RMRScience

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USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO

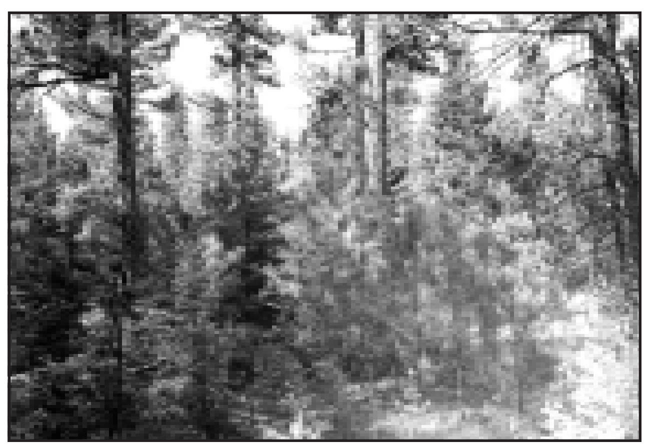
Effects of Fire Exclusion in Rocky Mountain Ecosystems

Smokey Bear's message was simple, direct and effective – "Prevent Forest Fires." But, as the western U.S. experiences yet another severe wildfire season, it has become evident that this message was also shortsighted. In a perfect world, resource specialists would have known that there would be adverse consequences of this fire exclusion policy. Growth of forest and range vegetation and the subsequent accumulation of hazardous fuels are gradual processes, so it was difficult for past generations of forest and range managers and scientists to observe and agree upon the adverse effects of excluding fire from ecosystems. Today, the nation is faced with critical ecological issues in the aftermath of the war on forest and range fires.

To help get a better handle on this issue, scientists with the Rocky Mountain Research Station have been studying the extent of fire exclusion in the Rocky Mountains and the diverse and cascading effects of suppressing fires on vegetation composition, landscape structure and ecosystem function at multiple spatial and temporal scales. So, what have they discovered?

Stand-Level Effects

Perhaps the most documented and studied effect of fire exclusion is the change in stand composition and structure. "In general, forest composition has gone from early seral, shade-intolerant tree species to late seral, shade-tolerant species, while stand structure has gone from single-layer canopies to multiple-layer canopies," says Research Ecologist Robert Keane, who works at the Station's Fire Sciences Laboratory in Missoula, Montana. Keane says this phenomenon is repeated over and over again for most fire-dominated ecosystems of the U.S. and Canada. "It is this fundamental change in vegetation composition and structure that cascades downward to impact a myriad of other ecosystem characteristics," he says.



Changes in vegetation structure and composition due to fire exclusion are evident when this 1909 photo (left) is compared to the (right) photo taken 70 years later. Exclusion of wildfire and soil disturbance during logging allowed ponderosa pine and Douglas-fir to develop into a dense understory on the Bitterroot National Forest, Montana.

Plant species adapted to the early stages of succession, such as those that best survive or regenerate after a fire, are replaced by species that are better able to compete for growing resources in the absence of fire. Especially abundant are the young shade-tolerant individuals, which bide their time in the understory waiting for a gap to open in the overstory canopy.

Biodiversity

Researchers have found that the diversity of plants, animals and ecological processes are enhanced by fire in many ecosystems. Landscapes having fires with high variability in timing, intensity, pattern and frequency tend to have the greatest diversity in ecosystem components. However, plant diversity tends to decrease with advancing succession because there are higher numbers of species adapted to colonize postfire settings from highly dispersed or dormant seeds. In addition, the density, cover, height and vigor of undergrowth species tend to decrease as the overstory becomes dense and tree leaf area increases because of dominance by shade-tolerant species. "Therefore," says Keane, "understory vascular plant species richness and density tend to be low in the late successional communities commonly found on fire-excluded landscapes.

Crown and Surface Fuels

One important stand characteristic that changes with advancing succession is the increase in amount of dead and live biomass called "fuels." Fuel loadings (mass per unit area) generally increase in the absence of fire because of a myriad of ecological factors. First and most important, long fire return intervals mean live fuels have more time to grow, and dead fuels have longer periods to accumulate on the ground. In addition, crown fuels increase because late seral, shade-tolerant species tend to have more canopy biomass due to their high leaf areas. This biomass tends to be well distributed over the height of late-seral trees. Higher leaf areas require additional tissue for physical support and conducting water and nutrients, which means the tree may need to produce more branches. Because late seral species are shade tolerant, there are many smaller seedlings and saplings present in the understory to take advantage of any gaps in the canopy. So, the greater crown leaf and branch biomass distributed along the stem, coupled with high seedling and sapling densities, can create "ladder" fuels that allow flames from surface fires to climb into the forest canopy and result in "crown" fires. Surface fuel loadings increase as fire is eliminated because the greater crown biomass ultimately results in increased leaf and woody material accumulating on the forest floor. Dense crowns also reduce solar radiation attenuated to the forest floor, which may lower soil temperatures resulting in decreased decomposition rates and still higher branch and litter accumulations.

Soils

Soil properties change as fires are reduced and succession advances in an ecosystem. Organic matter generally increases with decreased fire frequency, and this improves pore space, water-holding capacity and aggregation. However, when soils with thick organic horizons are burned, some of the volatilized organic matter moves downward along a steep temperature gradient and condenses to form a water repellent layer that impedes infiltration and can cause massive erosion. Consumption of the thick soil organic matter accumulations resulting from fire exclusion leads to soil heating that kills plant propagules and microorganisms to a greater depth. This leads to increased potential for erosion, slower recovery of native species, slower hydrologic recovery and increased likelihood of the site being dominated by invasive species.

The top photo, taken in 1909 on the Lewis and Clark National Forest, Montana, shows the effects of wildfire in the late 1800's that burned both sides of the drainage. Scattered ponderosa pine and Douglas-fir occupy the near slope and canyon bottom. Seventy-one years later, regeneration of Douglas-fir has resulted in a landscape dominated by conifers, which have largely eliminated early successional understory species.

Carbon and Water Cycles

"Some interesting and complex changes in major ecophysiological processes result as species and structure changes occur during the prolonged successional cycle resulting from the absence of fire," says Kevin Ryan, Project Leader and Scientist at the Fire Sciences Laboratory. "Increased leaf area at the species and stand level triggers complex physiological responses in the ecosystem dynamics of the stand. Canopy interception increases with higher leaf areas. Thus, less precipitation reaches the soil. This can result in an increase in the periodic seasonal depletion of soil water. The increased evapotranspiration associated with later successional stages results in decreased streamflow," he says. High leaf areas also diminish radiation to the forest floor, which when coupled with lower soil moistures, can slow decomposition rates, limit snow accumulation and delay soil thaw. Reduced decomposition can then result in delayed nutrient cycling and high woody fuel and duff accumulations, which, when burned, cause severe wildfires with deep soil heating and high plant mortality.

Fauna

High canopy cover and multistoried stand structure found in late stages of succession improve big game thermal and security cover. However, the dense canopies also shade out early seral shrubs and grasses that usually have high forage value for many ungulates. According to Keane and Ryan, production of palatable shrub forage in old, fire-excluded stands may be less than 1 percent of that found in young postfire communities. Moreover, ungulates may find dense late seral stands difficult to traverse because of the abundance of downed logs and thick understory. Perhaps the largest impacts of fire exclusion may be felt by nongame wildlife species. Landscapes with intact fire regimes have high variability in patch size, shape and type, which is extremely beneficial for the existence of many animal species. This can be said for many insect and fungal species as well, reports Keane.

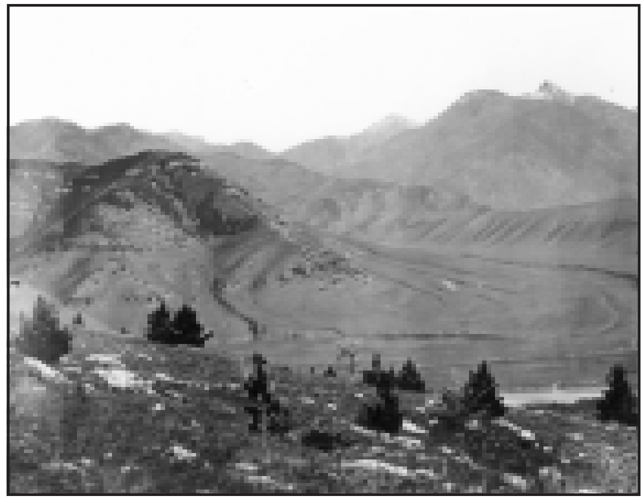
Exotics

The introduction of exotics into Rocky Mountain ecosystems has complicated and, in some cases, intensified fire exclusion efforts. Certain exotic plant species tend to efficiently colonize following disturbances, so restoration of fire regimes may increase exotic dominance and reduce diversity. Some exotic diseases and pests have accelerated the successional cycle, resulting in mid-seral stands having compositions and structures similar to old-growth stands.

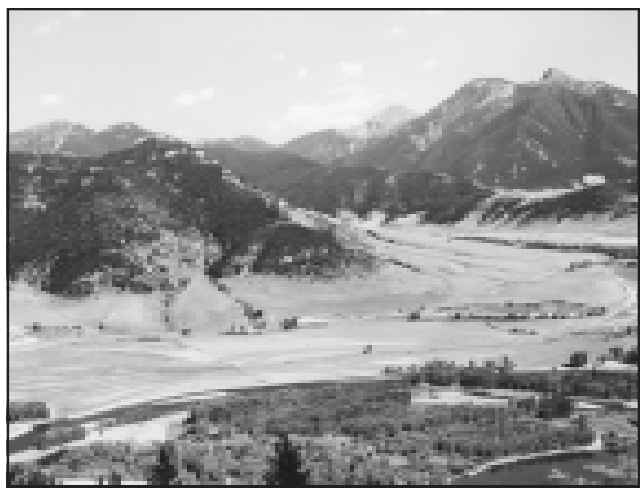
Cultural and Natural Resources

The absence of fire has had profound implications on natural resource management. For example, livestock forage resources in the West have been depleted in some areas because of conifer shading, and livestock and big game carrying capacities have decreased because of conifer and tall shrub encroachment. And, although fire is often blamed for destroying visual quality, it can actually be enhanced, along with viewing opportunities, by reducing tree densities. Open-growth, park-like stands of ponderosa pine created by frequent surface fires have a high aesthetic quality and, according to surveys, are preferred by today's outdoor enthusiasts. An actual decrease in recreation activities and visitation can occur as tree cover and density increase with fire exclusion.

Fire exclusion also heightens fire hazards to forest homes as people continue to develop and settle lands along the urban wildland interface. "As is evident during this and other severe wildfire seasons, the loss of homes and human life can escalate as the surrounding forest advances in succession because of the buildup of canopy and surface fuels," says Keane.



High on the slopes above the Yellowstone River, Montana, snags and young limber pine in this 1871 photo (above) indicate this area was swept by wildfire several decades earlier. By 1981 (below photo), a dense stand of Douglas-fir, limber pine and Rocky Mountain juniper occupied the near slope. The grass cover had been largely eliminated by tree canopy closure, and tree cover on distant slopes increased dramatically.



Landscape-level Effects

Historical fire regimes created dynamic mosaics of patches, processes and habitats on Rocky Mountain landscapes. These landscapes tend to become more homogeneous as fire is removed because succession will eventually advance all stands to similar communities dominated by shade-tolerant species. Keane says that landscape structure changes with fire exclusion as landscapes generally become less fragmented, have lower patch density, and evolve decreased patch diversity, which often results in more contagion, corridors and large patches. This leads to larger more uniformly severe wildfires. Contagion is generally described as the probability that similar patches are adjacent to each other.

Hydrology

Landscape hydrologic cycles can be altered as late seral communities progressively dominate landscapes without fires. Higher leaf areas from increased woody biomass will increase evapotranspiration and interception, resulting in lower streamflows and the drying of springs. "This reduces the amount of water available for irrigation and community water supplies," says Ryan, "especially during the late summer and early autumn."

Fire-excluded landscapes are especially vulnerable to changes in hydrology when stand-replacement wildfires inevitably do occur. Severe fires that burn in heavily forested stands that are outside historical fire frequencies may cause excessive erosion that degrades water quality and aquatic habitat. Snowmelt may be faster from the larger patches created by modern wildfires, resulting in earlier and higher spring runoffs. Peak flows usually increase several fold after large, intense wildfires, which would presumably increase surface and mass erosion. Keane and Ryan note that the increased vegetation cover near streams on fire-excluded landscapes decreases stream water temperatures, increases long-term inputs of coarse woody debris to streams, and delays and reduces peak runoffs. "However, when wildfires eventually occur on these protected watercourses, their high severity reduces shading, and increases erosion, peak flows and water temperatures," they say.

Cross-Scale Disturbance Effects

Perhaps the most important ecosystem process altered by fire exclusion is the historical fire regime. Fires generally become less frequent and more severe with active suppression on the landscape. Wildfires on late-seral landscapes tend to be larger, more intense and more severe because of high biomass loadings, multi-layer stand structures and the high connectivity of the biomass at the stand and landscape levels.

High surface fuel loads and complex vertical stand structures increase the chance that modern surface fires will become crown fires and burn overstory trees through torching and crowning. Once a crown fire has started, the high leaf areas and high crown bulk densities typical of later seral forests favor propagation of fire throughout the crowns in a stand. Furthermore, these crown fires are likely to be propagated across the homogenous landscapes because high contagion between multilayered stands ensures high connectivity in crown fuels.

Insects and Diseases

Insect and disease processes are also affected by the shift in host tree species across a landscape as fires are suppressed. Increases in insect and disease activity are attributed mostly to increased stress and reduced vigor of the early seral, fire-dependent tree species. "This plant stress is a direct result of the increased competition from rising stand biomass and ballooning plant density," says Keane. "Stressed plants and dense canopies are usually a recipe for severe insect and disease infestations," he says. For example, the absence of fire is implicated in chronic spruce budworm epidemics in many Douglas-fir and true fir stands in the Rockies; mountain pine beetle, bark beetles and dwarf mistletoe outbreaks are more common in ponderosa pine forests because tree densities increase due to lack of fire.

Increased patch contagion from lack of fire may amplify the severity of insect and pathogen outbreaks. Landscapes dominated by one cover type seem to have the greatest potential for epidemic infestations because host species patches are near and migration distances are small. Conversely, patchy landscapes under native fire regimes often have greater probabilities of non-host patches being barriers to pathogen dispersal.

Where Do We Go From Here?

"Restoration of some semblance of the historical fire regimes is a critical step toward improving the health of many Rocky Mountain ecosystems," says Keane. "However, hurdles exist. For one, the immensity of restoration efforts needed in the Rockies is somewhat daunting, considering projected future fires would need to burn from 3 to 7 times more than present. Seventy years of fire suppression have created high fuel accumulations in many stands that, when ignited, would create a fire that would be abnormally severe and kill most of the trees. So, reintroduction of fire must be done carefully to prevent further damage to the stressed old-growth trees and other ecosystem components," said Keane.

Keane and Ryan point out that developing a fire prescription to minimize fire intensity, but still accomplish restoration objectives, is problematic because the high fuel loadings may preclude the implementation of a low-severity burn on many sites. In addition, land management agencies are limited in conducting the extensive restoration treatments that are needed because of competing governmental regulations and the high cost of implementation from environmental assessments to executing treatments. "Despite these challenges," they say, "a functional restoration program is possible and necessary."

The role of fire will continue to change in the Rocky Mountains. It is not a question of "if" a landscape will burn, but rather, when it will burn, and how severe that fire will be. Extreme fire years, such as 1910, 1919, 1934, 1967, 1988, 1994, 1996 and 2000 (and it looks like we can add 2002 to this list) will tend to burn most plant communities regardless of fuels or ecosystem health, but the severity of these burns at the stand- and landscape-level will be dictated by the fuel loadings. "In the past, one could wonder what would happen if the extreme weather conditions of previous severe fire years occurred today on our fire-excluded landscapes of the Rocky Mountains. I'm afraid we may be discovering that sooner than we wanted," says Keane.

If you would like additional information on Keane's and Ryan's work, contact the Rocky Mountain Research Station and request General Technical Report RMRS-GTR-91, *Cascading Effects of Fire Exclusion in Rocky Mountain Ecosystems: A Literature Review*.

Publication Reviews

Evaluating the Effectiveness of Postfire Rehabilitation Treatments
(RMRS-GTR-63)

Spending on postfire emergency watershed rehabilitation has increased during the past decade. A west-wide evaluation of USDA Forest Service burned area emergency rehabilitation (BAER) treatment effectiveness was undertaken as a joint project by USDA Forest Service Research and National Forest System staffs. This evaluation covers 470 fires and 321 BAER projects, from 1973 through 1998 in USDA Forest Service Regions 1 through 6. A literature review, interviews with key Regional and Forest BAER specialists, analysis of burned area reports, and reviews of Forest and District monitoring reports were used in the evaluation. From this review, scientists recommend increased treatment effectiveness monitoring at the hillslope and sub-catchment scale, streamlined postfire data collection needs, increased training on evaluation of postfire watershed conditions, and development of an easily accessible knowledge base of BAER techniques. The report, *Evaluating the Effectiveness of Postfire Rehabilitation Treatments*, is available from the Rocky Mountain Research Station as RMRS General Technical Report 63.

Development of Coarse-Scale Spatial Data for Wildland Fire and Fuel Management
(RMRS-GTR-87)

This paper documents the methodology scientists used to develop seven coarse-scale, 1 km2 resolution, spatial data layers for the conterminous United States to support national-level fire planning and risk assessments. Four of these layers were developed to evaluate ecological conditions and risk to ecosystem components: Potential Natural Vegetation Groups; Current Cover Type; Historical Natural Fire Regimes; and Fire Regime Current Condition Class. The remaining three layers were developed to support assessments of potential hazards and risks to public health and safety: National Fire Occurrence, 1986 to 1996; Potential Fire Characteristics; and Wildland Fire Risk to Flammable Structures. Managers can use these spatial data to describe regional trends in current conditions and to support fire and fuel management program development and resource allocation. Request *Development of Coarse-Scale*

RMRScience is a quarterly report from the USDA Forest Service's Rocky Mountain Research Station. Each issue highlights on-going or recently completed research, and features findings useful to land managers and other natural resource specialists. To be added to the mailing list, free-of-charge, write RMRScience, Rocky Mountain Research Station, 2150 Centre Ave., Bldg. A, Fort Collins, CO 80526; or e-mail rfletcher@fs.fed.us; or fax (970) 295-5927. Comments and suggestions are always welcome.

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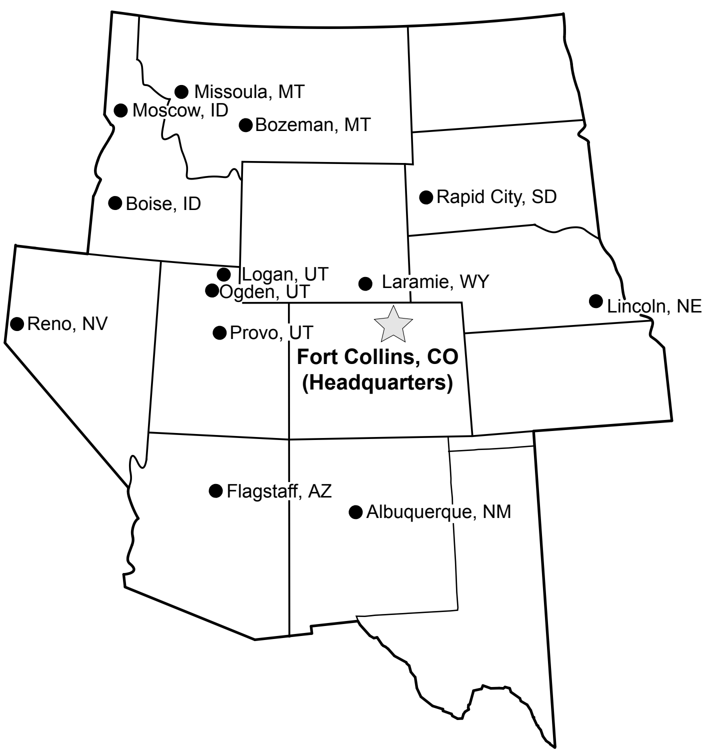

The USDA Forest Service's Rocky Mountain Research Station is one of seven units nationwide that make up the most extensive natural resource research organization in the world. Headquartered at the foot of the Rockies in Fort Collins, CO, the Station maintains 14 field laboratories within a 14 state territory (see map). Scientists conduct studies nationwide, with emphasis on the Rocky Mountains, Great Basin, Great Plains, and Southwest. Research serves the Forest Service, as well as other federal agencies, international organizations, private groups, and individuals. For more information, visit our website at http://