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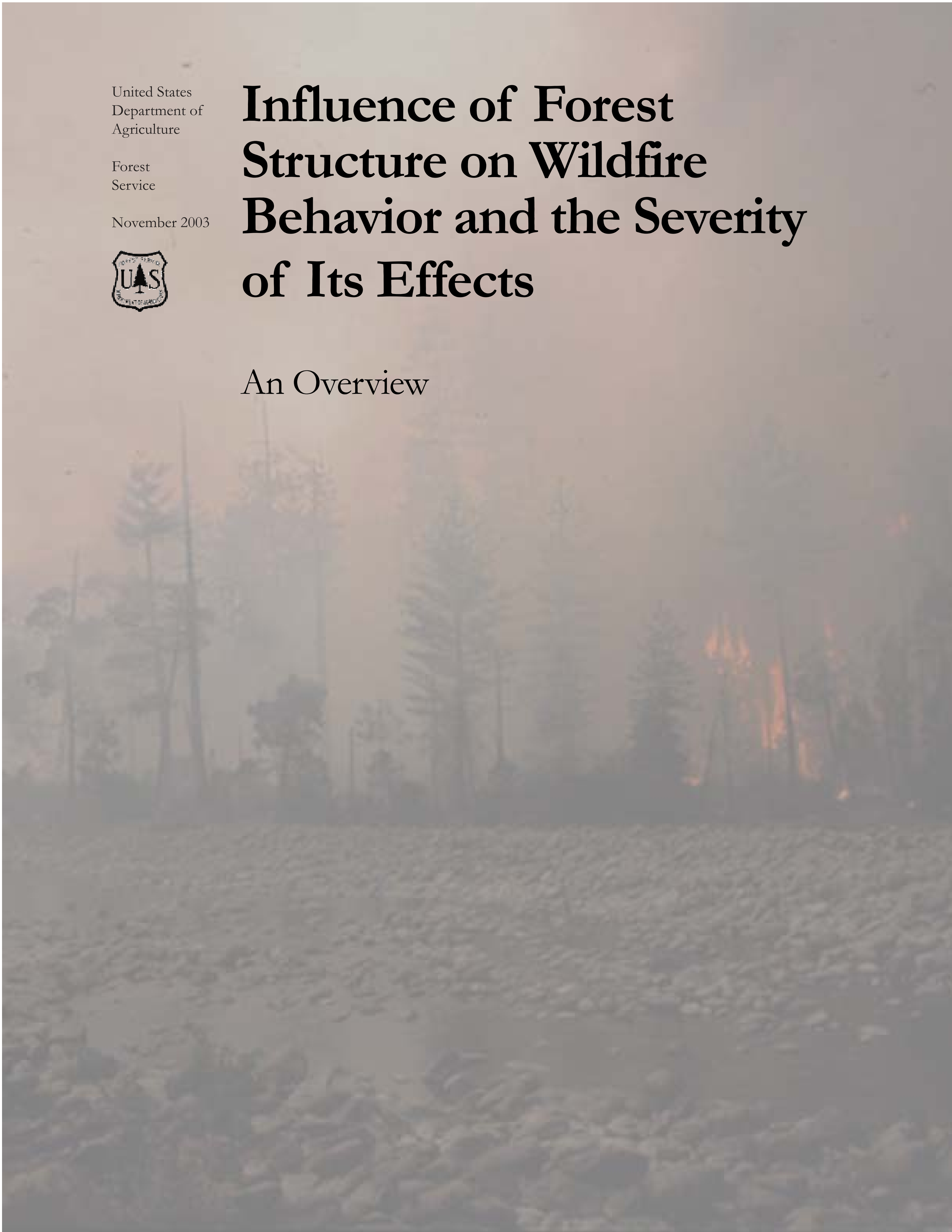
Influence of Forest Structure on Wildfire Behavior and the Severity of Its Effects

An Overview



Wildland fire flames of the Monument Fire, OR, 2002.

Introduction

The year 2002 was the second largest fire season in almost 50 years. Four States had the largest areas burned in wildfire since at least the early 1900s—Arizona, Colorado, New Mexico, and Oregon. California wasn't far behind. Across the Nation, almost as many acres burned in 2002 as in 2000, when the area burned was twice the 10-year average.

The 2002 season could have been much worse. The Forest Service and its partners in the firefighting community controlled 99 percent of the wildland fires during initial attack. The fires that did escape initial attack threatened life and property, compromised municipal watersheds, and damaged ecosystems—many of which will take decades to recover. Fire suppression expenditures for 2002 were $1.4 billion.

More than 90 years of fire research shows that four factors working in concert can result in the type of catastrophic wildfires witnessed in 2000 and 2002: weather, an abundance of fuel (combustible forest materials), lack of moisture, and terrain characteristics. Of these four factors, only fuel abundance can be directly influenced through human intervention; however, the treatments to reduce fuels can significantly modify fire behavior and severity and reduce environmental damage caused by fire.

Excluding fire from the natural cycle has resulted in a buildup of flammable plant materials across large areas of the forest landscape. As forest fuels accumulate, the forest structure changes, leading to greater continuity of fuels between the ground surface and the upper tree canopies. This altered structure provides "ladders" for wildfire to climb up into the tree tops. Where trees are densely packed, the fire can spread from tree to tree in a phenomenon known as crown fire or crowning. Crown fires are intense and fast-moving. They can threaten communities and damage key resources, including timber, fish and wildlife habitat, soils, and drinking water quality. Crown fires are virtually unstoppable, and often result in large burned areas despite costly and dangerous fire suppression efforts.

The effects of decreased fire occurrence on fuels and fire behavior vary from site to site. In the Western United States, the effects are most pronounced in arid to semiarid forests dominated by ponderosa pine, Douglas-fir, or a combination of the two. Historically, these ecosystems experienced frequent fires, which typically burned at low intensity in surface fuels, with only occasional damage to overstory trees. Removing

Grazing reduces surface fuels, which, in turn, decreases the incidence of wildland fire.

fire from the natural cycle has resulted in overcrowded stands with dense canopies and many small trees of shade-tolerant and less fire-resistant species growing between a few large trees. This type of overall forest structure increases the probability that a low-burning surface fire will develop into a high-intensity crown fire. The overly dense forest structure also means that trees are in stressful competition and more susceptible to disease, insects, and invasive species.

Wildland fires differ greatly in severity, which refers to the degree of impact on soils, vegetation, and other ecosystem components. Weather, forest structure, fuel condition, and vegetation composition interact with location to determine a fire's severity. Land managers can design fuel treatments to alter forest structure and influence fire behavior and burn severity. Treatments that reduce surface fuels tend to reduce damage to soils and decrease the likelihood of tree mortality from stem scorching and root damage. Surface fuel reduction also diminishes a fire's heat, a key factor in the initiation of crown fires. Thinnings designed to reduce crown density helps prevent tree crowns from severe, often fatal, burns. Reducing crown density also decreases the likelihood of a sustained crown fire moving through the forest, even if crown ignitions do occur.

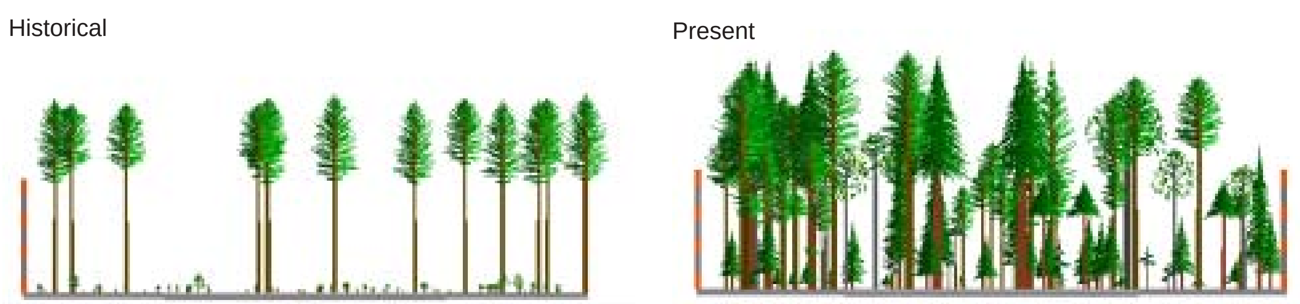
Proactive, ecosystem-based land management can improve and maintain forest health while reducing the danger of catastrophic fire in these arid and semi-arid western forests. However, the forest health and fire hazard problems arising from fire exclusion took decades to develop and the solution will not happen overnight. The remainder of this overview presents highlights of available scientific information and implications for management action.

Influence of Forest Structure on Wildland Fire Behavior and Effects

A forest stand may consist of several layers of live and dead vegetation in the understory, midstory, and overstory—or surface, ladder, and crown fuels.

Surface fuels consist of grasses, shrubs, litter, and woody material lying on the ground. Surface fires burn low vegetation, woody debris, and litter. Under the right conditions, surface fires reduce the likelihood that future wildfires will grow into crown fires.

Ladder fuels consist of live and dead small trees and shrubs, live and dead lower branches from larger trees, needles, vines, lichens, mosses, and any other combustible biomass located



Hypothetical simulation of changes in vertical arrangement and horizontal continuity in forest stand structure. Today's forests are more spatially uniform, with higher densities of fire-intolerant species and suppressed trees.

between the top of the surface fuels and the bottom of the overstory tree crowns.

Crown fuels are suspended above the ground in treetops or other vegetation and consist mostly of live and dead fine material. When historically low-density forests become overcrowded, tree crowns may merge and form a closed canopy. Tree canopies are the primary fuel layer in a forest crown fire.

Fire behavior is strongly influenced by surface, ladder, and crown fuels. Heavy ladder and crown fuels enable fires to climb upward into the crowns and help to sustain crown fires once they are started. Rapidly moving crown fires typically consume nearly all the fine fuels in a forest canopy when wind and a sloping topography are thrown into the mix. Crown fires caused by excessive fuel accumulation are generally a severe threat to ecological and human values and to infrastructure and are a major challenge for fire management. Such fires kill large numbers of trees, damage soils, increase erosion, impair air quality, and can degrade or destroy species habitat.

Fuel Treatments Can Influence Fire Behavior and Reduce Fire Severity

Where forests are overcrowded, the most effective strategy for reducing fire risks is to design treatments to decrease fuels in all three strata. Thinning reduces the flammability in the midstory and overstory, while treating surface fuels, including those resulting from thinning, decreases surface fire potential.

Three recent examples from the Hayman Fire in Colorado illustrate the relation between surface, crown and ladder fuels, and fire behavior.

- The Polhemus prescribed burn in November 2001 removed most surface fuel and pruned lower live branches from trees in a ponderosa pine forest, while maintaining a desirable overstory density. These changes were sufficient to stop the Hayman Fire when it burned into the area in June 2002.
- On the Manitou Experimental Forest, mechanical thinning reduced density in a pure pine forest and concentrated logging slash in large piles within the Trout Creek Timber Sale. These actions resulted in an easily suppressed surface fire when the Hayman Fire burned into the area.

Hayman Fire, June 15, 2002, about 9 p.m. Photo by Steven Smith, Colorado Springs Fire Department.

- On the other hand, all trees were killed in the Sheepnose Fuels Reduction Project. Although removing smaller trees dramatically reduced stand density, large amounts of surface fuels allowed the fire to burn intensely through the stand.

Thinning opens stands to greater solar radiation and wind movement, resulting in warmer temperatures and drier fuels throughout the fire season. While this openness can encourage a surface fire to spread, such fires do little ecological damage. Where human values are threatened, these types of low-intensity fires are relatively easy to control and less likely to support a crown fire even under severe weather conditions.

Mechanical thinning, especially when directed at the smaller and medium-sized trees, can be quite effective in reducing the conditions conducive to crown fire spread. However, thinning is most effective when followed by additional treatments such as prescribed fire to reduce surface fuels. If thinning is used, it is important to reduce the fine fuels, such as small branches, leaves and needles, or they will add to surface fire potential. Branches, limbs, and other slash may need to be treated with prescribed fire.

Piling and burning the slash and other material is an effective way to treat it. If burning is not acceptable due to smoke production, the residual fuel can be removed from the site.

Prescribed fire is one of the most effective means to remove surface fuels and reduce understory density. Prescribed burning affects

Site before thinning.

During thinning operation.

Site after thinning.

potential fire behavior by reducing surface fuel loads and horizontal fuel continuity. This treatment limits the spread of future surface fire, decreases fire intensity, and reduces the occurrence of spot fires. The effectiveness and appropriateness of prescribed fire varies depending on weather, initial fuel conditions, and the pattern of burning. Mechanical thinning followed by multiple applications may be required to reduce fuels gradually when ladder fuels are present. Use of prescribed fire requires caution where high surface fuel loads could lead to soil temperatures that might damage tree roots.

It's important to note that, with the current forest conditions in the western United States, one treatment may not be sufficient to achieve desired conditions. Once desired conditions have been attained, maintenance treatments, such as prescribed fire, will be required to prevent excess fuel accumulation as plants regenerate and regrow following treatment.

Thinning and prescribed burning are standard vegetation management practices whose implementation has been guided by hundreds of scientific investigations and years of professional experience. When properly conducted with safeguards developed from experience, past research, and emerging scientific findings, these practices can be combined in a treatment regime to improve forest health, reduce fire risk, and minimize side effects on environmental conditions and ecological processes. Using them together in an integrated fashion allows them to complement one another – as when slash from thinning is reduced by follow up burning, or when mechanical treatment of surface and ladder fuels reduces the probability that a prescribed fire will have excessively severe impacts or undesired results.

Importance of Managing Fuels Across Large Landscapes

Removing biomass and live fuels only in the wildland-urban interface can help protect homes

Prescribed burn.

Wildland-urban interface—Llamas grazing in a field watch as a wildfire comes close to home on the Deer Creek Ranch outside of Selma, OR.

and businesses. However, protecting resource values such as water quality, forest health and productivity, wildlife habitat, and recreation values requires vegetation and fuel management at a landscape scale. Fuel treatments carried out over large landscapes can reduce both the size and severity of wildfires and their effects on communities and the environment. Treating just a few stands in large contiguous forested landscapes will do little to modify fire behavior over the entire area. Protecting large landscapes requires land managers to develop large-scale fuel treatment patterns that reduce the potential for catastrophic fire and promote healthy forest conditions.

Evidence from natural fire patterns that have fragmented fuels across landscapes suggests that mosaic patterns can limit the growth of large fires. This type of spatial pattern limited fire growth and altered fire behavior in such places as Yosemite National Park, Sequoia National Park, and Baja California.

Studies that describe patterns of fire severity after large fires and intensive studies of fire history that describe fire patterns over centuries also show that topography plays a major role in determining the patterns of fire. The influence of topography on fire behavior escalates as the slope steepens and increases in complexity.

Model simulations of landscape fire behavior indicate that the spatial arrangement of treatments greatly influences the amount of area that needs to be treated. Strategic placement of treatments that takes into consideration information such as terrain, existing vegetation and fuel distribution, and probable fire paths creates landscape fuel patterns that can be expected to slow fire growth and modify behavior while minimizing the amount of treated area required. The arrangement of fuel treatment units changes fire behavior by forcing a fire to repeatedly flank around patches of treated fuels, or to burn through them at lower intensity, thus reducing the fire's overall intensity and growth rate. These model results suggest that random fuel treatments are not efficient in changing fire behavior. Strategic treatment is most effective when areas are not impeded by constraints such as land ownership, endangered species, and riparian buffers.

Another approach to managing fire on a landscape scale is the use of fuel breaks in strategic locations, such as along ridgelines or around communities. The concept behind fuel breaks is to provide a defensible location for use by firefighting crews, or to reduce fire intensity in the immediate wildland-urban interface. If the fuel break fails to stop a fire, it is unlikely to influence the fire's ultimate size and effects. However, fuel breaks can be efficient and cost-effective in protecting homes and other structures from catastrophic wildfire. As with other forms of

A bulldozer operator knocks down trees to create a safety zone for firefighters and fire equipment south of Show Low, AZ. Photo by Tom Schafer.

treatment, fuel breaks require maintenance. Fuel breaks are not a replacement for a strategic fuels treatment program. They are most effective when incorporated into a strategic fuel treatment program or community protection and preparedness program.

While the long-term effects of strategic fuel treatments at the landscape level on potential fire behavior are not fully known, research indicates that the spatial mixture of stand conditions is more important than exact conditions in a given stand. This effect is evident in the mosaic patterns of free burning fires at Yosemite National Park and Sequoia National Park. Previous burns do little to prevent reburning after about a decade, although they do lessen fire severity. Recently treated areas, on the other hand, can completely inhibit fire spread. Therefore, a combination of new treatments and maintenance treatments arrayed across a landscape can effectively disrupt fire growth and change fire behavior at the landscape scale, even though some stands within the landscape have not been treated recently.

Overall, how long treatments will last and how often they will need to be maintained will vary with forest type, climate, soils, and other factors that influence forest health.

Fire Prediction Models Can Be Effective as a Tool in Active Land Management

Most scientific investigation related to assessing the influence of fuel treatments on fire behavior at the stand and landscape levels relies on computer models to predict outcomes. There are a variety of models available to predict surface and crown fire behavior, environmental effects of fire, and the influence of treatments on stand development. These models are revised and improved constantly. Models help to simplify much of what really happens to further our understanding of the main factors involved in the system under study. Combining these models with map-based data and analysis tools can help integrate basic landscape analysis with fuel-treatment prescriptions for specific stands.

Fire Behavior Analyst Sue Husari from the Pacific Southwest Region uses a fire behavior computer model developed at the Fire Sciences Laboratory to predict fire behavior on fire in Flagler County Florida in 1998.

Model-based tools can also be used for scheduling fuel treatments over time or for visualizing and evaluating the potential effects of alternative treatments. For example, the fuel and fire effects extension of the Forest Vegetation Simulator can be used to predict vegetation growth and fuel accumulation. The model also helps managers evaluate different treatment types and schedules and their effects on fuels and future fire behavior. Managers can evaluate fuel-treatment scenarios and their effectiveness at keeping fire behavior within acceptable levels and balance this goal with effects of treatments. In short, models and model-based decision analysis tools help land managers make more informed tradeoffs.

For example, models can help managers develop a treatment schedule to reduce the occurrence of crown fires in a specific landscape. The treatment might include an initial heavy thinning followed by prescribed burning to reduce uncharacteristically high fuel accumulations and the likelihood of fire crowning. Afterward, periodic prescribed burning — every 5 to 20 years — might be sufficient to control tree regeneration and surface fuels. If such a schedule is not desirable or practical, thinning could be scheduled every 20 to 40 years, perhaps accompanied by prescribed fire, to reduce ladder fuels. Treatment prescriptions and schedules may be influenced by factors such as stand structure, species composition, site productivity, elevation, aspect, climatic zone, and soil fertility, ecological objectives, desired condition, and the economic potential and societal demand for forest products.

Research will continue to produce improved models of crown fire initiation and fire behavior, along with quantified canopy fuels data, more complete understanding of departures from historical conditions, and further study of logistic, economic, and management constraints. Using the best available models, decision analysis tools, and experience to integrate basic landscape analysis with fuel-treatment prescriptions for specific stands is currently the most effective approach to managing fuels and reducing crown-fire hazard.

Fire research can help determine the best treatment regimes for specific forest types, climates, soils, and other factors that influence forest health.

Summary

Fuels Management Can Reduce Negative Impacts of Fire, Benefit Forest Health, and Provide Social and Economic Benefits

Forest thinning and prescribed burning are two land-management techniques long employed by foresters and others to maintain forest health and reduce wildfire risk. The benefits of these practices are supported by hundreds of scientific investigations and years of professional field experience. These practices can be effectively combined in treatment regimes to improve forest health and reduce wildfire risk, while providing social and economic benefits. A science-based program of fuels management can reduce wildfire severity and protect environmental values, including soil, water, air, and wildlife habitat.

How long treatments will last and how often treated areas need follow-up maintenance will vary with forest type and with climate, soils, and other factors that influence forest health.

Ongoing research by Forest Service scientists and their colleagues in other organizations continues to expand the knowledge base and technology available to land managers charged with protecting America's greatest natural legacy. Fire science research, like medical research, allows practitioners to carry out treatments that are more specific and less invasive to the environment. In turn, field experience can inform the research so that the scientific base and real-world practice can mature together.

For more information about this topic, call Susan Conard at 703-605-5255 or Mike Hilbruner at 703-605-5254.