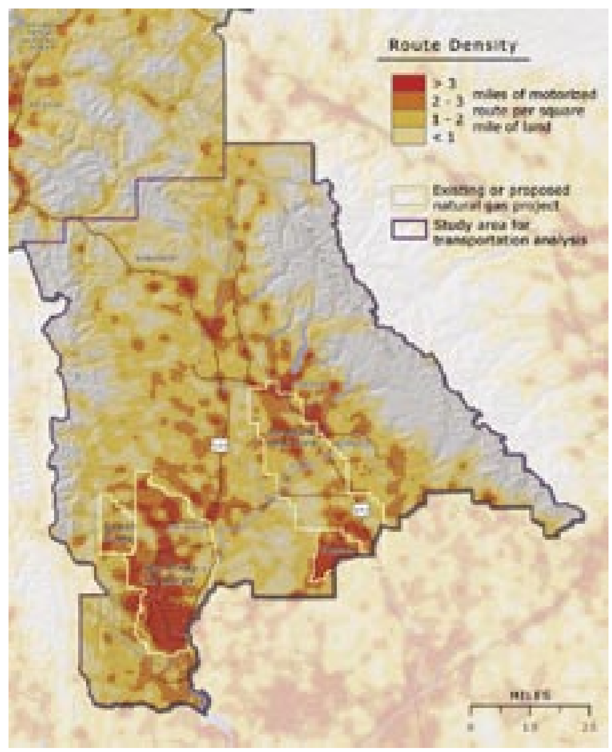


Figure 6. Transportation route densities in the Pinedale Resource Management Area. Eighty percent of BLM lands in the Pinedale RMA have route densities of more than 1 mi/mi^2. More than 35% of BLM lands have densities of more than 2 mi/mi^2. Fifty percent of the mule deer and pronghorn crucial winter range on BLM lands have route densities of more than 2 mi/mi^2. Fifty-four percent of the sage grouse leks on BLM land fall within areas with route densities of more than 2 mi/mi^2.

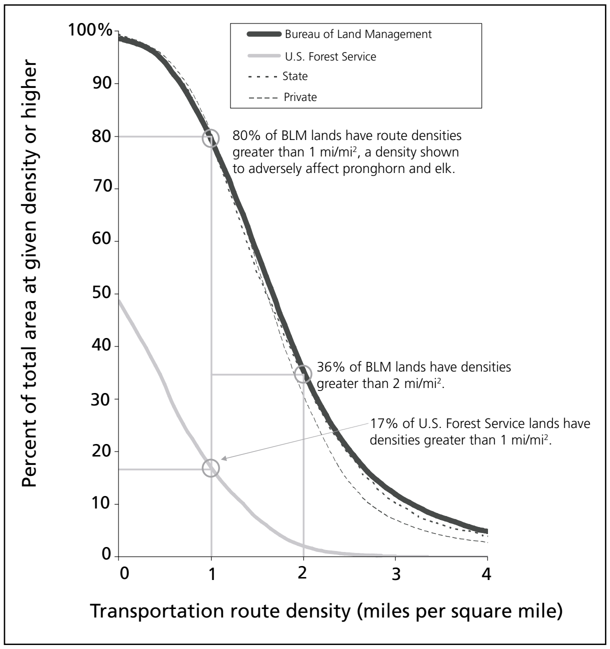


Figure 7. Transportation route density by land ownership type.

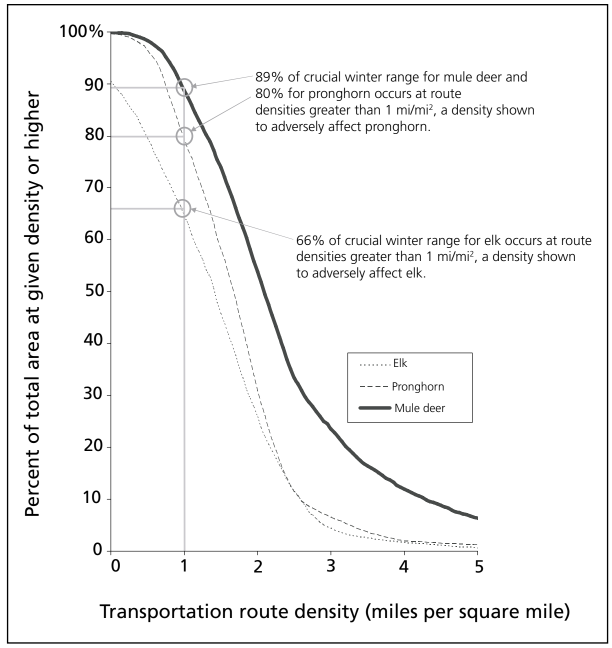


Figure 8. Transportation route densities for pronghorn, mule deer, and elk crucial winter ranges.

gas fields are summarized in Table 2. Route densities vary among the three fields. The Jonah Field, a fully developed gas field that is being considered for further "infill" drilling, has the highest route densities. Already, 95% of its area has route densities of more than 2 mi/mi². Route densities are lower in the Pinedale Anticline and proposed South Piney gas fields (Figure 9). The Pinedale Anticline is a recently permitted gas field (BLM 2000) where fewer than half the wells permitted have been drilled and half

Table 2. The development permit year and gas field size for the three gas fields where development is focused in the study area.

Gas field	Year permitted	Field size (acres)
Jonah	1998	47,000
Pinedale Anticline	2000	200,000
South Piney	pending	30,000

the new miles of road permitted have been bladed to date. The South Piney project is a proposed new gas field that to date has experienced only limited exploratory drilling. An EIS is currently being prepared to evaluate and potentially permit full field development. In both the Pinedale Anticline and South Piney fields, about 45% of the development area has route densities of more than 2 mi/mi².

Core area analysis and distance to route

The size of core areas—that is, wildlife habitat away from the disturbance of routes—varies substantially across the Pinedale RMA. State, private, and BLM lands are generally much closer to routes and have smaller core areas than USFS lands (Figures 10 and 11). About 63% of BLM land within the study area is less than ¼ mile from a route. Less than 20% of USFS land lies within this same proximity to

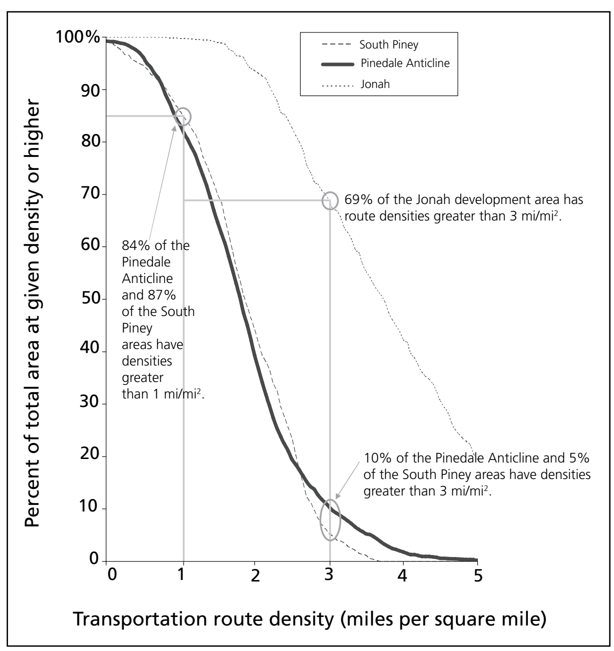


Figure 9. Transportation route densities in three gas fields.

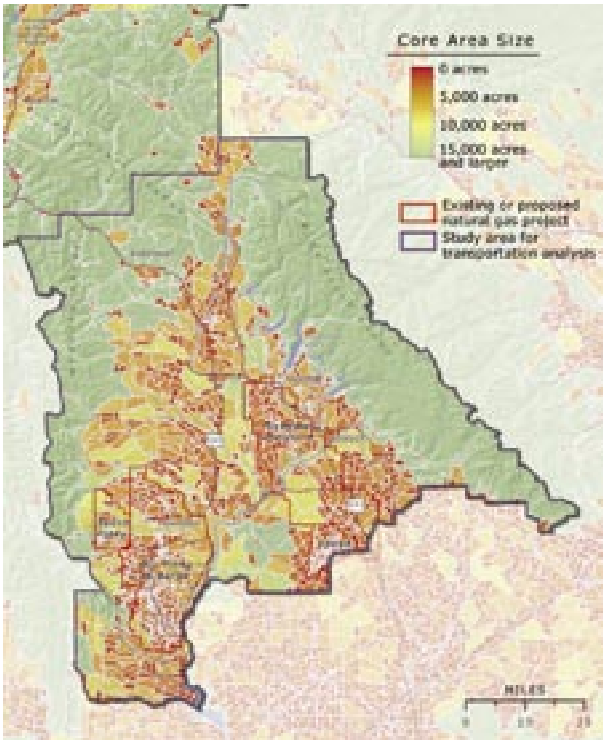


Figure 10. Core habitat areas outside the 500-foot transportation route effect zone. Considering an effect zone of 500 feet on either side of a route, the study area is fragmented into more than 2,021 "unroaded" core areas on BLM lands. These core areas have an average size of just over 300 acres.

a route. Notably, 87% of BLM land is within ½ mile of a route.

Statistics relating to core areas as defined by various route effect zone widths on BLM lands within the study area are shown in Table 3. For example, for effects on wildlife that extend 100 feet from a route, 90% of the landscape falls within the 2,596 core areas with a maximum patch size of 20,925 acres. For impacts on wildlife species that extend one mile from a route, only 2% of the landscape would fall within the 50 core areas with a maximum patch size of just 5,384 acres. A route effect zone of 500 feet is illustrated graphically in Figure 10, where BLM lands in the study area are fragmented into 2,021 core areas.

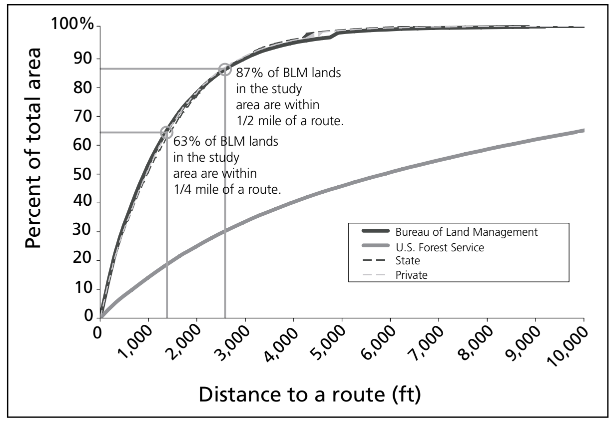


Figure 11. Cumulative distributions of distance to routes by land ownership type.

Core area habitat is limited in ungulate crucial winter range (Figure 12). For example, 90% of elk crucial winter range is within one mile of a route. Eighty-nine percent of pronghorn and 90% of mule deer crucial winter habitat is within ½ mile of a route. The study also shows little core area in the vicinity of sage grouse leks. Less than 30% of sage grouse leks falls within core areas farther than ¼ mile from a route, and only about 5% are farther than ½ mile from a route.

Core area habitat is most severely restricted within the study area's gas fields (Figure 13). The Jonah Field is most heavily affected by routes, with about 70% of its total area within 600 feet of a route and nearly all of the field within ½ mile of a route. In the Pinedale Anticline and South Piney fields, nearly 40% of the total area is within 600 feet of a route, and just under 90% is within ½ mile of a route.

Discussion

The nationally significant wildlife populations of the Upper Green River Valley are threatened by habitat loss and fragmentation from roads con-

Table 3. Characteristics of core areas as defined by different route effect zone widths.

	Route effect zone width				
Core areas	**100 ft**	**500 ft**	**¼ mi**	**½ mi**	**1 mi**
Number	2,596	2,021	1,105	430	50
Max acres	20,925	16,268	13,277	7,886	5,384
Min acres	<1	<1	<1	<1	<1
Mean acres	318	305	305	282	323
Total area in acres	826,172	616,685	336,526	121,380	16,163
Total area as percentage of study area	90%	67%	36%	13%	2%

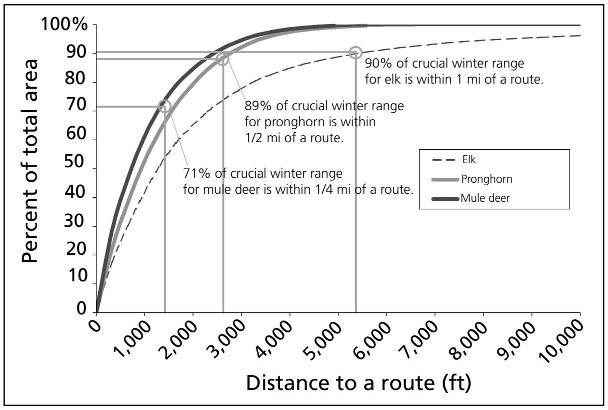


Figure 12. Cumulative distributions of distance to routes in pronghorn, mule deer, and elk crucial winter ranges.

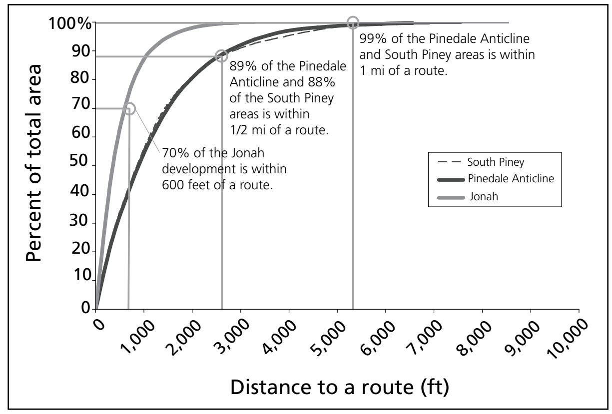


Figure 13. Cumulative distributions of distance to routes for three gas fields.

structed for energy development (WYG&F 2004). The BLM inventoried a substantial network of roads and other transportation routes, many directly associated with energy development, that fragment wildlife habitat in the Pinedale RMA.

Increasingly, scientists are assembling reviews of the effects of roads, other types of routes, and associated human activities on wildlife (Gucinski et al. 2001; Gaines et al. 2003). However, literature on this topic remains relatively scarce for rangeland landscapes. The Wyoming Game and Fish Department recently completed a report containing guidelines for wildlife protection in areas of energy development (WYG&F 2004). It includes a review of the literature on the impacts of roads, other infrastructure, and human activities associated with energy development on sagebrush and grassland habitats and their associated wildlife species in Wyoming.

Many studies have found that the effects of roads and other infrastructure extend well beyond the physical footprint of the feature (Lyon and Christensen 2002; Lutz et al. 2003; WYG&F 2004). The effects on terrestrial and aquatic wildlife include mortality from collisions, modifications of animal behavior (and effects on energetics), disruption of the physical environment, alteration of the chemical environment, fragmentation of connected habitats, spread of exotic species, and changes in human use of lands and water (Trombulak and Frissell 2000; Lutz et al. 2003).

More specifically addressing the infrastructure of energy development, the WYG&F report states: "As densities of wells, roads, and facilities increase, the effectiveness of adjacent habitats can decrease until most animals no longer use the habitat. Although vegetation and other natural features may remain unaltered within areas near oil and gas features, wildlife make proportionately less use of these areas than their availability. Animals attempting to forage inside the affected zones are also subjected to increased physiological stress. The avoidance/stress effect impairs the function by reducing the capability of wildlife to use the habitat effectively" (WYG&F 2004).

The Wyoming Game and Fish Department attributes six categories of effects specifically to oil and gas development: "1) direct loss of habitat, 2) physiological stress to wildlife, 3) disturbance and displacement of wildlife, 4) habitat fragmentation and isolation, 5) introduction of competitive and predatory organisms, and 6) secondary effects created by work force assimilation, growth of service industries, etc." (WYG&F 2004).

Implications of habitat fragmentation for wildlife species

In the present study, the highest route densities and lowest distance-to-route values (i.e., the smallest core areas) are found on the BLM, state, and private lands within the study area (Figures 7 and 11). In fact, route densities and distance-to-route values are very similar for these three land ownership classes. Route densities are lower and distance-to-route values higher on the USFS lands on the east, north, and west edges of the study area. Yet these less-fragmented lands cannot be expected to provide needed habitat for many of the wildlife species on BLM lands, because these lands are higher in elevation, provide substantially different vegetative habitat, and experience snow depths that prohibit use by many species during the winter months. The concentration of more-fragmented lands at the lower elevations critical for big game and sage grouse populations makes evaluating the impact of energy development and managing for sustainable habitat exceedingly important.

While the degree of impact of roads on wildlife is not fully understood, our results indicate that route densities are high enough, and distance-to-route values low enough, in the BLM route inventory to adversely affect the four wildlife species studied. Comparison of wildlife habitat areas (Figures 2, 3, 4, and 5) with the route density map (Figure 6) and the core area map (Figure 10) illustrates graphically just how abundant routes are in ungulate winter range, birthing areas, and migratory corridors, as well as around sage grouse leks.

Mule deer

Energy development has the potential to directly and indirectly impact mule deer and their habitat, possibly leading to reductions in survival and reproductive capacity and potentially limiting the population's ability to sustain itself (Lutz et al. 2003). These effects can extend well beyond the area of the development and continue past the time period of the development (Lutz et al. 2003). Rost and Baley (1979) used mule deer pellet counts in north-central Colorado as an indication of winter habitat use, reporting lower densities of deer in open, mixed shrub, and forest habitat compared to sites with more forest cover. Their data showed that deer were three times more likely to occur 984–1,312 feet from a road than 328 feet from a road. Within our study area in the Pinedale RMA, 23% of BLM land and 29% of mule deer crucial winter range are closer than 328 feet to a route, and thus likely to show relatively reduced use by mule deer.

Another study of female mule deer in sagebrush winter range in north-central Colorado observed response distances to people on foot and on snowmobiles (Freddy et al. 1986). Mule deer were observed to alert to persons on foot and on snowmobiles at 1,096 feet and 1,542 feet, respectively, and to move away from these disturbances at distances of 436 feet and 627 feet. Measuring these response distances relative to routes in the Pinedale RMA reveals that mule deer could be affected by activities on roads in 35–77% of their crucial winter range habitat. This suggests human activity around drill pads in the winter could affect mule deer movements. The Wyoming Game and Fish Department used the alert distance of 1,542 feet to calculate that there is a 29-acre area of reduced habitat effectiveness around each drill pad (WYG&F 2004).

While data on mule deer response specifically to energy development are minimal (Lutz et al. 2003), mule deer have been shown to avoid human activity associated with roads and energy production facilities. A study in a North Dakota energy development area observed that active deer used habitat within 316 feet of a road less than its availability might suggest, while bedded deer avoided habitat within 158 feet of a road (Fox 1989).

An ongoing study by Sawyer et al. (2004) of Global Positioning System (GPS)-collared deer in the Pinedale Anticline Field found that deer utilized habitat progressively farther from roads and well pads over three years of increasing gas development and showed no evidence of acclimating to energy-related infrastructure. The effects of development were immediate, and areas of "high probability of use" before gas development were used substantially less after development, suggesting that deer may be displaced to less-preferred habitat (Sawyer et al. 2004). Lutz et al. (2003) agree that mule deer can be pressured into using less-preferred or lower-quality habitat, and that this could negatively affect an individual's energy balance "and ultimately decrease population productivity, especially on winter range." Sawyer et al. (2004) further suggest that direct loss of habitat from road and pad construction, combined with indirect loss from changes in habitat quality, may reduce winter range carrying capacity. To date, NEPA-based monitoring of the impacts of energy development on mule deer has not been sufficient to add to needed knowledge and has not been published in peer-reviewed literature (Sawyer and Lindzey 2004).

Pronghorn

Pronghorn are likely to be affected by the same types of human disturbance as mule deer, but are known to have a more sensitive flight response (WYG&F 2004). Based on preliminary results from on ongoing study by Berger and Beckmann (2004) in the Jonah and Pinedale Anticline fields, WYG&F (2004) concludes that migrating pronghorn avoid areas of dense energy development. BLM documents indicate that pronghorn are adversely affected at road densities of 1 mi/mi^2 (BLM 1999). Eighty percent of BLM lands and 80% of pronghorn crucial winter range in the study area have road densities of more than 1 mi/mi^2.

A study in central Arizona showed that pronghorn generally exhibited a weak avoidance of areas within 3,168 feet of a maintained road, as well as areas near non-maintained dirt roads and fourwheel-drive trails (Ockenfels et al. 1994). Ninety-two percent of BLM lands and 94% of pronghorn crucial winter range in the study area fall closer than 3,168 feet to a route. Additionally, pronghorn may be more strongly affected by the noise and activity associated with a road than by the roadbed itself (Ockenfels et al. 1994), suggesting that temporal occupancy restrictions are particularly important. Also, an ongoing pronghorn study in the Pinedale area shows that the configuration and density of well pads and other surface disturbances further affect pronghorn use, and that there may be a threshold beyond which habitat utilization no longer occurs (Berger and Beckmann 2004).

Elk

In a major volume reviewing elk ecology and management, Lyon and Christensen (2002) stated, "Access—mainly that facilitated by roads—is perhaps the single most significant modifier of elk habitat and a factor that will remain central to elk management on public and private lands." Research by Lyon (1983) in forested habitat indicated that elk habitat effectiveness is reduced by 25% at road densities of 1 mi/mi^2, and by 50% at densities of 2 mi/mi^2. Eighty percent of the BLM lands in our study area have route densities of more than 1 mi/mi^2, and 36% have densities of more than 2 mi/mi^2. A study of elk habitat effectiveness in a forested area of north-central Wyoming found that few elk used areas with road densities of more than 0.5 mi/mi^2 (Sawyer et al. 1997). Ninety-five percent of BLM lands and 80% of elk crucial winter range in the study area of the Pinedale RMA have route densities of more than 0.5 mi/mi^2.

The above numbers are conservative, because the studies by Lyon (1983) and Sawyer et al. (1997) were conducted in forested landscapes, and road avoidance by wildlife is increased in open landscapes, such as in the study area, where one finds reduced habitat security (Perry and Overly 1976; Morgantini and Hudson 1979; Rost and Bailey 1979; Lyon 1979). A study in open habitat at Jack Morrow Hill in Wyoming observed that elk avoid areas within 1.2 miles of roads and active oil and gas wells in the summer and within 0.6 miles of these features in the winter (Powell 2003). It is possible that in areas with no cover, road densities of less than 1 mi/mi^2 may eliminate effective habitat (Lyon 1979). In our study area, 80% of BLM lands and 66% of elk crucial winter range have route densities of more than 1 mi/mi^2.

Additionally, Phillips and Aldredge (2000) observed that human disturbance during the calving season reduces elk calving success rates; they recommend maintaining "disturbance-free" areas during the calving season, based on work in alpine areas in Colorado. A radiotelemetry study by Edge and Marcum (1991) measured only a 5% probability of elk using lands within 0.6 mi of a road during calving season. In our study area, 82% of the 62,000 acres of elk birthing areas on BLM lands fall within 0.6 miles of a route.

Note that the role of elk winter feedgrounds is not addressed by the present study. State and federal agencies have made a substantial effort to protect ranchers' stored and feed hay from elk since the early 1900s (Dean et al. 2004). Since the 1970s, they have also endeavored to separate elk from cattle in order to minimize the spread of the ungulate disease brucellosis (Dean et al. 2004). These actions greatly complicate management strategies for elk. However, they do not negate the need to manage for high-quality elk winter range, birthing areas, and migration routes in the Upper Green River Valley.

Sage grouse

Research indicates that activities associated with gas field development—including road construction—can cause declines in nearby sage grouse populations (Braun 1998). Habitat used for wintering, lekking, nesting, and brood-rearing are of most concern in our study area. Because roads constructed for gas exploration and development result in permanent travel routes to previously inaccessible regions, the negative impacts on sage grouse are not limited to the initial development phase of an oil or gas field. Landscapes with less habitat fragmentation, better shrub structure, and a diverse understory of grasses and forbs are more secure for prey animals such as sage grouse (Braun 2002). The construction of fences, power lines, and other infrastructure, as well as the associated decreases in patch sizes and diversity, benefit sage grouse predators (Braun 2002).

Work by Lyon (2000) indicates that traffic disturbance has a long-term negative impact on breeding hens. The study, conducted in the region of the Pinedale Anticline Field, involved documenting nest-initiation and brood-rearing success rates of 48 hens from six leks in the area. The nest-initiation rate over a two-year period was 55% for hens from the three leks in close proximity to a road (average distance of 2,382 feet to a road). Hens from the three leks farther removed from roads (average distance of 7,742 feet) had a nest-initiation rate of 82% over the same period. Following the same hens through early brood-rearing, Lyon determined that the hens that were most successful at raising chicks nested farther from roads (an average of 3,734 feet) than hens whose broods did not survive the first three weeks after hatching. Unsuccessful brood-rearing grounds averaged 879 feet from the nearest road. Forty-nine percent of BLM lands in the study area are within this distance of a route.

A recent field study by Holloran and Anderson (2004) measured the influence of natural gas development on sage grouse in the Pinedale Anticline and Jonah fields between 1998 and 2004. Results showed mean annual declines of 32% in the maximum number of males at leks within two miles of a drilling rig and declines of 19% within 1,640 feet of a road. The authors also stated, "Although lek attendance, male and female survival, and female demographics varied depending on lek-to-drilling-rig and nest-to-drilling-rig distances, the data suggest that the presence of a drilling rig within 5.5 kilometers [3.4 miles] directly and indirectly influenced sage grouse."

The Wyoming Game and Fish Department (2004) recommends that where sage grouse habitat has already been fragmented (as we have documented for this study area of the Pinedale RMA), future development "should completely avoid remaining habitats." The agency proposes a series of guidelines for development within two miles of a lek or nesting and rearing habitat, and recommends no roads or other infrastructure within 656 feet of identified winter habitat. To protect breeding areas, a number of authors (Braun 2002; Connelly et al. 2000; Braun et al. 1977) have suggested that areas within three miles of leks should be free of road disturbance during breeding and brood-rearing. All BLM lands within the study area are within three miles of a route. In fact, 98% of BLM lands are within one mile of a route. This suggests that most of the leks identified by WYG&F (Figure 5) may lie within habitat sufficiently fragmented and potentially open to disturbance during the breeding season as to have already reduced breeding functions.

Additional route impacts to wildlife

Beyond the fragmentation effects discussed above, transportation routes directly affect these wildlife species by blocking migration paths. Natural and human-made bottlenecks, or pinch points, in the 40–150-mile migration corridors for pronghorn and mule deer in the Pinedale RMA have been documented by Sawyer and Lindzey (2000; 2001) and Berger (2004a). Severing migration routes at these pinch points through additional road building for energy development or other purposes would threaten the fall and spring migrations, and thus maintenance of healthy populations, of these species (WETI 2003). According to WYG&F (2004), "long term displacement of wildlife from preferred habitats and disruption of migration routes could, in the extreme case, extirpate 'migration memory' that required several thousand years to evolve." Additionally, vehicle traffic and other human activities along roads can tax animals' limited energy reserves during the winter months. Increased stress and activity required to avoid roads (or other infrastructure) are likely associated with many roads in our study area within ungulate crucial winter range.

Limitations of this assessment and future research needs

Most importantly, additional monitoring is needed to understand the specific direct, indirect, and cumulative effects of roads, well pads, other energy infrastructure, and related human activities on wildlife species. Citations from the biological literature included in this report—while not exhaustive—are some of the best available, but fall short of what is needed. Nevertheless, our comparison of landscape measures of route density and distance-to-route values with scientific literature on the responses of wildlife to such infrastructure indicates that substantial caution is warranted in the permitting of additional energy roads and infrastructure.

Further, because the RMP currently in preparation will likely guide activities in the Pinedale RMA for 15–20 years, it is reasonable to expect an increase in proposed roads and infrastructure, and a corresponding increase in impacts to wildlife, over that time. Still, additional research is vital to understandinging the effects of this development. In particular, research is needed on species-specific impacts from different types, levels, and times (of day and season) of road use as well as activity levels and times of use on drill pads.

Our analysis is based on the best available GIS data for transportation routes and for the habitat boundaries of the targeted wildlife species. However, no GIS dataset is ever entirely complete and accurate, and many of the data layers used in this study will continue to be updated by various land-management and wildlife-management agencies. As stated earlier, the GIS route data available from the BLM at the time of our assessment did not include seasonal restriction information; consequently, this information was not incorporated into our analysis.

There are several additional caveats. This study likely underestimates actual habitat fragmentation in the study area because it only addresses fragmentation resulting from transportation routes. That is, it does not account for other features that fragment the landscape such as other human infrastructure (e.g., pipelines, fences), natural topographic barriers, and natural vegetation breaks. In addition, the BLM route dataset did not capture all transportation routes. Nor does the study address habitat connectivity, variations in scale, differences in types of transportation features, or habituation to hunting regulations or other human activities. When these factors are considered, it may well be that even less optimal habitat remains than we have estimated here. With additional field research, a more comprehensive assessment of fragmentation metrics for each species or set of species could be generated.

Finally, the study does not address additional fragmentation and wildlife impacts from routes that have been permitted but not yet built. In the Pinedale Anticline Field, for example, many miles of roads, drill pads, and related infrastructure will be built in the coming years under the limits established in the 2000 EIS record of decision.

Recommendations and conclusions

This report demonstrates the feasibility of spatial analysis and its applicability to the decisions that will be made during the Pinedale RMP revision. Transportation routes and associated energy development infrastructure have a range of effects—direct, indirect, and cumulative—on the landscape. Informed decisionmaking requires state-of-the-art tools such as spatial analysis to provide critical information and gauge the potential negative effects of these routes on ecosystems.

As noted earlier, NEPA requires federal agencies to assess the direct, indirect, and cumulative environmental impacts of proposed actions, taking a "hard look" at environmental consequences and performing an analysis commensurate with the scale of the action at issue. In addition to field monitoring, spatial analysis is an appropriate way to take that hard look, particularly in relation to the impacts of roads and all energy development infrastructure on wildlife. We believe the BLM must apply these techniques to meet the requirements of NEPA.

The results of our spatial analysis suggest that the existing transportation route network in the Pinedale RMA is endangering wildlife populations through fragmentation and destruction of habitat. As noted above, the pressures on wildlife from development are likely to increase during the RMP's applicability over the next 15–20 years. Therefore, accurately assessing the effects of transportation routes on wildlife and taking action to ameliorate these impacts through RMP revision and other efforts is essential.

We recommend that the BLM employ the spatial analysis techniques used in this report to carefully evaluate the impacts of the existing transportation network on other species and natural and cultural resources in order to assess the need for closure and other limitations on the use of existing roads (and other routes), and to develop and thoroughly evaluate alternative transportation networks. We also recommend that the BLM continue to update data on the distribution and quality of wildlife habitat. Under the Data Quality Act, the BLM is required to use high-quality information that is objective, useful, and verifiable by others, and to use "sound statistical and research" methods (BLM 2002).

Especially in the absence of adequate data, science cannot always provide clear and certain answers to important questions about potential environmental impacts in a timely fashion. Lack of accurate boundaries for wildlife habitats and an incomplete understanding of the impacts of roads and other types of routes on wildlife are real problems that demand additional research.

However, such gaps in knowledge must not stop or delay decisions to protect wildlife resources by reducing the number and mileage of transportation routes across a landscape. Substantial numbers of published scientific studies suggest that roads and other transportation routes and their associated human activities can negatively affect wildlife at route-density and distance-to-route values like those measured in the present study. We recommend that management planning—using the best available data, techniques, and results such as those presented in this report—should proceed, with an emphasis on reductions in road densities and increases in the number and size of core habitat areas in ungulate wintering grounds and along migration corridors, and in sage grouse wintering, lekking, nesting, and rearing areas.

A key step in achieving these goals is implementing a consistent approach to identifying roads and other routes for closure and reclamation. We recommend that the BLM identify and schedule for closure routes that do not have a specific ongoing use (i.e., those that are not associated with active energy development or do not provide access to a publicly recognized destination) and those providing redundant access, as suggested in the BLM's "Guidance for the Management of Sage Brush Plant Communities for Sage grouse Conservation" (BLM 2004).

In addition, we recommend that the BLM identify routes that impact wildlife habitat or increase the likelihood of non-compliance with existing conservation mandates, such as the Endangered Species Act, and then consider closing those routes or otherwise mitigating their identified impacts, including by rerouting, seasonal closures, or limitations on use. For those roads and routes that will be closed, the BLM should adopt obliteration and reclamation standards that will restore the area.

Our recommendations are in concert with the "precautionary principle" of conservation biology, which states that precautionary measures should be taken when a certain activity or inactivity threatens to harm human health or the environment, even when science has not fully established cause-and-effect relationships (Meffe and Carroll 1994; Noss and Cooperrider 1994). This principle is rooted in the recognition that scientific understanding of ecosystems is complicated by numerous factors, including dynamic ecosystem processes and the various effects of human activities. Put simply, it is easier to prevent harm to biodiversity than to attempt to repair it later. This prevention of harm is critical for ungulate winter range and migratory routes and for sage grouse wintering, lekking, nesting, and rearing areas in the Pinedale RMA.

Specific wildlife recommendations

Our analysis indicates that the existing transportation network identified by the BLM fragments wildlife habitat across the Pinedale RMA and is sufficiently likely to cause negative effects on all four of the wildlife species studied such that constraints on road use and energy development are warranted. We did not assess the potential impacts of the transportation network on other wildlife species in this analysis. However, the study area contains numerous additional species that would also be subject to the effects of transportation routes and their use. We recommend that the BLM take several actions to alleviate these effects:

(1) Ensure that plans are developed and implemented so that the scientifically derived standards listed below for reducing the impact of transportation routes on the four wildlife species addressed in this report are met. These standards should be met by closing and reclaiming routes not associated with active energy development or other specifically designated uses, routes providing redundant access, and routes excessively impacting habitat—and by mitigating the impacts of transportation routes through seasonal activity restrictions.

a. *Mule deer:* Increase the amount of core area to more than 1,542 feet (Freddy et al. 1986) from a road or other transportation route within mule deer crucial winter range and along migration routes. Allow no drilling or surface occupancy between November 15 and April 30 (WYG&F 2004) within crucial winter range.
b. *Pronghorn:* Increase the amount of core area to more than 3,168 feet (Ockenfels et al. 1994) from a road or other transportation route and reduce route densities to less than 1 mi/mi^2 (BLM 1999) within pronghorn crucial winter range and along migration routes. Allow no drilling or surface occupancy between November 15 and April 30 (WYG&F 2004) within crucial winter range.
c. *Elk:* Reduce road or other transportation route densities to less than 1 mi/mi^2 (Lyon 1979) within elk crucial winter range and along migration routes. Allow no drilling or surface occupancy between November 15 and April 30 (WYG&F 2004) within crucial winter range.
d. *Sage grouse:* Implement seasonal restrictions on traffic on all roads and other transportation routes within 656 feet (WYG&F 2004) of winter habitat (9:00 AM–5:30 PM, mid-November through March), within three miles of leks (Braun 2002; Connelly et al. 2000; Braun et al. 1977) or breeding and nesting areas (9:00 AM–5:30 PM, March through mid-May), and in brood-rearing areas (9:00 AM–5:30 PM, June through mid-July) (C. E. Braun, pers. comm.). Set a maximum speed limit of 30 miles per hour during restricted seasons during unrestricted hours (C. E. Braun, pers. comm.).

(2) Allow few exceptions to temporal occupancy restrictions. Temporal restrictions allow the BLM to fulfill its mandate to manage lands for multiple use and to prevent undue and unnecessary degradation of the land. Only short-term exceptions to temporal occupancy restrictions should be allowed, and only in limited cases as identified in the RMP.

Per the BLM's *Handbook on Planning for Fluid Minerals,* "[a]ll circumstances for granting a waiver, exception, or modification must be documented in the plan" (BLM 1990). BLM regulations also emphasize the importance of limiting exemptions from stipulations, stating: "[a] stipulation included in an oil and gas lease shall be subject to modification or waiver only if the authorized officer determines that the factors leading to its inclusion in the lease have changed sufficiently to make the protection provided by the stipulation no longer justified or if proposed operations would not cause unacceptable impacts" (43 CFR §3101.1–4). Also, a 30-day public review and comment period should be provided for modification or waiver of a stipulation prior to lease issuance if the stipulation involves an issue of major concern to the public and subsequent to lease issuance if the modification or waiver is deemed "substantial" (43 CFR §3101.1–4).

(3) Ensure directional drilling and cluster development. In its revision of the Pinedale RMP, the BLM should establish guidelines and requirements for operators to use directional drilling techniques and clustering of drill holes and other infrastructure on a single pad (UGRVC 2004). Such techniques can reduce the physical footprint of energy development and the impacts on wildlife (Molvar 2003; WYG&F 2004) and reflect best management practices endorsed by the BLM to mitigate the impacts of oil and gas development in Instruction Memorandum No. 2004-194, Integration of Best Management Practices into Application for Permit to Drill Approvals and Associated Rights-of-Way.

(4) Implement a plan for staged development for potential future energy development. The revision of the Pinedale RMP should lay out a staged leasing strategy in which some areas of the landscape are open for development while others are temporarily withdrawn. The staged leasing should be designed to ensure that critical winter range, birthing areas, and migration corridors for ungulates and winter habitat, breeding grounds, and nesting and rearing areas for sage grouse are not intensely developed all at once. This will not only disperse wildlife impacts over time and allow economic benefits to last longer, but also will allow time for the monitoring and evaluation of development impacts on wildlife.

(5) Restrict new roads and energy development. The revision of the Pinedale RMP should not allow any new energy development, expansion of existing development, or road construction within big game crucial winter range or at the pinch points of migration routes. Directional drilling should be required for any extraction of natural gas under these areas, with no surface disturbance or road construction allowed.

(6) Designate Areas of Critical Environmental Concern (ACEC). Designate the lands comprising winter range and/or migration route pinch points for multiple big game species as Areas of Critical Environmental Concern (ACEC), subject to management prescriptions that will protect their use for big game winter range and/or migration. The prescriptions should include: no creation of new routes, no expansion of existing routes, no new leasing (unless "no surface occupancy"), no new energy development, no cross-country travel, limitation of off-road vehicle use to designated routes, and closure of unnecessary routes. The new ACEC should include those nominated by various groups in a joint 2002 petition to the BLM during the RMP scoping period (Defenders of Wildlife et al. 2002) and addressed in the "Responsible Energy Development" proposal submitted to the BLM by the Upper Green River Valley Coalition (2004): the Trapper's Point Mule Deer and Pronghorn Migratory Bottleneck, Cora Butte Mule Deer and Pronghorn Transition Range, Fremont Lake Mule Deer Migratory Bottleneck, Green River Crossing Area, LaBarge Creek Native Elk Winter Range, and the Wind River Front area currently off-limits to leasing. We also recommend including ACEC designation for the Wyoming Range front proposed for no leasing or leasing with no surface occupancy by the Upper Green River Valley Coalition (2004). Sage grouse winter habitat is not yet fully documented. This habitat needs to be mapped, and at least 90% should be designated as ACEC, with the implementation of management strategies that would preserve cover and forage required for winter months (Braun 2002).

The above recommendations are based on the best available research about wildlife–road interactions and the distribution of habitat for the targeted species. As better data become available from agency and academic sources, the above recommendations can and should be adjusted and improved through an adaptive management process.

General recommendations for protection of wildlife

(1) Apply the analysis used to create this report, and the results generated, to inform the Pinedale RMP revision and to create a responsible travel management plan as part of the current planning

process. The BLM is legally required to designate areas and routes, avoid impairment of the public lands, and protect wildlife and other resources through its land use planning process. A spatial analysis of the impact of roads, other transportation routes, and other infrastructure on wildlife is also a key component of creating a comprehensive travel plan for the Pinedale RMA. In the Pinedale RMA, rapid expansion of roads to support gas exploration and development has been occurring and is projected to continue at a similar pace, heightening the adverse impacts on wildlife and, as a consequence, the corresponding importance of addressing these impacts through travel planning.

(2) Adopt an RMP that includes significant route decommissioning and restoration of the landscape's ecological health and integrity. Specific procedures, protocols, and priorities should be defined and implemented to close and reclaim roads and other transportation routes, including a schedule for closure and reclamation of specific roads and routes; requirements for immediate reclamation of unused areas and commencement of initial reclamation if no production activities have taken place for six months; requirements for submission and approval of reclamation plans with applications for permit to drill; requirements that reclamation plans include decompaction of soils, restoration of original contour and drainage, replanting of native vegetation, obliteration of visual evidence, and use of specified seed, fill, and other materials and methods as appropriate; monitoring of compliance with reclamation plans; and institution of scientifically based standards to assess when reclamation has been achieved (over and above simple re-seeding requirements).

(3) Use landscape fragmentation metrics to guide any and all management decisions regarding transportation routes. Calculate route density, core area, and distance-to-route (or route effect zone) metrics in accordance with scientific literature on wildlife species and evaluate the likely impacts of potential road networks on wildlife species and other resources the BLM is required to protect under relevant laws and policies. Goals should include reductions in road density and increases in core areas to provide greater habitat security.

(4) For all new roads that are built, follow the road construction guidelines of WYG&F (2004) to minimize the effect of routes on wildlife.

(5) Include clear enforcement mechanisms in the revision of the Pinedale RMP so that impacts of energy development on wildlife are minimized. These mechanisms should include a plan for enforcing permanent road closures, temporary/seasonal road closures, limits on off-road travel in designated areas or times of year, limits on road and well pad construction in critical habitats, and requirements for directional drilling and cluster development.

(6) Continue to evaluate the impacts of routes on wildlife (and other resources) as part of the travel management planning process and subsequent ongoing adaptive management. Ongoing NEPA-related monitoring of wildlife impacts from routes, well pads, and related human activities such as those described by Sawyer and Lindzey (2004) should be defined in the final RMP and implemented over the course of the development. The BLM must apply landscape fragmentation analysis to design a plan that meets its responsibility to protect all of the region's resources for multiple use and sustained yield, and give priority to designation and protection of ACEC.

(7) Promote additional wildlife research by the BLM, WYG&F, and other agencies and institutions. The BLM should encourage the collection of up-to-date, accurate digital data on the distribution of wildlife habitats and work to understand more thoroughly the ecological impacts of all types of transportation routes on wildlife species in the Pinedale RMA. In particular, research is needed on species-specific impacts from different types, levels, and times (of day and season) of road use, as well as impacts from different activity levels and times of use on drill pads.

Conclusions

Sagebrush ecosystems found in the Upper Green River Valley of western Wyoming contain crucial habitat for some of the largest migratory populations of ungulates in North America, and offer a chance for survival of healthy populations of sage grouse and other obligate sagebrush species. Yet fragmentation and declining quality of the valley's sagebrush and grassland ecosystems are the principal reasons why populations and distributions of dependent wildlife are declining (WYG&F 2004). Given the rapid recent development of new roads and infrastructure for oil and gas development in this area, the BLM is now at a critical juncture in deciding the long-term fate of key habitat for the nationally significant wildlife populations found here.

The BLM is responsible for adopting a protective RMP, including a travel management plan, that improves the Pinedale RMA's long-term ecological health and integrity while providing for balanced public access and use of the landscape and its resources. The scientific literature documents direct, indirect, and cumulative impacts of transportation features on ecological processes, wildlife, plants, and archeological sites. In its upcoming RMP revision for the Pinedale RMA, the Pinedale BLM Field Office must make management decisions that recognize the best available science and proactively mitigate documented impacts to wildlife and other resources.

Good science, the law, and sound policy can guide the BLM as it develops an RMP and a travel management plan to preserve large core areas of habitat for the four species studied in this report. Those areas will have value far beyond the targeted species. Maintenance of unroaded core areas or minimally roaded areas in key habitat units as recommended in this report will provide an opportunity to balance the needs of the area's important wildlife populations with the area's growing energy development.

This paper offers science-based information and analysis for use in making critical management decisions. The Pinedale RMA, while heavily developed for oil and gas, hosts critical wildlife habitat for many species and has the potential to protect this habitat for generations to come. In its upcoming Pinedale RMP revision and in other analyses and plans, we encourage the BLM to reach sound, science-based management decisions that will close routes to restore and maintain critical habitat and habitat linkages.

Acknowledgments

We express our thanks to The Aspenwood Foundation for its generous support of our conservation science program in the Northern Rockies, as well as to The William and Flora Hewlett Foundation for its support of our BLM Action Center. Our appreciation goes to the Earth Friends Wildlife Foundation for its support of our work in the Upper Green River Valley. We thank the Environmental Systems Research Institute (ESRI) for its ongoing donation of GIS software. We thank biologists Bernie Holz of the Wyoming Game and Fish Department and Hall Sawyer of Western EcoSystems Technology, Inc., for their thoughtful reviews of earlier drafts of the report. Their participation as independent reviewers in no way implies agreement with or endorsement of the science, recommendations, or other content of this document.

References

Berger, J. 2003. Is it acceptable to let a species go extinct in a national park? *Conservation Biology* 17:1451–1454.

Berger, J. 2004a. The last mile: how to sustain long distance migration in mammals. *Conservation Biology* 18:320–329.

Berger, J. 2004b. Can we save the last of the great long-distance migrations? *Wild Earth* (Fall/Winter 2004–2005):22–25.

Berger, J., and J. P. Beckmann. 2004. Pronghorn survival and energy development in western Wyoming: assessing effects of human disturbance during winter. *Annual Report from the Wildlife Conservation Society*. New York: Wildlife Conservation Society.

Braun, C. E. 1998. Sage grouse declines in western North America: what are the problems? *In Proceedings of the Western Association of State Fish and Wildlife Agencies* 78:139–156.

Braun, C. E. 2002. A review of sage grouse habitat needs and sage grouse management issues for the revision of the BLM's Pinedale District Resource Management Plan. Tucson, Ariz.: Grouse Inc., for The Wilderness Society, the Wyoming Outdoor Council, and the Greater Yellowstone Coalition.

Braun, C. E., T. Britt, and R. O. Wallestad. 1977. Guidelines for maintenance of sage grouse habitats. *Wildlife Society Bulletin* 5(3):99–106.

Bureau of Land Management (BLM). 1990. *Handbook on planning for fluid minerals*. Washington, D.C.: Bureau of Land Management, H-1624 at IV.C.3.

Bureau of Land Management. 1998. Record of decision for the Jonah II natural gas development project environmental impact statement, Sublette County, WY. Pinedale, Wyo.: U.S. Department of the Interior, Bureau of Land Management, Rock Springs, Pinedale, and Green River Resource Areas.

Bureau of Land Management. 1999. Draft environmental impact statement for the Pinedale Anticline oil and gas exploration and development project, Sublette County, WY. Pinedale, Wyo.: U.S. Department of the Interior, Bureau of Land Management, Pinedale Field Office.

Bureau of Land Management. 2000. Record of decision and final environmental impact statement for the Pinedale Anticline oil and gas exploration and development project, Sublette County, WY. Pinedale, Wyo.: U.S. Department of the Interior, Bureau of Land Management, Pinedale Field Office.

Bureau of Land Management. 2002. Information quality guidelines. Washington, D.C.: Bureau of Land Management. <http://www.blm.gov/nhp/efoia/data_quality/guidelines.pdf>.

Bureau of Land Management. 2004. Guidance for the management of sagebrush plant communities for sage grouse conservation, national sage grouse habitat conservation strategy. Washington, D.C.:

Bureau of Land Management.

Connelly, J. W., and C. E. Braun. 1997. Long-term changes in sage grouse (*Centrocercus urophasianus*) populations in western North America. *Wildlife Biology* 3/4:123–128.

Connelly, J. W., M. A. Schroeder, A. R. Sands, and C. E. Braun. 2000. Guidelines to manage sage grouse populations and their habitats. *Wildlife Society Bulletin* 28(4):967–985.

Dean, R., M. Gocke, B. Holz, S. Kilpatrick, T. Kreeger, B. Scurlock, S. Smith, E. T. Thorne, and S. Werbelow. 2004. Elk feedgrounds in Wyoming. Cheyenne, Wyo.: Wyoming Game and Fish Department. <http://gf.state.wy.us/wildlife/ElkFeedgrounds/index.asp>.

Defenders of Wildlife, Greater Yellowstone Coalition, The Wilderness Society, Wyoming Outdoor Council, Upper Green River Valley Coalition, American Lands Alliance, and L. Dorsey. 2002. Critical condition: areas of critical environmental concern for big game in the upper Green River valley, Wyoming. A petition to the Wyoming BLM in accordance with the Pinedale RMP scoping process.

Edge, W. D., and C. L. Marcum. 1991. Topography ameliorates the effects of roads and human disturbance on elk. Pages 132–137 *in* A. G. Christensen, L. J. Lyon, and T. N. Lonner, comps., *Proceedings of the elk vulnerability symposium*. Bozeman, Mont.: Montana State University.

Forman, R. T. 1999. Estimate of the area affected ecologically by the road system in the United States. *Conservation Biology* 14:31–35.

Fox, R. A. 1989. *Mule deer (*Odocoileus hemionus*) home range and habitat use in an energy-impacted area of the North Dakota badlands*. Master's thesis, University of North Dakota, Grand Forks, N.D.

Freddy, D. J., W. M. Bronaugh, and M. C. Fowler. 1986. Responses of mule deer to disturbance by persons afoot and snowmobiles. *Wildlife Society Bulletin* 14:63–68.

Gaines, W. L., P. H. Singleton, and R. C. Ross. 2003. Assessing the cumulative effects of linear recreation routes on wildlife habitats on the Okanogan and Wenatchee National Forests. General Technical Report PNW-GTR-586. Portland, Ore.: U.S. Department of Agriculture, U.S. Forest Service, Pacific Northwest Research Station.

Gucinski, H., M. J. Furniss, R. R. Ziemer, and M. H. Brookes. 2001. Forest roads: a synthesis of scientific information. General Technical Report PNW-GTR-509. Portland, Ore.: U.S. Department of Agriculture, U.S. Forest Service, Pacific Northwest Research Station.

Holloran, M. J., and S. H. Anderson. 2004. Sage grouse response to natural gas field development in northwestern Wyoming. Abstract *in* 24th Meeting of the Western Agencies Sage and Columbian Sharp-Tailed Grouse Technical Committee, Wenatchee, Washington, June 28–July 1.

Knick, S. T., D. S. Dobkin, J. T. Rotenberry, M. A. Schroeder, W. M. Vander Haegen, and C. van Riper. 2003. Teetering on the edge or too late? Conservation and research issues of avifauna of sagebrush habitats. *The Condor* 105:611–634.

Lehmkuhl, J. F., and L. F. Ruggiero. 1991. Forest fragmentation in the Pacific Northwest and its potential effects on wildlife. Pages 35–46 *in* L. F. Ruggiero, K. B. Aubry, A. B. Carey, and M. H. Huff, tech. coords., *Wildlife and vegetation of unmanaged Douglas-fir forests*. General Technical Report PNW-GTR-285. Portland, Ore.: U.S. Department of Agriculture, U.S. Forest Service, Pacific Northwest Research Station.

Lutz, D. W., B. F. Wakeling, L. H. Carpenter, D. Stroud, M. Cox, D. McWhirter, S. Rosenstock, L. C. Bender, and A. F. Reeve. 2003. Impacts and changes to mule deer habitat. Pages 13–61 *in* J. C. de Vos, Jr., M.R. Conover, and N.E. Headrick, eds., *Mule deer conservation: issues and management strategies*. Logan, Utah: Jack H. Berryman Institute Press, Utah State University.

Lyon, L. J. 1979. Habitat effectiveness for elk as influenced by roads and cover. *Journal of Forestry* 77:658–660.

Lyon, L. J. 1983. Road density models describing habitat effectiveness for elk. *Journal of Forestry* 81:592–596.

Lyon, A. G. 2000. *The potential effects of natural gas development on sage grouse (*Centrocercus urophasianus*) near Pinedale, Wyoming.* Master's thesis, University of Wyoming, Laramie, Wyo.

Lyon, L. J., and A. G. Christensen. 2002. Elk and land management. Pages 557–581 *in* D. E. Toweill and J. W. Thomas, eds., *North American elk ecology and management*. Washington, D.C.: Smithsonian Institution Press.

Meffe, G. K., and C. R. Carroll. 1994. *Principles of conservation biology*. Sunderland, Mass.: Sinauer Associates, Inc..

Molvar, E. M. 2003. Drilling smarter: using minimum-footprint directional drilling to reduce oil and gas impacts in the intermountain West. Laramie, Wyo.: Biodiversity Conservation Alliance.

Morgantini, L. E., and R. J. Hudson. 1979. Human disturbance and habitat selection in elk. Pages 132–139 *in Symposium on elk ecology and management*, April 3–5, 1978, Laramie, Wyo.

Noss, R. F., and A. Y. Cooperrider. 1994. *Saving nature's legacy: protecting and restoring biodiversity*. Washington, D.C.: Island Press.

Ockenfels, R. A., A. Alexander, C. L. D. Ticer, and W. K. Carrel. 1994. Home range movement patterns and habitat selection of pronghorn in central Arizona. Technical Report 13. Phoenix, Ariz.: Arizona Game and Fish Department.

Phillips, G. E., and A. W. Alldredge. 2000. Reproductive success of elk following disturbance by humans during calving season. *Journal of Wildlife Management* 64(2):512–530.

Powell, J. H. 2003. *Distribution, habitat use patterns, and elk response to human disturbance in the Jack Morrow Hills, Wyoming.* Master of Science thesis, University of Wyoming, Laramie.

Rost, G. R., and J. A. Bailey. 1979. Distribution of mule deer and elk in relation to roads. *Journal of Wildlife Management* 43(3):634–641.

Sawyer, H. H., and F. G. Lindzey. 2000. Jackson Hole pronghorn study. Laramie, Wyo.: Wyoming Cooperative Fish and Wildlife Research Unit, University of Wyoming, prepared for Ultra Petroleum, Wyoming Game and Fish Department, U.S. Fish and Wildlife Service, USDA Forest Service, Bureau of Land Management, and Teton Science School.

Sawyer, H. H., and F. G. Lindzey. 2001. Sublette mule deer study. Laramie, Wyo.: Wyoming Cooperative Fish and Wildlife Research Unit, University of Wyoming.

Sawyer, H. H., and F. G. Lindzey. 2004. Assessing impacts of oil and gas development on mule deer. *Transactions of the 69th North American Wildlife and Natural Resources Conference*, Spokane, Washington. Washington, D.C.: Wildlife Management Institute.

Sawyer, H. H., F. G. Lindzey, and B. A. Jellison. 1997. Applying GIS technology to test an elk habitat effectiveness model in north-central Wyoming. Pages 176–183 *in* J. de Vos, ed., *Proceedings of the 1997 Deer/Elk Workshop*, Rio Rico, Arizona. Phoenix, Ariz.: Arizona Game and Fish Department.

Sawyer, H. H., R. Nielson, L. McDonald, and D. Strickland. 2004. Sublette mule deer study (phase II): long-term monitoring plan to assess potential impacts of energy development on mule deer in the Pinedale Anticline project area. Cheyenne, Wyo.: Western EcoSystems Technology, Inc., prepared for Questar Exploration and Production Company, TRC Mariah Associates, Inc., Bureau of Land Management, and Wyoming Game and Fish Department.

Trombulak, S. C., and C. A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology* 14:18–30.

Upper Green River Valley Coalition (UGRVC). 2004. A responsible energy development alternative for consideration in the Bureau of Land Management Pinedale Resource Area resource management plan revision. Pinedale, Wyo.: Upper Green River Valley Coalition.

Weller, C., J. L. Thomson, P. Morton, and G. H. Aplet. 2002. *Fragmenting our lands: the ecological footprint from oil and gas development*. Washington, D.C.: The Wilderness Society.

Western EcoSystems Technology, Inc. (WETI). 2003. An evaluation of the 1988 BLM Pinedale resource management plan, 2000 BLM Pinedale Anticline final environmental impact statement and recommendation for the current revision of the Pinedale resource management plan. Cheyenne, Wyo.: Western EcoSystems Technology, Inc., prepared for The Wilderness Society, Wyoming Outdoor Council and Greater Yellowstone Coalition (January 22).

Wyoming Game and Fish Department (WYG&F). 2004. Minimum recommendations for development of oil and gas resources within crucial and important wildlife habitats on BLM lands. Cheyenne, Wyo.: Wyoming Game and Fish Department.

Fire in the Yellowstone Landscape: Surprises and Lessons

Monica G. Turner

Department of Zoology, University of Wisconsin, Madison, WI 53706 (608-262-2592, turnermg@wisc.edu)

William H. Romme

Department of Forest Sciences, Colorado State University, Fort Collins, CO 80523 (970-491-2870, romme@cnr.colostate.edu)

Morning Keynote, October 18, 2005 (Dr. Turner)

Monica G. Turner grew up in New York, and first visited Yellowstone (and the western U.S.) in 1978, when she worked at Old Faithful as a ranger-naturalist through the Student Conservation Association. That formative summer confirmed her decision to become an ecologist. After completing a BS in Biology from Fordham University, she earned a PhD in Ecology from the University of Georgia. As a graduate student, she worked as a summer intern with the NPS in Washington, D.C.; she conducted her doctoral research in Virgin Islands National Park and Cumberland Island National Seashore. Currently a professor at the University of Wisconsin, she has studied fire, vegetation, and ecosystem processes in Yellowstone since 1988, and is also studying elk movement and habitat use. She was a member of the National Research Council committee that evaluated ungulate management in Yellowstone (*Ungulate Dynamics on Yellowstone's Northern Range,* 2002, National Academy Press). Currently, she is co-editor-in-chief of *Ecosystems,* an editorial board member for *BioScience,* and a member of the Rapid Response Team of the Ecological Society of America. She has received awards for distinguished scholarship, and was elected to membership in the National Academy of Sciences in 2004.

Introduction

The size and severity of the fires that burned through Yellowstone National Park (YNP) and surrounding lands during the summer of 1988 surprised scientists, park managers, and the general public. These fires burned under conditions of severe drought and high winds (Renkin and Despain 1992), ultimately affecting nearly 40% of the park. Although clearly not unprecedented within the ecosystem, the fires were the largest observed since the park was created in 1872, and they challenged contemporary understanding of fire dynamics and policy. Many people initially thought the fires had destroyed America's crown jewel, based on media reports that summer (Smith 1996). That perception was largely corrected as recovery of the burned areas through natural processes became increasingly evident. Stand-replacing fires have occurred in YNP at 100-to-500-year intervals throughout the past 10,000 years (Romme 1982; Romme and Despain 1989; Millspaugh et al. 2000; 2004). The 1988 fires were most certainly not an ecological catastrophe, but rather a natural event to which the plants and animals that inhabit the Yellowstone landscape are well adapted (Turner et al. 2003a; Romme and Turner 2004).

Natural disturbances are key sources of heterogeneity in many ecosystems, yet the causes and consequences of disturbances that are large, severe, and infrequent are not well understood. Many northern conifer forests, including those in Yellowstone, are characterized by a natural fire regime of infrequent, stand-replacing fires driven largely by climate (Turner and Romme 1994; Johnson 1992). The 1988 Yellowstone fires provided scientists with a valuable opportunity for ecological study of a large, infrequent disturbance in a system minimally influenced by humans. Such studies can provide important insights into how ecological systems respond to extreme events. We have studied vegetation and ecosystem processes in response to the 1988 fires, and here we highlight several of the surprises and lessons that emerged from our research. Our studies have addressed the effects of fire in the conifer forests that dominate the central plateau, and we focus on four major areas: (1) landscape heterogeneity, (2) patterns of succession, (3) ecosystem function, and (4) long-term trajectories.

Landscape heterogeneity

Disturbances both respond to and create heterogeneity in landscapes. During the period of natural fire management in Yellowstone (1972–1987), naturally ignited fires burned primarily in the oldest forests, where there was abundant and well-connected (both vertically and horizontally) live fuel. During that time, the summer of 1981 had the largest area burned, with 3,300 ha affected by 28 fires (Renkin and Despain 1992). During less severe drought years, when conditions were suitable for burning but not extreme, fire spread was constrained by the amount and spatial distribution of old-growth (>250-yr) forests. Fire behavior during the early summer of 1988 was similar to that which had been observed previously—fires burned through old forest and stopped when they encountered young forests. However, as the drought of 1988 worsened and conditions of high wind developed, the fires no longer responded to heterogeneity across the landscape. Forests of all ages burned, and natural firebreaks such as the Grand Canyon of the Yellowstone River did not stop fire spread. Analyses of the spatial patterns of burning conducted after the fire season quantified these differences in fire patterns between the early and late summer periods of 1988 (Turner et al. 1994). As in other landscapes with a natural fire regime of severe, stand-replacing fire, pre-fire heterogeneity of the landscape is important under moderate burning conditions, but not when fire weather is extreme. This is consistent with results reported for many areas in which few fire events (or years) result in most of the area burned (Johnson 1992; Bessie and Johnson 1995; Flannigan and Wotton 2001).

The 1988 fires were large and severe, but importantly, they did not homogenize the landscape. Rather, they produced a complex mosaic of patches of varying size, shape, and burn severity (Christensen et al. 1989, Turner et al. 1994). Photographs of the post-fire landscape patterns provided striking visual evidence of this spatial heterogeneity (see Christensen et al. 1989 and Turner et al. 2003a). Within the burned area, 50% of the areas of crown fire was within 50 m of green forest, and 75% was within 200 m of a green edge (Turner et al. 1994). Thus, the fires increased landscape diversity within the burn perimeter. In addition, the complex burn mosaic motivated our initial field studies to explore the influence of this post-fire landscape heterogeneity on succession.

Patterns of succession

Plant re-establishment following the 1988 fires was rapid. The fires did not burn deeply into the soil, averaging 14 mm in areas of stand-replacing burn (Turner et al. 1999). The "biotic legacies" that remained after the fires dominated post-fire recovery and generated plant communities similar to those present before the fires. Native perennial plants resprouted from surviving roots and rhizomes in 1989 and flowered abundantly in 1990, resulting in a large pulse of seedling recruitment of numerous wild flowers, grasses, and sedges within the burned area (Turner et al. 1997). Local dispersal from surviving individuals, rather than long-distance dispersal from unburned forest, appeared to be the most important process. Non-native invasive plant species largely did not expand into the burned areas, counter to our initial expectations (Turner et al. 1997).

Seedlings of the dominant tree, lodgepole pine (*Pinus contorta* var. *latifolia*), established abundantly in 1989 and 1990 (Anderson and Romme 1991; Turner et al. 1997; 1999). The spatial variability in the density of lodgepole pine seedlings was particularly noteworthy. Some burned forests had few if any tree seedlings, whereas others had >500,000 seedlings per hectare. We determined that this wide variability in post-fire tree density resulted from two primary causes. First, there exists in Yellowstone considerable spatial variation in the proportion of lodgepole pine trees that bear serotinous cones—an adaptation to fire in which closed cones that are sealed with a resin are retained on the tree for many years, releasing their seeds when heated, as by fire. Lodgepole pine is well known to be a serotinous species, but the variation in this trait across the landscape was surprising (Tinker et al. 1994). Lodgepole pine seedlings were most abundant in locations where pre-fire serotiny was high, and least abundant where pre-fire serotiny was low (Anderson and Romme 1991; Turner et al. 1997; 1999). In turn, the occurrence of serotiny in Yellowstone's lodgepole pine stands varied with elevation, which is correlated with fire return interval. Schoennagel et al. (2003) found a low proportion of trees bearing serotinous cones at high elevations (>2,300 m), where fire return intervals average nearly 300 years. At lower elevations (<2,300 m), where fire return intervals average 170 years, however, the proportion of trees bearing serotinous cones was quite high for stands >70 yrs old.

The second factor influencing post-fire lodgepole pine seedling density was burn severity. Post-fire seedling densities were highest in areas of severe surface fire, where the trees were killed but the needles and cones not consumed by the fire (Turner et al. 1997; 1999). Thus, the landscape mosaic of burn severities had a direct influence on the initial pattern of stand density after the fire. Collectively, the variation in topography, serotiny, and fire severity resulted in a spatially complex pattern of stand densities initiated by the fires (Turner et al. 2004) that was established soon after the fires. As of 1999, post-fire stand densities of lodgepole pine averaged 29,380 stems ha^{-1} (median of 3,100 stems ha^{-1}). Densities exceeded 20,000 stems ha^{-1} over 20% of the burned landscape; densities were <5,000 stems ha^{-1} over 55% of the landscape. Clearly, the spatial variation in stand structures produced by the fires was substantial. By 2003, many of the trees were highly productive and already producing abundant cones, with cone densities ranging from 4,000 to 4,000,000 cones ha^{-1}. Thus, post-fire tree recruitment was both abundant and rapid.

Trembling aspen (*Populus tremuloides*) is a tree species of concern in YNP and throughout the Intermountain West. Aspen produces clonal stands that may persist for centuries or more, but many authors have noted a decline in the number, extent, and vigor of aspen stands throughout the West (Romme et al. 1995). In 1989, the year after the fires, there was widespread and locally abundant establishment of seedling aspen only in burned forests and well beyond the pre-fire distribution of aspen (Romme et al. 1997; Turner et al. 2003b). This appeared to be an infrequent seedling recruitment event in a long-lived species, and genetic diversity in the seedling populations increased relative to mature aspen stands in Yellowstone (Tuskan et al. 1996; Stevens et al. 1999). As of 2000, the seedling aspen were persisting in many locations, but most stems were not very tall (averaging 30 cm) because of sub-optimal environmental conditions and browsing by native ungulates, primarily elk (*Cervus elaphus*) (Romme et al. 2005).

In sum, vegetation recovery in YNP occurred rapidly and through natural processes. Reproduction by surviving grasses, forbs, and shrubs within the burned area was more important than long-distance dispersal from unburned forests, and exotic invasive species did not establish. Post-fire lodgepole pine establishment was also rapid and abundant, and the spatial patterns of stand density developed early and have persisted thus far. Variation in the occurrence of serotinous cones and burn severity were important controls on post-fire tree recruitment. Establishment of seedling aspen may not be so unusual after all, but recruitment of tree-sized aspen may be rare under current conditions.

Ecosystem function

What are the implications of the spatial variation in post-fire vegetation for ecosystem function? We have addressed several functional indicators in the YNP landscape, including aboveground net primary production (ANPP), leaf area index (LAI), the accumulation of coarse wood (fallen dead trees) after the fires, and rates of decomposition, nitrogen cycling, and microbial activity. We were surprised by the high rates of ANPP that we observed only 10 years after the fires (Turner et al. 2004). ANPP averaged 2.8 Mg ha^{-1} yr^{-1} in 1998, increased with increasing lodgepole pine density, and was as high as 15 Mg ha^{-1} yr^{-1} in some stands. When extrapolated to the entire burned landscape, ANPP exceeded 2 Mg ha^{-1} yr^{-1} across 33% of the area burned, and exceeded 4 Mg ha^{-1} yr^{-1} in 10% of the burned area (Turner et al. 2004). Thus, rates of primary production are being restored rapidly across the landscape.

Although loss of nitrogen (N) following disturbances has been observed in many forested ecosystems (cf. Chapin et al. 2002), changes in N cycling associated with severe, stand-replacing fires have received surprisingly little study (Smithwick et al. 2005a). Studies in YNP have not documented elevated nitrate concentrations in stream water after the fires of 1988 or 1996 (Minshall et al. 2004; Romme and Turner 2004). We observed higher rates of nitrification in soils two years after the 1996 Pelican fire compared to stands that were 10, 120, or >300 years post fire, but rates were still relatively low (Romme and Turner 2004). None of our results to date suggest extensive losses of N following fires in Yellowstone, but ongoing studies will provide much greater insight into these processes.

The trees killed by the 1988 fires began falling noticeably in the mid-1990s, and 74% of the fire-killed trees had fallen by 2003 (unpublished data). There was considerable spatial variability in tree-fall rates, however, with 90% of the trees down in some locations and none in others. Trees were more likely to still be standing at higher elevations and to have fallen down at lower elevations. The fallen trees provide physical structure within the developing forest stands and, as they decay, serve as long-term sources of carbon and nutrients to the soil. However, the downed wood also influences ecosystem processes both within stands and across the landscape. For example, decomposition rates were lower under newly fallen logs that were elevated above the ground and more rapid when associated with "legacy logs" (dead wood that was present before the fires) (Remsburg and Turner in press). Only 8% of the dead wood that was in the forests prior to the 1988 fires was consumed in the fires (Tinker and Knight 2000), so legacy logs remain an important component of post-fire ecosystems. The recently fallen elevated logs appear to create more spatial variability in microclimates within a stand, resulting in dry soils directly under the elevated logs but moister conditions where the water is channeled down. Microbial communities and the expression of extracellular enzymes also varied with position relative to coarse wood or pine saplings (unpublished data).

The abundant coarse wood and dense pine saplings within the forests burned in 1988 appear to be influencing habitat use patterns of Yellowstone's native elk populations. During summer, elk are preferentially using the burned forests, especially if they are within proximity to non-forest habitats (e.g., meadows) that provide a source of food (Forester 2005, Mao et al. 2005). The dense, young forests may provide cover for the elk and protection from wolf (*Canis lupus*) predation, and they may also make it more difficult for wolves to effectively make a kill. This also suggests that despite what several authors have suggested (e.g., Ripple and Larsen 2001; Turner et al. 2003), the abundant, coarse wood may not protect aspen seedling from browsing if elk preferentially use these sites (Forester 2005). Nonetheless, there may be an important indirect effect of the fires on higher trophic levels.

In summary, ecosystem function in the Yellowstone landscape seems quite resilient to the effects of the 1988 fires. The fires clearly had a significant and quantifiable effect on many ecosystem processes, but ANPP and LAI recovered rapidly, with increasing vegetative cover throughout the burned areas. Our ongoing studies focus on both characterizing and explaining the variability in ecosystem processes through time and across the landscape following stand-replacing fires in YNP.

Long-term trajectories

What happens to post-fire stand structure and function as succession proceeds through time? For how long is the imprint of the 1988 fires likely to persist in the landscape? By studying a chronosequence of 62 lodgepole pine stands across the YNP landscape, Kashian et al. (2005a; 2005b) documented declines in mean stand density and the spatial variability in stand density with increasing stand age. The stands that regenerated following the 1988 fires are of higher mean density and much more spatially variable than older stands, but considerable variation remains in stands that are 125–175 yrs old (mean density ca. 3,000 stems ha^{-1} with coefficient of variation among stands ca. 80%). By 200 years, however, stand density and growth rates converge, and variability declines (mean stand density ca. 1,200 stems ha^{-1} with coefficient of variation among stands ca. 30%). The variability in numerous other functional attributes also changes with stand age. For instance, variation in total soil N and the ratio of fungi:bacteria in the soil have higher variability among stands in younger age classes (Smithwick et al. 2005b). Collectively, these results suggest that fires are a source of significant functional heterogeneity at landscape scales, and that the spatial variation in stand structure and function produced by the 1988 fires may be detectable in this ecosystem for as many as 175 years.

Conclusions

Infrequent but severe stand-replacing fires have long been part of the Yellowstone landscape. The 1988 fires offered an unusual opportunity for scientists to study a rare event, to observe natural processes of recovery at work, and to unravel at least some of the complex mechanisms that underpin the system's resilience. Studies to date indicate that Yellowstone's biota are well adapted to such disturbances. The YNP landscape has demonstrated striking resilience following the 1988 fires. Clearly **not** catastrophes in any ecological sense, the fires were an important source of landscape heterogeneity, producing tremendous spatial variation in forest structure and function throughout the burned areas. The lessons learned from the 1988 fires should provide valuable data for land managers in the Greater Yellowstone Ecosystem, and may also apply to other forests characterized by natural, stand-replacing fire regimes. "Natural laboratories" like YNP are invaluable systems in which to study for such research, providing a baseline of understanding of disturbance and recovery that may help interpret the effects of large, infrequent disturbances in other locations. As succession continues on its course, subsequent studies of the patterns and processes associated with the 1988 fires are likely to continue producing new insights into the structure and function of this dynamic landscape.

Acknowledgements

Dr. Turner thanks the organizers of the 2005 science conference in Yellowstone National Park for the opportunity to present a keynote address and contribute this paper. We are indebted to the many individuals who have worked as part of our field crews during the past 17 years and to the very capable collaborators, graduate students, and postdocs with whom we have been so fortunate to work. In particular, we thank Bob Gardner, Dennis Knight, Mike Ryan, Dan Tinker, Jerry Tuskan, Don Despain, Linda Wallace, Tania Schoennagel, Dan Kashian, Creighton Litton, Erica Smithwick, Kris Metzger, Michael Stevens, James Forester, and Alysa Remsburg. The YNP staff have always been very helpful, and we appreciate their consideration and support. We are extremely grateful to the following agencies for funding our research on fire, vegetation, and ecosystem processes in the Yellowstone landscape: National Science Foundation (Ecology and Ecosystem Studies Programs); USDA NRIGCP Forest/Crop/Range/Aquatic Ecosystems Program; Joint Fire Sciences Program; National Geographic Society; University of Wyoming–National Park Service Research Center's Small Grants Program; and the Andrew W. Mellon Foundation.

References

Anderson, J. E., and W. H. Romme. 1991. Initial floristics in lodgepole pine (*Pinus contorta*) forests following the 1988 Yellowstone fires. *International Journal of Wildland Fire* 1:119–124.

Bessie, W. C., and E. A. Johnson. 1995. The relative importance of fuels and weather on fire behavior in subalpine forests. *Ecology* 76:747–762.

Chapin, F. S. III, P. A. Matson, and H. A. Mooney. 2002. *Principles of terrestrial ecosystem ecology*. New York: Springer-Verlag.

Christensen, N. L., J. K. Agee, P. F. Brussard, J. Hughes, D. H. Knight, G. W. Minshall, J. M. Peek, S. J. Pyne, F. J. Swanson, J. W. Thomas, S. Wells, S. E. Williams, and H. A. Wright. 1989. Interpreting the Yellowstone fires of 1988. *BioScience* 39:678–685.

Flannigan, M. D., and B. M. Wotton. 2001. Climate, weather and area burned. Pages 351–373 *in* E. A. Johnson and K Miyanishi, eds. *Forest fires*. New York: Academic Press.

Forester, J. D. 2005. Multi-scale resource selection in heterogeneous landscapes: effects of forage, predation and disturbance on habitat use by elk in Yellowstone National Park, USA. Ph.D. dissertation, University of Wisconsin–Madison.

Johnson, E. A. 1992. *Fire and vegetation dynamics*. Cambridge University Press, New York.

Kashian, D. M., M. G. Turner, and W. H. Romme. 2005a. Changes in leaf area and stemwood increment with stand development in Yellowstone National Park: relationships between forest stand structure and function. *Ecosystems* 8:48–61.

Kashian, D. M., M. G. Turner, W. H. Romme, and C. J. Lorimer. 2005b. Variability and convergence in stand structure with forest development on a fire-dominated landscape. *Ecology* 86:643–654.

Mao, J. S., M. S. Boyce, E. H. Merrill, D. W. Smith, F. J. Singer, D. J. Vales, J. M. Vore, and E. H. Merrill. 2005. Habitat selection by elk before and after wolf reintroduction in Yellowstone National Park. *Journal of Wildlife Management* 69(4):1691–1707.

Millspaugh, S. H., C. Whitlock, and P. J. Bartlein. 2000. Variations in fire frequency and climate over the past 17,000 years in central Yellowstone National Park. *Geology* 28:211–214.

Millspaugh, S. H., C. Whitlock, and P. J. Bartlein. 2004. Postglacial fire, vegetation and climate history of the Yellowstone–Lamar and Central Plateau Provinces, Yellowstone National Park. Pages 10–28 *in* L. L. Wallace, ed., *After the fires: the ecology of change in Yellowstone National Park*. New Haven: Yale University Press.

Minshall, G. W., T. V. Royer, and C. T. Robinson. 2004. Stream ecosystem response to fire: the first ten years. Pages 165–188 *in* L. L. Wallace, ed., *After the fires: the ecology of change in Yellowstone National Park*. New Haven: Yale University Press.

Remsburg, A. J., and M. G. Turner. In press. Amount, position and age of coarse wood influence litter decomposition within and among young post-fire *Pinus contorta* stands. *Canadian Journal of Forest Research*.

Renkin, R. A., and D. G. Despain. 1992. Fuel moisture, forest type and lightning-caused fire in Yellowstone National Park. *Canadian Journal of Forest Research* 22:37–45.

Ripple, W. J., and E. J. Larsen. 2001. The role of postfire coarse woody debris in aspen regeneration. *Western Journal of Applied Forestry* 16:61–64.

Romme, W. H. 1982. Fire and landscape diversity in subalpine forests of Yellowstone National Park. *Ecological Monographs* 52:199–221.

Romme, W. H., and D. G. Despain. 1989. Historical perspective on the Yellowstone fires of 1988. *BioScience* 39:695–699.

Romme W. H., and M. G. Turner. 2004. Ten years after the 1988 Yellowstone fires: is restoration needed? Pages 318–361 *in* L. L. Wallace, ed., *After the fires: the ecology of change in Yellowstone National Park*. New Haven: Yale University Press.

Romme, W. H., M. G. Turner, R. H. Gardner, W. W. Hargrove, G. A. Tuskan, D. G. Despain, and R. A. Renkin. 1997. A rare episode of sexual reproduction in aspen (*Populus tremuloides*) following the 1988 Yellowstone fires. *Natural Areas Journal* 17:17–25.

Romme, W. H., M. G. Turner, G. A. Tuskan, and R. A. Reed. 2005. Establishment, persistence and growth of aspen (*Populus tremuloides*) seedlings in Yellowstone National Park. *Ecology* 86:404–418.

Romme, W. H., M. G. Turner, L. L. Wallace, and J. Walker. 1995. Aspen, elk and fire in northern Yellowstone National Park. *Ecology* 76:2097–2106.

Schoennagel, T., M. G. Turner, and W. H. Romme. 2003. The influence of fire interval and serotiny on postfire lodgepole pine density in Yellowstone National Park. *Ecology* 84:1967–1978.

Smith, C. 1996. Media coverage of fire ecology in Yellowstone after 1988. Pages 25–34 *in* J. Greenlee, ed., *The ecological implications of fire in Greater Yellowstone*. Proceedings of the Second Biennial Scientific Conference on the Greater Yellowstone Ecosystem. Fairfield, Wash.: International Association of Wildland Fire.

Smithwick, E. A. H., M. G. Turner, M. C. Mack, and F. S. Chapin, III. 2005a. Post-fire soil N cycling in northern conifer forests affected by severe, stand-replacing wildfires. *Ecosystems* 8:163–181.

Smithwick, E. A. H., M. G. Turner, K. L. Metzger, and T. C. Balser. 2005b. Variation in NH_4^+ mineralization and microbial communities with stand age in lodgepole pine (*Pinus contorta*) forests, Yellowstone National Park (USA). *Soil Biology and Biogeochemistry* 37:1546–1559.

Stevens, M. T., M. G. Turner, G. A. Tuskan, W. H. Romme, and D. M. Waller. 1999. Genetic variation in postfire aspen seedlings in Yellowstone National Park. *Molecular Ecology* 8:1769–1780.

Tinker, D. B., and D. H. Knight. 2000. Coarse woody debris following fire and logging in Wyoming lodgepole pine forests. *Ecosystems* 3:472–483.

Tinker, D. B., W. H. Romme, W. W. Hargrove, R. H. Gardner, and M. G. Turner. 1994. Landscape-scale heterogeneity in lodgepole pine serotiny. *Canadian Journal of Forest Research* 24:897–903.

Turner, M. G., and W. H. Romme. 1994. Landscape dynamics in crown fire ecosystems. *Landscape Ecology* 9:59–77.

Turner, M. G., W. H. Hargrove, R. H. Gardner, and W. H. Romme. 1994. Effects of fire on landscape heterogeneity in Yellowstone National Park, Wyoming. *Journal of Vegetation Science* 5:731–742.

Turner, M. G., W. H. Romme, and R. H. Gardner. 1999. Prefire heterogeneity, fire severity and plant reestablishment in subalpine forests of Yellowstone National Park, Wyoming. *International Journal of Wildland Fire* 9:21–36.

Turner, M. G., W. H. Romme, R. H. Gardner, and W. W. Hargrove. 1997. Effects of fire size and pattern on early succession in Yellowstone National Park. *Ecological Monographs* 67:411–433.

Turner, M. G., W. H. Romme, R. A. Reed, and G. A. Tuskan. 2003b. Postfire aspen seedling recruitment across the Yellowstone (USA) landscape. *Landscape Ecology* 18:127–140.

Turner, M. G., W. H. Romme, and D. B. Tinker. 2003a. Surprises and lessons from the 1988 Yellowstone fires. *Frontiers in Ecology and the Environment* 1:351–358.

Turner, M. G., D. B. Tinker, W. H. Romme, D. M. Kashian, and C. M. Litton. 2004. Landscape patterns of sapling density, leaf area, and aboveground net primary production in postfire lodgepole pine forests, Yellowstone National Park (USA). *Ecosystems* 7:751–775.

Tuskan, G. A., K. E. Francis, S. L. Russ, W. H. Romme, and M. G. Turner. 1996. RAPDs demonstrates genetic diversity within and among aspen populations in Yellowstone National Park, USA. *Canadian Journal of Forest Research* 26:2088–2098.