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Smoke from prescribed burning—
Issues on public forestlands of the Western United States

Ecological Restoration Institute

The Ecological Restoration Institute

The Ecological Restoration Institute at Northern Arizona University is a pioneer in researching, implementing, and monitoring ecological restoration of southwestern ponderosa pine forests. These forests have been significantly altered over the last century, with decreased ecological and recreational values, near-elimination of natural low-intensity fire regimes, and greatly increased risk of large-scale fires. The ERI is working with public agencies and other partners to restore these forests to a more ecologically healthy condition and trajectory—in the process helping to significantly reduce the threat of catastrophic wildfire and its effects on human, animal, and plant communities.

Cover photo: A surface prescribed fire clears out forest litter and debris on an ERI Fort Valley research site, near Flagstaff Arizona.

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Large wildfires threaten forests and humans alike. Thinning and controlled burning canaddress many of the forest health and community safety concerns. However, the smoke generated during these burns can be a nuisance, a public health issue, and can have other consequences. As more acres are burned, the public will be faced with more smoke in the air. It is important to understand the importance of and the reasoning behind low-intensity burning, and the issues associated with it. Particularly in the west United States, public forestlands are overgrown and we are confronted with a choice between smaller amounts of smoke more often, or large amounts of smoke less frequently—each of these choices carries trade-offs and long-term consequences.

Introduction

Increasingly severe wildfires have spurred many policymakers and foresters to strongly advocate expanded forest thinning. Thinning to reduce the number and density of overstocked trees lowers the speed and intensity of wildfires and, in many forest types, contributes to improved forest health.[1] Thinning is often accomplished by cutting smaller or over-abundant trees followed by low-intensity prescribed burning (see cover photograph). Benefits of prescribed burning have long been observed and known.[2] This relatively gentle intentional burning removes high-fire-danger thinning debris and other accumulated fuels and promotes forest health by reducing competition, reinvigorating growth, and increasing resiliency and tolerance to disturbances. As the pace of thinning and prescribed burning on public forestlands accelerates, the effects of smoke and other consequences of prescribed burns will be more apparent, and will be more prominent public issues.

A wide range of human and ecosystem issues can be associated with prescribed burning. Forest ecosystem impacts can include effects on wildlife, riparian areas, soil productivity, erosion, timber growth, and more. Among human and societal issues are public health and safety, aesthetics, economics, recreation, and accountability. There is concern over prescribed fires escaping their management boundaries, and this risk raises fears of property damage, particularly as a greater number of fires are set and more are set near urban areas and in the wildland-urban interface. Improved planning and careful management are decreasing the risk of runaway burns and minimizing smoke production. But smoke is inevitable, can be unpredictable, carries harmful particulate matter and aerosol chemical compounds, obscures vision, and is difficult to manage. Smoke often travels great distances and can affect communities far away some time after burning has ceased, or it can persist in an area for long periods. Weather conditions can aggravate effects, local inversions may hold smoke “pinned” to an area, and prevailing winds can concentrate smoke in particular locations. These issues must be approached with consideration of the many benefits of forest restoration thinning and prescribed burning.

Public acceptability of prescribed burning will become a more critical issue in the future, and smoke, as the most tangible aspect, will be the focus. The following pages introduce some of the smoke issues which public lands managers, communities, and society will be obliged to consider in conducting burns. While reviewing these issues it is of course important not to lose sight of why thinning and burning are done and the benefits.

The potential for lots of smoke

The vast number of acres recommended for thinning—variously estimated between 30 and 200 million[3]—contain many hundreds of millions of trees, the great majority small-diameter and stressed or unhealthy. These overstocked small trees crowd each other and compete for limited resources with larger, older, healthier trees. This situation is largely the result of over-grazing and forest management practices based on fire exclusion, compounded by past logging practices and, most recently, continued drought and insect outbreaks.[4] Before almost a century's worth of fire exclusion, natural low-intensity surface fires reduced the number of seedlings and cleared the forest floor of accumulated debris. Ecologists now hope that removing a high percentage of these smaller trees will reduce the incidence of severe fire and promote healthier forest ecosystems. Prescribed burning, designed to approximate surface-fire regimes, keeps fuel levels low and mimics natural fire processes. These actions, over large forested areas, will produce significant amounts of smoke.

Many decades of fuels buildup means the smoke potential during fuels reduction work, even if the task is carried out over many years, is enormous. Initial thinning and burning greatly reduces fuel, but this effect is only temporary as new growth occurs and debris begins re-accumulating. Once the bulk of initial forest thinning is accomplished, some periodic reintroduction of fire will be required in many areas to manage regrowth and debris. Smoke from this maintenance burning may be more constant and more frequent than we are used to, but removal of many small trees and accumulated fuels and reintroduction of surface fire regimes will reduce large, intense fires. It is these fires that generate so much smoke and a higher proportion of pollutants (see photograph, above, and compare with cover photo). Future smoke levels should be reduced, but it will be more common and may be generated and dispersed over more areas. In terms of smoke, the rationale for pursuing thinning can be summed up as "restoration projects that produce moderate amounts of smoke reduce the potential for large smoke-producing wildfires and will eventually lead to a maintenance cycle of lighter smoke-producing fires."[5]

Trail Creek Fire, Atlanta, Idaho

The Forest Service and other federal agencies burn significantly more than a million acres of public land a year, and this acreage is increasing. However, not only is natural forest regrowth outpacing thinning efforts, population growth is complicating the ability of land managers and local governments to conduct burns. Even at a relatively low burning rate, towns and cities have felt negative consequences, and increased thinning and accelerated burning will affect many more communities.

> *The amount of smoke which will be produced by increased prescribed burning will be significant—and a significant public policy issue for which there should be intensified research, public education, and planning.*

Historical perspective

After a century of fire exclusion, livestock grazing, and poor logging practices,[6] many of the forests of the West are overgrown and in poor health. For insight into current forest conditions, it is helpful to look briefly at fire history in the western United States.
The majority of fires in the western states have always been caused by lightning, and fire regimes varied by strike occurrence, altitude and latitude, topography, fuel type, and other factors. While extensive areas were characterized by stand-replacing fire regimes, in much of the pine-dominated forests of the West the most common natural fire regime was low-intensity surface fire. These fires occurred periodically and kept vegetation thinned and fuel levels low. Although evidence for landscape-scale effects is sparse, Native Americans used fire for a variety of purposes, among these land clearing, reinvigorating vegetation growth, warfare, pest management, and driving game.[7] Between natural and human-caused fires, researchers believe that smoke was present a good deal of the time. While overall levels may have been low, indications are that smoke was fairly common and well-dispersed over the landscape when Euro-American settlers arrived.[8] Early settlers engaged in widespread agricultural burning. Along with unintentional ignitions and other fire activities, they rapidly surpassed Native Americans as a source of fire on the landscape.

As large-scale settlement of the West gained momentum, however, natural fires began interfering with property and livelihoods, leading to calls for fire suppression. As grazing removed much of the material that carried fire, as trees were cut down, and as Westerners continued changing the landscape—and began fighting fires, the number of fires dropped. While there was brief support for letting natural fires burn, by the 1920s the Forest Service had a well-established policy of fire exclusion and aggressive suppression. After World War II there was a rededication to fire protection and suppression, motivated in part by widely available war-surplus equipment, new technology, a recharged labor pool, and heightened public awareness and concern.[9] Over the next decades it was widely assumed and accepted that fire was bad and had to be extinguished as quickly as possible. The still-evolving shift in attitude toward fire as a desired natural component of forest health is fairly recent. Prescribed burning is now a widely recognized and used fire and forest health management tool. However, some public resistance to the use of fire certainly remains. Its use is complex, affected by questions of where and when to burn, how much, sensitive areas and populations, and other factors.

Historically, it appears that low levels of smoke were relatively pervasive and constant over many parts of the West, and certainly in much greater quantities and extent than seen today. Accelerated burning will likely raise levels again such that smoke will often be visible over more communities and areas.

Smoke issues in prescribed burning

Public concerns about prescribed burning have been directed toward:[10]

- risk factors (public safety and adjacent property damage),
- aesthetic concerns (scenic quality and recreation use),
- health issues (smoke and air quality),
- ecological effects (wildlife, vegetation, and water quality), and
- economic consequences (loss of timber, tourism, property and material damage).

Some of these might be considered more general "nuisance" issues, while others are hazards and can potentially affect large numbers of people or cause considerable damage.

Risk factors

The smoke produced by prescribed burning is a public safety issue for a variety of reasons. Smoke reduces visibility (an issue of particular relevance on busy roadways) and increases the number of calls to health and law-enforcement agencies. Smoke incidents can require additional public safety and health staff or more personnel time to monitor conditions, coordinate traffic, answer citizen questions, and attend to accidents and transport any victims. In some cases sensitive people have to be temporarily moved to other locations. Researchers have documented increases in accidents (and in lawsuits) due to impaired visibility during prescribed fire events.[11] Smoke-related accidents usually occur at night or dawn, as daily cyclical weather patterns drive smoke lower and across roadways. The extra work and stress can be a hazard both to the public and to public safety staff. Other weather conditions, most common at night or under conditions of high humidity, can cause water vapor and smoke particulates to create thick fog. Particulate matter in smoke can scatter headlight beams. Similarly, reduced above-ground visibility from rising

Instrument flying conditions near a prescribed fire
USDA Forest Service Archives, USDA Forest Service, www.forestryimages.org

or accumulated smoke can impede aircraft movement (see photograph, facing page), with economic consequences as well as obvious public safety worries. Reduced visibility may lead to temporary airport closures or rerouting of aircraft.

Risk to life and property are critical considerations when planning burns, and the perception of risk must be addressed so that the public is comfortable with and understand thinning.

Aesthetic consequences and concerns

Aesthetic issues are important, as public tolerance can vary widely, change rapidly, and can have political ramifications. Smoke and haze can obscure the scenic character of an area, diminishing a place's value to residents. Besides potential degradation in visibility and scenic assets—and disregarding for the moment any potential health effects—residents may worry about impacts on property values (on the other hand, some residents may see this protection of property as a real benefit, an asset in safeguarding their investment or even raising property values), effects on tourism, and quality-of-life issues. For instance, residents may have to endure, perhaps for several weeks or longer, the unpleasant smell of smoke. Falling and accumulated ash may mar views, and scenic streams may suffer contamination. And while planners can leave belts or screens of vegetation to shield burn areas from view, the results of fire on the landscape may be temporarily visible and unattractive. All these elements can contribute to a lessening of personal or community-perceived place-value, and public concerns could pressure land managers to slow or curtail burning.

The areas most in need of thinning are the national forests of the West, and these scenic forestlands are precisely the reason many people move to the region. Populations in many of these areas are growing rapidly, bringing people drawn by a particular image of the forested West. These new arrivals often do not understand fire danger and the need for thinning, and could be less accepting of the role of burning and the smoke generated. The amount of smoke that will be produced is uncertain but significant. Perhaps the only certainty is uncertainty about how western residents will adapt to higher and more frequent and persistent levels of smoke over the next decade.

The effects of thinning and burning on forest health and visual structure take time to be evident. Some residents will always prefer, or see as natural, existing forest conditions ("achieving natural, healthy forest systems is complicated by a range of perceptions of what `natural' forests might be").[12] Some residents may not see value in the effects of prescribed burning, or will not feel the trade-offs are worth the increased smoke, possible hazards, and alteration of personal concepts of "natural" forest. Prescribed fires may in fact be viewed by some as an attack on a cherished image of a valued resource.

Visible smoke and visibility impairment—the most obvious consequences of prescribed burning—will be key issues in public education and acceptance, and in burn planning.

Health risks

For most communities, health risks are the most pressing smoke issue, and one that can affect a large number of people. Both direct and indirect health problems are associated with any fire. The direct health risks from smoke are well-known, while the indirect or cumulative effects are not as well understood.[13] Effects are generally more pronounced in the very young, the elderly, and those already suffering respiratory difficulties. Very active people can also be more adversely affected.

The danger in smoke arises from the vaporization of the chemical constituents of woody fuel as it undergoes combustion. The burning of typical forest materials produces a large number of chemical products—several hundred identified substances are "formed, liberated, or modified."[14] Particulates, smoke-borne particles of various sizes, are the greatest hazard. Wildfires can produce huge volumes of particulate matter, while intentional burns as a rule produce much smaller amounts. At larger sizes particulate matter may cause bronchial and lung irritation and respiratory illness; at smaller sizes inhaled particles can lead to lung cancer or emphysema. Exposure can aggravate existing respiratory conditions such as asthma, and can irritate eyes and mucus membranes. Chemical aerosols produced by burning are of less concern, as their volume compared to that of particulates is relatively small. Toxic carbon monoxide is produced as well, but dilution and dispersal takes place rapidly; volatile organic compounds (including carcinogens) are generally produced in small enough amounts to be of lesser concern.[15] Primary and secondary smoke combustion products vary depending on vegetation composition and mix, volume, and moisture levels.

The types of smoke compounds created depend to a large extent on the intensity of combustion; brief but intensely smoky burns may have different exposure effects than a long-smoldering fire.[16] Wildfires, often simply because of their size, propel large quantities and a wider range of particulates and other pollutants into the air, and their intense heat can modify and even create new chemical compounds. Because of lower temperatures and relative differences in fire severity, prescribed burns produce less smoke than wildfire, fewer pollutants, and fewer potentially hazardous chemicals.[17] It is believed that personnel who set and monitor intentional burns are subject to comparatively less intense smoke reactions than during wildfire events.[18] The usually relatively mild burn of prescribed events, then, lowers the risk per incident or per unit of time compared to wildfire.

While repeated occupational exposure to relatively short-term severe smoke, such as that experienced by firefighters, is being studied, less is known about infrequent exposure to short-term acute events, such as might be experienced by residents near a large fire. Similarly, research is lacking into the long-term effects on people exposed to more frequent but lesser volumes of smoke. The amount and duration of smoke exposure and a person's health are principal determinants of risk. While firefighters may be in admirable physical condition, they obviously have a high chance of exposure. The 1988 Yellowstone fires brought attention to the issue, as thousands of firefighters experienced respiratory problems.[19] These fires brought about more active investigation into fireline health risks. Still, research into the dangers that smoke poses to fire personnel is relatively recent and still limited. A 2000 report on western fires did conclude that smoke exposure was a relatively insignificant health hazard. While exposure (which varies widely depending on the nature of the fire and by job activity) could be severe, these periods were usually short and overall effects negligible. The authors note that the only well-documented smoke hazards to firefighters are respiratory irritants and carbon monoxide. As a consequence many personnel now head to the fire line equipped with exposure monitoring devices.[20] Protective equipment is widely available, and there is continued research and development in this area. Improved planning and burning strategies will also help lower risks to firefighters and to communities.

Setting a prescribed fire line with a drip torch

James H. Miller, USDA Forest Service, www.forestryimages.org

The direct and indirect human health effects will become more and more of a concern as increased burning is undertaken and long-term impacts become better known and understood.

Ecological effects

The ecological effects of prescribed burning are complex. From an ecological perspective, forest ecosystems are rarely destroyed by fire—in fact, many components require fire for periodic renewal and rejuvenation. While severe fires can be lethal ("stand-replacing") to many plants, low-intensity surface fires more uniformly increase plant vigor, generate and promote recycling of nutrients (such as nitrogen), and increase biodiversity and productivity.[21] Alongside a reduction in severe fire risk, prescribed burning is conducted precisely to increase forest health and vigor. Fire is accompanied by smoke, and smoke is an important component of the natural forest ecosystem.

Ecological effects of fire and smoke can either be at a small scale—changes in soil grain porosity—or large scale, such as theorized effects on climate.[22] More of the direct ecological effects on flora and fauna are associated with fire (not addressed here) rather than smoke.

While they can be locally severe, the negative effects of smoke on the forest ecosystem are probably negligible overall. Moreover, some plant species are dependent on smoke for germination.[23] There is some evidence that smoke may function as a plant pest biocide, and smoke and smoke residues can act as plant fertilizer.[24] Even though smoke and convection can carry large amounts of particulate matter, the overall ecosystem nutrient balance may be maintained somewhat by this material then falling on other parts of the forest. Smoke may temporarily drive some wildlife away, and some individuals are known to have been asphyxiated by heavy smoke concentrations they could not escape,[25] but the effects are generally temporary. Many animals are attracted to smoke, fire, and recently burned areas, and some use burned areas exclusively or require some aspect of these sites or of fire. The overall effects of fire and smoke on most floral and faunal populations in fact appears to be positive.[26]

Prescribed fire is designed to replicate as closely as possible natural low-intensity surface fire. Ecosystems in which these types of fires historically occurred evolved hand-in-hand with these fires. Flora and fauna adapted, and this fire regime was an important component of ecosystem structure and function. The ecological effects of prescribed fire are numerous, complex, and varied. But these effects are in most cases comparable to natural low-intensity surface fire and much less than intense wildfire.[27] There is almost universal agreement that forest ecosystems will be better off, but certainly there will be challenges as prescribed burning becomes more common and frequent.

> *There are a wide range of potential ecological impacts from prescribed burning and smoke, and many of the large-scale effects are not known.*

Economic impacts

The economic ramifications of prescribed fire can be either direct or indirect, and may not all be negative. Setting aside the risk of fires escaping their planning bounds (a complicated issue for another time), smoke has a broad range of possible economic consequences. Smoke and smoke compounds can damage buildings, surfaces, and materials, requiring cleanup and repair. There can be public safety costs and short- and long-term public and private healthcare costs. The public safety costs associated with fire management have already been mentioned, and there are individual and societal costs related to accidents, missed work days, travel and commercial traffic delays, activity or event postponements, and loss in tourism revenue or other sales (and declines in tax receipts).[28] On the other hand, local merchants may benefit from the sale of respiratory medications, emergency preparedness supplies, fireline supplies and services, and other items.
However, these various costs must be compared to the very large local, state, and federal outlays in the event of a severe fire. As one example, the 2002 Hayman Fire in Colorado cost an estimated $39,100,000 to suppress, more than $20,000,000 in post-fire rehabilitation, and large losses in property values and economic activity—a rough total cost and lost-opportunity estimate of $1 billion is not too difficult to arrive at nor believe. While quantifying these costs is complicated, it is being done more frequently and comprehensively.[29] Add in intrinsic and other more intangible values of healthier forest ecosystems and the issue of costs versus benefits becomes much less of a trade-off.

Economic ramifications of increased burning and smoke could perhaps be considered neutral. While there are minor opportunities for local economic development, there will be costs to local government that will not be recouped, and additional societal costs which will be difficult to quantify.

Public perception and behavior

Many people move to the West for sunny days, rich vistas, and proximity to open or green spaces—particularly forests. Their desires for a perhaps mythic western lifestyle can collide with the realities of thinning needs and pressures, pressures that will lead to at least a short-term degradation of aesthetic and perhaps other values. Population growth and influx of new residents make the problem more visible and contentious. Retirement populations, often with more sensitive health problems, are growing, as are more-mobile populations able to work from home. People are pushing father and farther into fire-prone areas, and many newcomers have no experience with forest fires. New residents often come from areas not subject to fire, so they may be unfamiliar with fire, its effects, and prescribed burning.

If the public can agree that forests are in need of thinning, then land management agencies have a responsibility to educate citizens on exactly what is involved.[30] Wider and more effective public education is a significant challenge to fire management, and efforts have had mixed success. But an informed public is an important first step. The community must also accept the concept and then the operational details of thinning and burning—"citizen support is an essential component of effective fire management programs."[31] Public reactions to smoke can differ substantially as "public tolerance to smoke is highly subjective and can vary widely depending on location."[32] Opinions may differ by observer location, weather patterns or cycles, length of smoke periods, and other factors such as an individual's relative health level at a particular time.[33]

Awareness and understanding of the factors that shape public perception and the expression of policy is crucial. Keeping some balance between prescribed burning and what can be perceived as its negative consequences will be a challenge for land management agencies and communities. Compromises in some form will be necessary along the way, and education will be an ongoing process.

Providing good information and full and timely notice to the public will increase understanding of the process and the rationale, and build trust. Public understanding and acceptance of thinning and prescribed burning will be a key to continued and increased progress. Education efforts must be backed with sufficient funds and social and political will.

Prescribed burn and smoke management

Prescribed burn and smoke management has become—some notable and very visible exceptions notwithstanding—very good. Yet there is some hesitation on the part of land managers to pursue aggressive burning strategies because of the fear of property damage and litigation. The issue of liability is being more commonly explored. Some states in the South have adopted legislation to reduce liability by creating a certification process involving training and an examination. In Florida, for instance, once burn managers are state-certified, they are not held liable for runaway events if all plan steps and protocols were followed.[34] Nevertheless, with an increase in burning, not just in acreage but in frequency and in more areas, there could well be legal actions and political repercussions if burns destroy property. Burn managers also face ambiguity in regulatory standards, sometimes-conflicting restrictions or more stringent regulations, and volatile public opinion. Smoke issues are particularly challenging to the manager because the benefits of burning are long-term, not guaranteed, may not be visible, and are fairly intangible unless wildfire occurs. That is, the public may not see positive benefits for many years or unless a wildfire occurs.

Two of the principal aims in comprehensive prescribed burn management are to contain the fire within prescribed bounds and to minimize smoke production. Many states have Smoke Management Programs to authorize and manage prescribed fires, and all burns must conform to the federal Clean Air Act (individual state programs can be more stringent but not less). While conducting burns, agencies are required to adhere to air quality regulations and may be required to obtain state approval. Season, weather, topography, resources, and other factors also play large roles in determining burn areas, extent, and timing. There are techniques to reduce smoke during burning (e.g., favorable wind conditions, clearing around stumps and remove larger logs to avoid smoldering), and ways to reduce exposure, but it may not be possible to implement these in all cases. This is particularly true as burning increases in volume and extent (there is already a backlog of work in most areas of the West).

Agency decisions, funding constraints, and personnel short-falls can alter burn plans, or delay a burn to a non-optimal time. The complications of cross-boundary management can be an obstacle to quick implementation and the best use of limited resources, with attendant ecological consequences caused, for instance, by delays or inadequate planning. Federal coordination of forest management actions is mandated but still challenging, and cross-boundary management may be one of the most important considerations for minimizing harm to the ecosystem and maximizing positive results. The Clean Air Act and land-use designations (e.g., Wilderness) may govern or limit burn activity. Depending on circumstances, other federal and state regulations or land management agency rules may come into play as well. Since each situation is unique, tackling conflicts between wider land management policy and smoke management may be best done on a case-by-case basis.

Smoke management concerns should be reduced, over time, due to the shorter duration and lower volumes of smoke generated with less available forest fuel and less intense fires. Fewer and healthier trees, as a result of thinning, will become more fire resistant, and understory vegetation and grasses will become established. With these lowered fuel levels, the acceptable ambient conditions and window for burning is broader too than for initial burns, with warmer, drier, windier situations being advantageous to burn conduction and smoke dispersion. As fuel levels drop, and as managers gain more experience, work could be spread over longer periods.

Work continues in refining weather prediction models and models to predict emissions and smoke movement.[35] More sophisticated models and techniques, and experience, will make burning more predictable and efficient, but the size of the task and the shortage of resources will hinder large-scale progress into at least the near future.

> *Rx burn management is quite good and becoming better—it will have to be up to the challenge of the enormous thinning need.*

Discussion

Ecologists and foresters agree that western forests are in poor health and need thinning both to improve ecosystem health and to reduce the extreme nature and number of wildfires. Fuels accumulation over the last century and tree die-back from drought and insect-kill has put many forests in an unsafe and unstable state. This condition endangers both communities and forests. One way to tackle the problem is appropriate forest thinning and low-intensity burning.

Because the health and functional stability of many western forest ecosystems was in the past keyed to low-intensity frequent fire, the importance of proper fire reintroduction is clear. The alternatives are prescribed burning, natural fire, or some combination. It is quite unlikely that natural fire regimes will have a significant role in the foreseeable future. Because of population growth into forested areas and long-standing societal feelings and values attached to forests and to fire, there is little chance of wide adoption of natural fire use across the landscape as a whole. Suppression will still be the most common response to the majority of fires, at least anywhere near human settlement. While burn managers will allow—or may even strive for—some combination of natural-use and intentional burns, prescribed burning represents the best opportunity to reintroduce the controlled and beneficial effects of surface fire.

Because of the quantity of slash and debris produced, fuels reduction and restoration thinning have the potential to produce large amounts of smoke. Prescribed fire and smoke will always have some effects on human, plant, and animal populations. However, the overall effects will be substantially less than those caused by large wildfires and healthier forest ecosystems will result. While the focus here has been on issues in terms of negative impacts, the underlying message is that thinning and prescribed burning offer positive approaches toward a range of problems.

The intent of this short issue review is to introduce low-intensity fire smoke considerations. Additional research is needed in many areas, such as pubic perception and long-term health effects. In terms of forest health and community protection, planning, implementation, and progress will be easier and more effective if challenges and opportunities are anticipated and addressed as early as possible. Continued extreme fire risk—and fires—

and declining forest health will confront society with a choice: relatively infrequent, large, severe, unpredictable fires, or, more frequent but smaller, less intense, and more predictable ones. This is a complex choice that will take time to evolve.

Aggressive but careful thinning accompanied by careful prescribed burning will over time lower the risk of extreme wildfire and will increase forest ecosystem health. However, there are an important range of issues to consider to yield the best and most publically-acceptable results.

Bottom line

- ✓ Thinning and prescribed burning improve forest health and lower community fire risk
- ✓ Increased burning will mean greater amounts of smoke in the air
- ✓ We will be faced with a choice between the effects of increased smoke and the effects of declining forest health and increased community risk

Endnotes

1. See, for instance, Omi and Martinson 2002.

2. Fernandes and Botelho 2003, Blank 2001, Sackett, Haase, and Harrington 1996, Weaver 1957.

3. For example, Bosworth 2003; Vissage 2003; McCarthy 2002; USDA 2000; GAO 1999.

4. Dahms and Geils 1997.

5. Barkmann 2003.

6. Fire exclusion - see Arno and Allison-Bunnell 2003; livestock grazing - Belsky and Blumenthal 1997 and Weaver 1964; and logging practices - Noss, LaRoe, and Scott 1997.

7. Allen 2002, p160–166, p180; Alcoze 2003; Cooper 1960.

8. "Early visitors to the Southwest apparently took for granted the frequency of surface fires in the pine forest" (Cooper 1960, p137).

9. See Stephen Pyne (1995, p183) for a brief history and discussion of US fire policy.

10. List adapted from Blue Mountains Natural Resources Institute 1997.

11. Mobley (1989) compiled accident reports for the period 1979 to 1988, noting 28 fatalities, 60 serious and many minor injuries, and millions of dollars in lawsuits; Achtemier and colleagues (1998) estimate over 150 smoke-related incidents annually for the southern United States.

12. Shindler 2002, p143.

13. Barkmann 2003.

14. Sandberg and Dost 1990, p201.

15. Sandberg and Dost 1990, p192.

16. Reinhardt and Ottmar 2000.

17. For instance, production of smoke particles of 10 microns (PM10) is roughly twice as high for wildfires; Huff et al. 1995, p10, and see p26.

18. Reinhardt, Ottmar, and Hanneman 2000.

19. McMahon 1999.

20. Reinhardt and Ottmar 2000.

21. Dahms and Geils 1997; MacCleery 1995; Hardy and Arno 1996.

22. See, for instance, Levine 1996 and Crutzen and Goldammer 1993.

23. Keeley and Fotheringham 1997.

24. For instance see selections in Walstad, Radosevich, and Sandberg 1990.

25. Smith 2000.

26. See Smith 2000 for a complete discussion of fire effects on fauna, and Cunningham et al. 2001 for a case study of one extreme fire event.

27. McNabb and Cromack 1990; McMahon and deCalesta 1990.

28. For examples of the range of impacts and valuation see Morton et al. 2003, Kent et al. 2003, and Hesseln, Loomis, and González-Cabán 2003.

29. Kent et al. 2003.

30. Barkmann 2003.

31. Shindler 2002, p139.

32. Barkmann 2003, p381.

33. Shindler and Toman 2003.

34. Brenner and Wade 2003.

35. Such as PD-Piedmont (Achtemeier 1994).

References

Achtemeier, Gary, William Jackson, Bernie Hawkins, Dale Wade, and Charles McMahon. 1998. The smoke dilemma: a head-on collision! Pp. 415–421 in Transactions of the 63rd North American Wildlife and Natural Resources Conference, March 20–25, 1998; Orlando, Florida. Washington, D.C.: Wildlife Management Institute.

Achtemeier, Gary. 1994. A computer wind model for predicting smoke movement. *Southern Journal of Applied Forestry* 18: 60–64.

Alcoze, Thom. 2003. First peoples in the pines: Historical ecology of humans and ponderosa. Pp. 48–57 in Peter Friederici (ed.) Ecological Restoration of Southwestern Ponderosa Pine Forests: A Sourcebook for Research and Application. Washington, D.C.: Island Press.

Allen, Craig. 2002. Lots of lightning and plenty of people: an ecological history of fire in the upland southwest. Pp. 143–193 in Thomas Vale (ed.) Fire, Native Peoples, and the Natural Landscape. Washington, D.C.: Island Press.

Arno, Stephen, and Steven Allison-Bunnell. 2003. Managing fire-prone forests: roots of our dilemma. *Fire Management Today* 63(2).

Barkmann, Gretchen. 2003. Air quality and smoke management. Pp. 371–386 in Peter Friederici (ed.) Ecological Restoration of Southwestern Ponderosa Pine Forests. Washington D.C.: Island Press.

Belsky, Joy, and Dana Blumenthal. 1997. Effects of livestock grazing on stand dynamics and soils in upland forests of the interior west. *Conservation Biology* 11(2): 315-327.

Blank, Robert. 2001. Prescribed burning as a tool for restoration. Resource Notes 56. Bureau of Land Management, National Science and Technology Center. Accessed December 10, 2003 at the BLM Web site at www.blm.gov/nstc/resourcenotes/respdf/RN56.pdf.

Blue Mountains Natural Resources Institute. 1997. Public perspectives on prescribed fire and mechanical thinning. Tech Notes BMNRI-TN-9. Portland, Oregon: USDA Forest Service, Pacific Northwest Research Station, Blue Mountains Natural Resource Institute.

Bozworth, Dale. 2003. Fires and forest health: Our future is at stake. *Fire Management Today* 63(2): 4–11.

Brenner, Jim, and Dale Wade. 2003. Florida's revised prescribed fire law: protection for responsible burners. Pp. 132–136 in Krista Galley, Robert Klinger, and Neil Sugihara (eds.), Proceedings of Fire Conference 2000: The First National Congress on Fire Ecology, Prevention, and Management, Miscellaneous Publication No. 13. Tallahassee, Florida: Tall Timbers Research Station.

Cooper, Charles. 1960. Change in vegetation, structure, and growth of southwestern pine forests since white settlement. *Ecological Monographs* 30: 129–164.

Crutzen, Paul, and Johann Goldammer. 1993. Fire in the environment: the ecological, atmospheric, and climactic importance of vegetation fires. Report of the Dahlem Workshop, Berlin, March 15–20, 1992. New York: Wiley.

Cunningham, Stanley, Lindsey Monroe, LariBeth Kirkendall, and Cindy Ticer. 2001. Effects of the catastrophic Lone Fire on low, medium, and high mobility wildlife species. Technical Guidance Bulletin No. 5. Phoenix, Arizona: Arizona Game and Fish Department, Research Branch.

Dahms, Cathy, and Brian Geils. 1997. An assessment of forest ecosystem health in the Southwest. General Technical Report RM-GTR-295. Fort Collins, Colorado: USDA Forest Service, Rocky Mountain Research Station.

Fernandes, Paulo, and Hermínio Botelho. 2003. A review of prescribed burning effectiveness in fire hazard reduction. *International Journal of Wildland Fire* 12: 117–128.

GAO. 2000. Fire Management: Lessons learned from the Cerro Grande (Los Alamos) fire. Statement prepared for the Committee on Energy and Natural Resources, U.S. Senate. GAO/T-RCED-00-257. Washington, D.C.: General Accounting Office.

GAO. 1999. Western National Forests, a cohesive strategy is needed to address catastrophic wildfire threats. Report to the Subcommittee on Forests and Forest Health, Committee on Resources, House of Representatives. GAO/RCED-99-65. Washington, D.C.: General Accounting Office.

Hardy, Colin, and Stephen Arno (eds.). 1996. The use of fire in forest restoration. General Technical Report INT-GTR-341. Ogden, Utah: USDA Forest Service, Intermountain Research Station.

Hesseln, Hayley, John Loomis, and Armando González-Cabán. 2003. The effects of fire on hiking demand: a travel cost study of Colorado and Montana. Proceedings, RMRS-P-29. Fort Collins, Colorado: USDA Forest Service, Rocky Mountain Research Station.

Huff, Mark, Roger Ottmar, Ernesto Alvarado, Robert Vihnanek, John Lehmkuhl, Paul Hessburg, and Richard Everett. 1995. Historical and current forest landscapes in eastern Oregon and Washington—Part II: linking vegetation characteristics to potential fire behavior and related smoke production. General Technical Report PNW-GTR-355. Portland, Oregon: USDA Forest Service, Pacific Northwest Research Station.

Ice, George, Daniel Neary, and Paul Adams. 2004. Effects of wildfire on soils and watershed processes. *Journal of Forestry* 102(6): 16–20.

Keeley, Jon, and C. J. Fotheringham. 1997. Trace gas emissions and smoke induced seed germination. *Science* 276(5316): 1248–1250.

Kent, Brian, Krista Gebert, Sarah McCaffrey, Wade Martin, David Calkin, Ervin Schuster, Ingrid Martin, Holly Bender, Greg Alward, Yoshitaka Kumagai, Patricia Cohn, Matt Carroll, Dan Williams, and Carol Ekarius. 2003. Social and economic issues of the Hayman Fire. Pp. 315–396 in Russell Graham (technical ed.), Hayman Fire Case Study, General Technical Report RMRS-GTR-114. Ogden, Utah: USDA Forest Service, Rocky Mountain Research Station.

Levine, Joel. (ed.). 1996. Biomass Burning and Global Change, Volumes 1 and 2. Cambridge, Massachusetts: MIT Press.

Loomis, John, Lucas Bair, and Armando González-Cabán. 2001. Prescribed fire and public support: knowledge gained, attitudes changed in Florida. *Journal of Forestry* 9(11): 18–22.

Macadam, Anne. 1989. Effects of prescribed fire on forest soils. British Columbia Ministry of Forests, Research Report 89001-PR; Victoria, British Columbia.

McCarthy, Laura. 2002. Defining the debate: agreement about hazardous fuel reduction treatment is elusive. Forest Trust *Quarterly Report*, November 2002.

McMahon, Charles. 1999. Forest fires and smoke—impacts on air quality and human health in the USA. Pp. 443–453 in Proceedings, TAPPI International Environmental Conference, Nashville, Tennessee, April 18–21, 1999. Nashville, Tennessee: TAPPI.

McMahon, Thomas, and David deCalesta. 1990. Effects of fire on fish and wildlife. Pp. 233–250 in Natural and Prescribed Fire in Pacific Northwest Forests, John Walstad, Steven Radosevich, and David Sandberg (eds.). Corvallis, Oregon: Oregon State University Press.

McNabb, David and Kermit Cromack. 1990. Effects of prescribed fire on nutrients and soil productivity. Pp. 125–142 in Natural and Prescribed Fire on Pacific Northwest Forests. John Walstad, Steven Radosevich, and David Sandberg (eds.). Corvallis, Oregon: Oregon State University Press.

MacCleery, Douglas. 1995. The way to a healthy future for National Forest ecosystems in the West: what role can silviculture and prescribed fire play? Pp. 37–45 in Forest health through silviculture, proceedings of the 1995 National Silviculture Workshop; 1995 May 8–11, Mescalero, New Mexico. General Technical Report RM-GTR-267. Fort Collins, Colorado: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station.

Mobley, Hugh. 1989. Summary of smoke-related accidents in the South from prescribed fire (1979–1988). Technical Release 90-R-1 1, American Pulpwood Association.

Morton, Douglas, Megan Roessing, Ann Camp, and Mary Tyrrell. 2003. Assessing the environmental, social, and economic impacts of wildfire. GISF Research Paper 001, Forest Health Initiative. New Haven, Connecticut: Yale University, School of Forestry and Environmental Studies, Global Institute of Sustainable Forestry.

Neary, David, Steven Overby, Gerald Gottfried, and Hazel Perry. 1996. Nutrients in fire-dominated ecosystems. Pp. 107–1117 in Peter Ffolliott, Leonard DeBano, Malchus Baker, Jr., Gerald Gottfried, Gilberto Solis-Garza, Carleton Edminster, Daniel Neary, Larry Allen, R. Hamre (technical coordinators). Effects of fire on Madrean Province ecosystems—A symposium proceedings, March 11-15, 1996. Tucson, Arizona. General Technical Report RM-GTR-289. Fort Collins, Colorado: USDA Forest Service, Rocky Mountain Research Station.

Noss, Reed, Edward LaRoe III, J. Michael Scott. 1997. Endangered ecosystems of the United States: A preliminary assessment of loss and degradation. Technical Report BSR 9501. Washington, D.C.: United States Geological Service, Biological Resources Division.

Omi, Philip, and Erik Martinson. 2002. Final report: Effect of fuels treatment on wildfire severity. Fort Collins, Colorado: Western Fire Research Center, Colorado State University.

Pyne, Stephen. 1995. *World Fire*. New York: Henry Holt.

Reinhardt, Timothy and Roger Ottmar. 2000. Smoke exposure at Western wildfires. General Technical Report PNW-RP-525. Seattle, Washington: USDA Forest Service, Pacific Northwest Research Station.

Reinhardt, Timothy, Roger Ottmar, and Andrew Hanneman. 2000. Smoke exposure among firefighters at prescribed burns in the Pacific Northwest. Research Paper PNW-RP-526. Portland, Oregon USDA Forest Service, Pacific Northwest Research Station.

Sackett, Stephen, Sally Haase, and Michael Harrington. 1996. Prescribed burning in Southwestern ponderosa pine. Pp. 178–186 in Peter Ffolliott, Leonard DeBano, Malchus Baker, Jr., Gerald Gottfried, Gilberto Solis-Garza, Carleton Edminster, Daniel Neary, Larry Allen, R. Hamre (technical coordinators). Effects of Fire on Madrean Province Ecosystems—A symposium proceedings, March 11-15, 1996. Tucson, Arizona. General Technical Report RM-GTR-289. Fort Collins, Colorado: USDA Forest Service, Rocky Mountain Research Station.

Sandberg, David, Roger Ottmar, Janice Peterson, and John Core. 2002. Wildland fire in ecosystems: Effects of fire on air. General Technical Report RM\RS-GTR-42-vol. 5. Ogden, Utah: USDA Forest Service, Rocky Mountain Research Station.

Sandberg, David, and Frank Dost. 1990. Effects of prescribed fire on air quality and human health. Pp. 191–218 in Natural and Prescribed Fire in Pacific Northwest Forests, John Walstad, Steven Radosevich, and David Sandberg (eds.). Corvallis, Oregon: Oregon University Press.

Shindler, Bruce, and Eric Toman. 2003. Fuel reduction strategies in forest communities—a longitudinal analysis of public support. *Journal of Forestry* 101(6): 8–15.

Shindler, Bruce. 2002. Citizens in the fuel-reduction equation: problems and prospects for public forest managers. Pp. 139–147 in Fitzgerald, Stephen (ed.) Fire in Oregon's Forests: Risks, Effects, and Treatment Options. Portland, Oregon: Oregon Forest Resources Institute.

Smith, Jane Kapler (ed.). 2000. Wildland fire in ecosystems: Effects of fire on fauna. RMRS-GTR-42-vol. 1. Ogden, Utah: USDA Forest Service, Rocky Mountain Research Station.

USDA Forest Service. 2000. Protecting people and sustaining resources in fire-adapted ecosystems–a cohesive strategy, the Forest Service management response to the General Accounting Office Report GAO/RCED-99-65. Accessed March 20, 2003 at the Society of American Foresters Web site at www.safnet.org/policy/costrategy1013.pdf.

Vissage, John, and Patrick Miles. 2003. Fuel-reduction treatment: a West-wide assessment of opportunities. *Journal of Forestry* 101(2): 5–6.

Walstad, John, Steven Radosevich, and David Sandberg (eds.). Natural and Prescribed Fire in Pacific Northwest Forests. Corvallis, Oregon: Oregon State University Press.

Weaver, Harold. 1964. Fire and management problems in ponderosa pine forests. Pp. 60–179 in Proceedings of the Annual Tall Timbers Ecology Conference 3. Tallahassee, Florida: Tall Timbers Research Station.

Weaver, ______. 1957. Effects of prescribed burning in ponderosa pine. *Journal of Forestry* 55(2): 133–138.