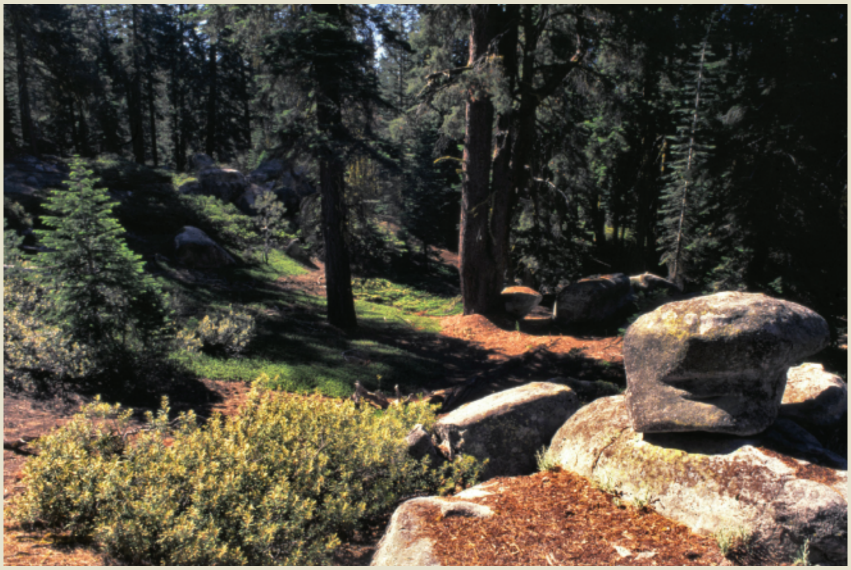
Pacific Southwest Research Station
Forest Service, U.S. Department of Agriculture

Restoring Forest Health



Fire and thinning effects on mixed-conifer forests

Even after 140 years without a fire, mixed-conifer forest such as Teakettle's Experimental Forest has a distinct patch pattern and complex structure. Researcher Malcolm North and colleagues examined the structure and function of these ecosystems and their response to widely used restoration treatments. Collectively the studies found fire was essential to restoring many ecosystem processes and that thinning could be best used as a tool to influence burn intensity and extent.

Walk into many forests in the Sierra Nevada and you will have to thread your way through dense clusters of small trees, step over a clutter of woody debris, and navigate under a closed, darkened canopy. Yet in the late 19th century, John Muir wrote of "the inviting openness of the Sierra woods. Trees of all the species stand more or less apart in groves, or in small, irregular groups, enabling one to find a way nearly everywhere." Like many forests of the Western United States, Sierra Nevada forests have significantly changed following a century of fire suppression, land use, and climate change. Historically, fire burned through mixed conifer about every 15 years, but now fire burns so little forest acreage that some scientists have estimated the fire-return interval is more than 600 years. When wildfire inevitably occurs, accumulated needle litter and ladder fuels (intermediate-sized trees that can carry a ground fire into the tree tops) often combine to produce catastrophic crown fires that kill all trees and can threaten homes. State and federal agencies have developed plans for reducing fire risk and restoring forest health, but these plans are controversial.

What exactly constitutes a healthy forest? After a century of fire suppression, how can land managers use methods such as fire and thinning to restore forests? Can thinning help restore forests adapted to frequent fire, and if so, how should forests be thinned?

A major experiment in mixed-conifer forest at the Teakettle Experimental Forest is designed to shed light on these questions. As the most extensive forest type in the Sierra Nevada and a key source of timber, mixed conifer is the focus of research led by plant ecologist Malcolm North of the USDA Forest Service, Pacific Southwest Research Station (PSW). Teakettle, managed by the PSW Research Station, is a 3,000-acre (1300 hectare) old-growth forest on the western slopes of the Sierra Nevada 45 miles (75 kilometers) east of Fresno, California. At this site, a team of more than two dozen researchers examined ecosystem processes over a 7-year period. The team coordinated their studies by using the same design, and by sampling at common locations. "It's said that trying to coordinate scientists from different disciplines is like trying to herd cats," comments North, "but at Teakettle, researchers worked well together because everyone was

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From Science…

Major Themes

Water stress: In fire-suppressed forests with high tree densities, limited soil moisture strongly affects many ecosystem processes.

Large tree linkages: Overstory trees significantly modify forest microclimate and sustain food webs through fungal and seed production.

Fire and forest function: Many ecosystem processes can be "jump started" with fire.

Research Results

Patch legacy effect: Vegetation patches interact with fire and thinning treatments to strongly influence local posttreatment ecological processes.

Litter and slash: Thinning treatments reduce ladder fuels, but if forest is left unburned, the additional slash and litter reduce understory diversity and regeneration, and create additional fire risk.

Historical conditions: Under an active fire regime in the 1860s, historical mixed-conifer stands had few trees, an equal number of all sizes, and more large trees than are present in modern old-growth forests.

Fire-suppressed stand at Teakettle.

Why the change in the last 100 years? By studying tree rings and fire scars, which together reveal when and how often historical burns occurred, scientists have deciphered much of the fire history of forests in the West. Before 1865, fires occurred at Teakettle at approximately 12- to 17-year intervals. But after 1865, not only at Teakettle but also throughout much of the West, fire has generally been scarce. In the absence of fire, bark beetles and disease become the main causes of mortality. However, unlike fire, they do not periodically remove young trees and leave mature canopy trees intact. Instead, pests and pathogens attack dense clumps of trees that have become moisture stressed, killing both the young saplings and old trees that survived many past fires.

When fire does occur, usually at long intervals, destructive conflagrations often develop. The prolific growth of understory vegetation, which carries flame from ground level to the canopy, has played a large role in creating hard-to-control, hot fires that consume, rather than restore, forests.

During the last 60+ years, fire suppression has played a major role in understory survival and fuel buildup. Prior to that time, scientists can only speculate why fire became scarce. It may have been the change to a warmer, wetter climate, extensive grazing, or possibly fewer fires set by Native Americans, whose populations were decimated by newly arrived settlers.

Testing Restoration Treatments

The changed structure of fire-deprived Western forests has left them prone to destructive fires. But does simply restoring the appearance of the forest by thinning ladder fuels rejuvenate the forest and maintain a healthy ecosystem? And if so, how large of a tree can be removed to cover some of the costs of the restoration treatment? Or must low-intensity fire be used as well to restore the forest's function and health?

The first step to answering these questions for Sierra mixed-conifer forest was to better understand its current fire-deprived condition, initiated through studies that began at Teakettle in 1998.

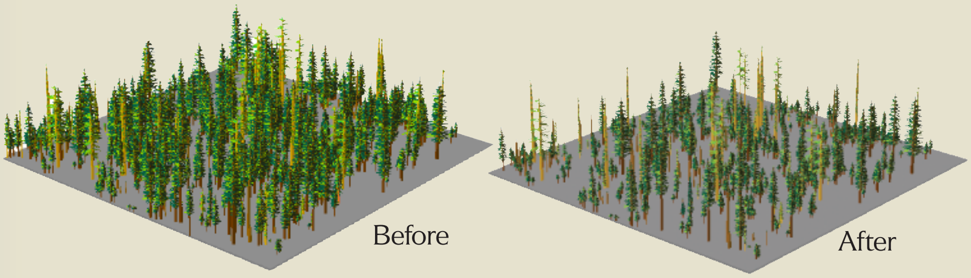
Scientists carefully selected 18 plots within contiguous old-growth mixed conifer—each plot with an equal proportion of the three patch types (closed canopy, shrub, and gap) that make up mixed conifer. Then, scientists compared five potential fire and thinning management scenarios with untreated forest. The scientists used three plots for each scenario.

There were five treatments: (a) fire, (b) understory thinning (trees <30 inches [76 centimeters] in diameter), (c) shelterwood thinning (which left 8 regularly spaced large-diameter trees per acre [20 trees per hectare]) (d) understory thinning plus fire, and (e) shelterwood thinning plus fire. The experiment also included a no treatment control.

In addition to understanding the effects of restoration on forest structure, the scientists also studied how the treatments affected soil conditions, ecosystem processes, and food chains, all of which give some sense of the health of the forest.

Forest Structure—Trees and Plants

Developing a reconstruction of Teakettle's stand conditions in 1865 immediately after the last large-scale fire, Malcolm North and Jim Innes, PSW, and Harold Zald, Pacific Northwest Research Station (PNW), USDA Forest Service, evaluated how effectively the five alternative restoration treatments had returned mixed-conifer forests to conditions produced by an active fire



A 10-acre (4-hectare) plot before and after an understory thinning treatment.

White fir regenerating in a gap surrounded by large pine.

regime (i.e., what the stands were like in 1865). The scientists determined that combined understory thinning and fire treatments worked most effectively to reduce the density of trees, while simultaneously increasing the percentage of pines, historically a larger component of mixed-conifer forests. Restoration treatments should be based on more than simply modifying current forest structure; the development of the regenerating forest after these disturbances should also be considered. Andy Gray of the PNW Forest Inventory and Analysis Program and Zald found that light and soil moisture increased with treatment intensity, particularly in the thin and burn plots, because higher fuel loads increased fire-induced mortality of small trees. They found that pine recruitment is limited by a lack of large pines supplying seed and an abundance of large white fir and incense-cedar with prolific seed rain. If managers wish to increase pine composition, they may need to consider planting only pine seedlings, reapplying prescribed fire, or reducing overstory white fir and incense-cedar seed sources.

Over 50 percent of California's plant species occurs in the Sierra Nevada—and most of this diversity occurs as the herbaceous understory beneath conifer forests. Rebecca Wayman, University of California, Davis, and Malcolm North found that the understory response depended on the interaction of the patch type and the fire and thinning treatment so that pretreatment vegetation had a strong legacy effect on restoration conditions. Burn/thin combinations led to significant increases in the number and cover of herbaceous species. Thinning increased understory light and soil moisture, burning reduced leaf litter and slash, and both treatments reduced shrub cover. Because prescribed fires were lit in the fall, after first precipitation, fires did not burn sufficiently hot to rejuvenate the herbaceous layer without year-old slash from understory thinning to help fuel the fire.

Soils-Nutrients, Litter, and Water

Nitrogen: Soil scientist Heather E. Erickson of PNW Research Station, USDA Forest Service, tracked the key nutrient nitrogen during Teakettle experiments. Plants can only take up available nitrogen in one of two forms: nitrate ion (NO_{3-}) and ammonium ion (NH_{4+}). So, the form of nitrogen in forest soils is just as important as the quantity. Whitethorn ceanothus contains symbiotic bacteria in root nodules that fix N^2 in the air, converting it to ammonia. Soils beneath patches of ceanothus contained the highest levels of available nitrogen, both before and after restoration treatments. Nitrogen that plants could use during forest recovery was considerably higher after the burn/thin treatments.

Water and litter: In the fire-suppressed forest at Teakettle, scientists found that soil moisture controlled many of the ecological processes—understory diversity, tree regeneration, soil respiration, nutrient cycling and decomposition, and soil invertebrate abundance to name a few. Because Sierran summers are so dry, the amount of soil moisture depends on snowpack depth and distribution. Annual climate, particularly El Niño events, has a strong influence on plant diversity and establishment, and many ecosystem processes. After treatments, soil moisture was still important to many processes, but another forest condition also became influential—the absence of litter and slash. Many processes positively responded to the burn's removal of the thick litter layer that had accumulated with fire suppression. Thinning alone, because it put more litter and slash on the soil surface, tended to stall many ecosystem processes.

Carbon: With global climate change a worldwide concern, forest management must emphasize carbon storage over its release as CO^2, a greenhouse gas that contributes to warming trends. Amy Concilio and Jiquan Chen, University of Toledo, and Siyan Ma, University of California, Berkeley, and their colleagues, followed soil carbon levels after restoration treatments by measuring levels of respiration, the biological process whereby living organisms release CO^2. In plots where thinning had taken place, no change was found at 1 year, but by 2 years posttreatment, CO^2 release significantly increased. Although fire initially releases a pulse of carbon into the atmosphere, increases in root and tree bole growth contribute to carbon storage. These early findings suggest that in the long run, thinning may contribute more to elevated CO^2 and global climate change than prescribed fire.

Climbing into the crown of a 200-feet (60-meter) tall red fir to sample lichens.

Food webs: Small mammal response to burning and thinning treatments differed by dietary habit. Researcher Marc D. Meyer, University of California Davis, and colleagues followed how chipmunks, which have an adaptable generalist diet, and flying squirrels, which are truffle and lichen specialists, responded to treatments. Chipmunks altered their diet depending on the abundance of different food sources, but their numbers did not change. At Teakettle, near the southern-most extent of their range, flying squirrels were concentrated in riparian areas with almost 90 percent of their nest trees located within 500 feet (150 meters) of a perennial creek. Because of this concentration, their habitat was not extensively affected by treatments; however, their main food source, truffles, decreased in abundance and diversity as fire and thinning intensity increased. A greater abundance and diversity of truffles and lichens near streams and a greater density of all small mammals sampled suggest the importance of riparian habitat in seasonally dry forests.

Northern flying squirrel eating a truffle.

...To Management

A Conversation With Malcolm North

Q ***What do Teakettle findings tell us about various restoration treatments? Which treatments work most effectively to restore forest structure?***
It's not realistic to try to move forests backward to a condition found prior to European settlement because Native American ignitions, grazing intensity, and climate have all changed. However, we do know the ecological processes in these forests depend on frequent fire; it was their evolutionary environment. In our study, the combination of understory thinning, followed by burning 1 year later, proved most effective in moving the forest toward a condition produced by a frequent fire regime. These thinning treatments followed specifications originally designed for spotted owl protection. However, the combined treatment needs to be further adjusted to optimize restoration. Many more small-diameter trees that contribute to moisture stress should be removed, particularly those around large, old-growth trees. Some intermediate-size trees, trees with a diameter between 20 and 30 inches (50 to 76 centimeters), need to be left to provide the next generation of large, old trees. Thinning prescriptions should differ by species and rarely should pines or hardwoods be cut.

Q ***How about maximizing understory diversity?***
Again, the combination of understory thinning and burning proved most effective because it increased soil moisture, reduced litter and slash, and decreased shrubs that are strong competitors for light and soil moisture. Neither burning nor thinning alone achieved these ends.

Q ***What do Teakettle studies tell us about managing mixed-conifer forests for the northern flying squirrel and its foremost predator, the spotted owl?***
Postrestoration studies showed that all treatments reduced the flying squirrel ' s main food source, truffles, but treatment intensity made a difference. Understory, as opposed to shelterwood cutting, and lower intensity fires best retain truffles. Protecting larger trees and decaying logs leaves fungal banks providing a source of spores after restoration treatments. Additionally, the finding that 90 percent of squirrel nests are near creeks has important implications. Retaining large trees, especially those close to streams may be essential for flying squirrels and the food on which they depend.

Q ***Overall, how should forest restoration be approached?***
Fire is the most important tool in forest restoration, but often it may need to be supplemented by understory thinning to reduce ladder fuels and to burn sufficiently in late fall when control burns are typically carried out. The slash produced by thinning adds enough fuel for fire to burn hot enough to recycle nitrogen to the soil, open up forest stands, and restore many ecosystem processes. Thinning allows heavier removal of white fir and incense-cedar, which need to be significantly reduced. Restoration of forest health cannot be done through thinning alone; rather, any logging treatments should be designed to optimize restoration through fire.

A plot treated with understory thinning and prescribed fire.

Losing large trees: Insects and pathogens have replaced fire as the main source of mortality, and during droughts they can kill many old-growth trees.

Restoring "health": Fire is needed to restore most ecosystem functions. Thinning without burning may reduce ladder fuels, but the additional slash and litter stall ecosystem recovery.

Fire-focused silviculture: Thinning may be a tool that is best used to increase the ecological "work" done by fire, particularly when prescribed burns are lit during cooler conditions in spring or fall.

Flexible thinning prescriptions: Thinning rules should be flexible to leave most shade-intolerant pines and retain many intermediate-size (20- to 30-inch, [50- to 76-centimeter] diameter) trees.

Forest trajectory: To maintain an open stand and increase pine, repeated prescribed burns and planting pine seedlings may be needed in mixed-conifer stands.

Highly diverse understory of mixed-conifer forest.

Scientist Profile

Malcolm P. North, Ph.D.
Sierra Nevada Research Center
Pacific Southwest Research Station
USDA Forest Service
2121 2nd Street
Suite A-101
Davis, CA 95616

Phone: 530-754-7398
e-mail: mpnorth@ucdavis.edu
http://www.psw.fs.fed.us/snrc

"I've always been interested in how disturbances affect forests" says plant ecologist Malcolm North. "In particular, how disturbance changes forest structure, species composition, and reverberates through ecosystem functions."

Studying how northern spotted owls used wind- and fire-disturbed old growth in the Pacific Northwest was the start of North's research work. This also kindled an interest in food webs and how owls, flying squirrels, and truffles are connected and influenced by forest structure. In 1995, North moved to California and started working with the USDA Forest Service Forestry Sciences Lab in Fresno on nest conditions of the California spotted owl. It was shortly after this that the "Sierra Nevada Ecosystem Project Final Report" was published summarizing what was known about Sierra forests and what areas particularly needed research. "It was a wonderful synopsis of some exciting research ideas. One recurrent theme in the report was the lack of information about how ecosystems respond to fire and thinning treatments commonly used to restore fire-suppressed forests."

In 1997 North began the Teakettle experiment to investigate this question using a replicated field experiment with eighteen 10-acre plots. More than two dozen scientists and graduate students joined the experiment to measure a wide array of ecosystem processes for 3 years before and after thinning and burning treatments were applied. The effort helped develop a multidisciplinary understanding of some of the key functions in mixed-conifer forest, how they've been affected by fire suppression, and how they respond to management practices.

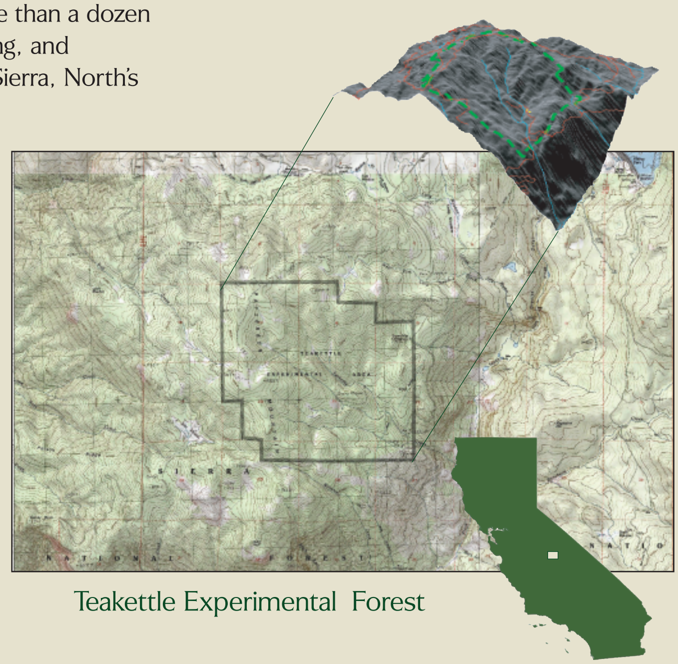
North is especially interested in developing robust field experiments that address conservation and restoration issues of forest managers in the Sierra Nevada. He is now part of the Sierra Nevada Research Center in Davis and has an affiliate appointment in the Department of Plant Sciences at University of California Davis. With more than a dozen years backpacking, climbing, and backcountry skiing in the Sierra, North's long-term goal is to provide research that can improve stewardship of the Sierra Nevada's ecosystems.

North received his Ph.D. in forest ecology from the University of Washington in Seattle. He also has an M.S. in forestry from Yale University, and a B.A. in English from Vassar College.

Continued from front page

excited by the possibility of discovering linkages between their different research disciplines." This led to some interesting findings and an awareness of common themes. "As scientists, we were looking for complex answers; suites of mechanisms that would each influence different ecological processes. In the pretreatment forest, however, as complicated as we wanted to make it, it usually came down to one limiting factor, water."

After the fire and thinning treatments were applied in 2000 and 2001, however, the ecological responses were more complicated. "The treatments reduced the number of trees taking water up from the soil, and this appears to have relaxed a moisture constraint," says North. Water availability was still important, but other factors became influential such as the amount of litter and slash, and the kind of vegetation patch (closed-canopy forest, shrub, or gap) that was on a site before treatment. "Although the focus and controversy have always been on whether the forest should be thinned and what size of tree can be removed, in the end, most Teakettle scientists felt thinning was better viewed as a tool that served the burn. It's the fire that does the real work of restoring these forest's health."



Teakettle Experimental Forest

What's Next

To make this information readily accessible to managers, students, and any interested members of the public, an interactive DVD with a film about the experiment is in postproduction. The film will summarize the experiment, five short special feature films will provide greater detail about specific components of the research, a library of publications provide research results, and a Web site and query function will provide an active question-and-answer resource.

A second phase of the Teakettle experiment is in planning, in which the experiments' findings will be used to test new thinning and burning prescriptions at the watershed scale. Different prescribed burn applications (varying season and burn intensity) will be compared, and thinning prescriptions will be modified so that they differ by tree species and retain a target level of trees in different diameter sizes.

Work is also underway to expand the scope of the research by starting projects in the central, northern, and eastern Sierra to examine how ecosystem processes and response to these treatments differ between geographic locations and forest types.

Film shoot at Teakettle.

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P.O. Box 245
Berkeley, CA 94701

For Further Reading

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Web Resource
http://teakettle.ucdavis.edu

Early draft of this issue of Science Perspectives by **Anne M. Rosenthal**, is a science writer based in the San Francisco Bay Area.