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Chapter 25

Managing Air Pollution Impacted Forests of California

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Abstract

Fuel treatments (prescribed fire and mechanical removal) on public lands in California are critical for reducing fuel accumulation and wildfire frequency and severity and protecting private property located in the wildland–urban interface. Treatments are especially needed in forests impacted by air pollution and subject to climate change. High ambient ozone (O_3) concentration and elevated nitrogen (N) deposition weakens and predisposes trees to bark beetle attacks, increases foliar senescence and fuel build-up, and increases water stress during drought periods. Climate variability is expected to increase beyond historic ranges of variation, resulting in more severe droughts. Combinations of future climate variability and air pollution are likely to increase risk of episodic tree mortality, long-term ecosystem changes, and frequency and severity of wildland fires. Fuel treatments, however, are difficult to implement in these forests. Smoke from prescribed fires can adversely affect local and regional air quality leading to conflicts with local and regional air regulatory agencies. Over the past several years federal land air quality and fire managers have responded to these conflicting needs by expanding beyond the boundaries of their historical job responsibilities. For example, they are now actively forging cooperative relationships with local, state, and federal air regulators. The result has been fewer conflicts about smoke in populated or protected areas, with managers achieving an adequate level of prescribed fire treatments. Smoke monitoring by air managers has played a key role in this success. Social and regulatory acceptance of fire as a management tool in air polluted forests will depend on land managers developing a better understanding of air pollution and smoke interactions and interactions between air pollution, drought,

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and insects. Acceptance of fire as a management tool also requires better large-scale monitoring efforts (field collected and remotely sensed), development of models for predicting spatial and temporal distribution of air pollution and smoke resulting from forest fires, and incorporation of air pollution and climate effects into forest mensuration models used to predict stand development.

25.1. Introduction

Managing the impacts of air pollution on public lands in California is a complex ecological, political, and regulatory task. The federal Clean Air Act (CAA, 1990) mandates that the National Park Service (NPS) and the USDA Forest Service (FS) protect air quality-related values in Class I Areas. Class I areas are defined as National Parks over 6000 acres and Wilderness Areas over 5000 acres that were in existence on August 7, 1977. All other clean air regions are designated Class II areas, which allow moderate pollution increases. New wilderness areas added since that time have not been designated as additional Class I areas, but additions to existing mandatory areas added after 1977 are also Class I Areas. Class I Areas are provided with special protection from new and modified major stationary sources emissions. Historically, program emphasis of both agencies has been to review and comment on the applications and proposed permits related to the primary and secondary emissions from stationary sources and their accumulated impacts to Class I areas.

The CAA requires the permitting authority consult with federal land managers (FLM) when considering applications from major stationary sources near Class I areas. This requirement provided impetus to the NPS and FS to establish management and then research programs that have developed leadership roles in research, monitoring, and management strategies to address the effects of air pollution on forest ecosystems in the United States.

Original program emphasis of both agencies was to understand and mitigate the effects of criteria pollutants (defined by the Environmental Protection Agency (EPA) as indicators of air quality that have established maximum concentrations above which adverse effects on human health may occur) on air quality-related values in parks and forests of the United States. Over time additional threats have required FLM to expand their roles and responsibilities. The roles of air resource managers in California have expanded, as smoke from prescribed and wildland fire have become issues of increasing concern to air quality regulatory agencies seeking to regulate particulate, toxic, and ozone precursor emissions. The complexity of air management is further increased by the need to consider prescribed fire effects on regional haze and California's Assembly Bill 32 that established regulations limiting greenhouse gas (GHG) emissions. Changes in climate variability also present challenges to management, especially in areas where changes in weather patterns may result in abnormally high mortality of trees.

25.2. Regulatory complexity of federal land air resource management

The respective air quality management programs of the NPS and FS developed as a response to the 1977 amendments to the CAA. The CAA gives the NPS and FS an affirmative responsibility to protect air quality-related values in designated Class I Areas. In addition to the CAA, several other laws specify air, air quality, or the atmosphere as a resource to protect and manage. They include:

- The Federal Land Policy and Management Act (FLPMA, 1976) that specifies clean air as an important forest resource to be protected.
- The Organic Act (NPS 1916) that created the NPS to preserve and protect natural and cultural resources and allow visitors to experience National Parks now and in future.
- The Forest and Rangeland Renewable Resources Planning Act (FRRRPA, 1974) that directs the Secretary of Agriculture to protect and, where appropriate, improve soil, water, and air resources.
- The Wilderness Act (1964) requires natural conditions to be sustained in wilderness areas.

The air quality regulatory structure and agencies responsible for compliance with these laws include the California EPA, Air Resources Board (ARB), regional air quality regulatory agencies, and county-level air pollution control districts (Fig. 25.1).

25.2.1. Environmental Protection Agency

Federal agencies implement regulations of national air quality standards, oversee state and local actions and implement programs for toxic air pollutants, heavy-duty trucks, locomotives, ships, aircraft, off-road diesel equipment, and some types of industrial equipment. The role of federal, state, and local governments builds on the CAA and amendments of 1977 and 1990. Some of the components, regulations, and policies related to

Figure 25.1. Local air quality regulatory jurisdictions in California.

the CAA that may directly or indirectly affect land management in California include the following:

- National Ambient Air Quality Standards (NAAQS)—These are standards for pollutants considered harmful to public health and the environment. The EPA has set NAAQS for six principal pollutants, which are called "criteria pollutants" (Table 25.1).
- Prevention of Significant Deterioration and Class I Areas—Class I Areas include National Parks, Wilderness Areas, and some U.S. Fish and Wildlife Refuges that were in existence at the passage of the 1977 CAA amendments. They are provided special protection from new and

Table 25.1. National and California Ambient Air Quality Standards set by the EPA for seven principal pollutants

Pollutant	U.S. standard value	California standard value
Carbon monoxide (CO)		
8-hour average	9 ppm (10 mg m^{-3})	9 ppm (10 mg m^{-3})
1-hour average	35 ppm (40 mg m^{-3})	20 ppm (25 mg m^{-3})
Nitrogen dioxide (NO_2)		
Annual arithmetic mean	0.053 ppm (100 µg m^{-3})	0.030 ppm (57 µg m^{-3})
1-hour average	None	0.018 ppm (34 µg m^{-3})
Ozone (O_3)		
1-hour average	0.12 ppm (235 µg m^{-3})	0.09 ppm (176 µg m^{-3})
8-hour average	0.08 ppm (157 µg m^{-3})	0.07 ppm (137 µg m^{-3})
Lead (Pb)		
Quarterly average	1.5 µg m^{-3}	None
30-day average	None	1.5 µg m^{-3}
Particulate matter (PM_{10})		
Annual arithmetic mean	None	20 µg m^{-3}
24-hour average	150 µg m^{-3}	50 µg m^{-3}
Particulate matter ($PM_{2.5}$)		
Annual arithmetic mean	15 µg m^{-3}	12 µg m^{-3}
24-hour average	35 µg m^{-3}	Federal Standard Used
Sulfur dioxide ($S0_2$)		
24-hour average	0.14 ppm	0.04 ppm
1-hour average	None	0.25 ppm

modified major stationary sources. The Prevention of Significant Deterioration is the permitting rule and concept for federal attainment areas (areas that meet federal standards). Only a small increment of additional pollution is allowed in these "clean air areas." Federal land managers are mandated an affirmative responsibility to protect air quality-related values that can be impacted by air pollution, including visibility. Other values include flora, fauna, soils, water, cultural resources, and geologic features. Sensitive receptors such as species or populations known to have documented sensitivity have been established. Sensitive indicators are measurable elements of injury or change. An example of this concept for ozone might include the following elements: vegetation as an air quality-related value, ponderosa pine as the sensitive receptor, and chlorotic mottle as the sensitive indicator. Although this concept was originally developed to fulfill the mandates of Class I protection, it is used frequently now throughout Class II National Forests and Parks as well.

- Regional Haze Rule—These regulations require states to review how pollution emissions from within the state affect visibility at "Class I" areas across a broad region. The rule also requires states to make "reasonable progress" in improving visibility conditions in Class I areas and to prevent future impairment of visibility. The states are required by the rule to develop a plan which brings Class I areas from current conditions to "natural background" conditions by 2064. Natural background visibility exists when no human-caused pollution is present. This program, while aimed at Class I areas, will improve regional visibility and air quality throughout the country.

- Conformity Rule—This applies in federal nonattainment areas and prohibits the federal government from taking actions that cause or contribute to any new violation or delays the timely attainment of a standard. A project or activity "conforms" if its air pollution emissions are included in an approved State Implementation Plan (SIP).
- EPA Interim Policy on Wildland and Prescribed Fire—This EPA interim policy integrates two public policy goals: to allow fire to function, as nearly as possible, in its natural role of maintaining healthy wildland ecosystems; and to protect public health and welfare by employing best management practices to mitigate the impacts of air pollutants on air quality and visibility.
- Exceptional Events Rule—Exceptional events are unusual or naturally occurring events that can affect air quality and may impair an air regulatory agency's ability to attain the National Ambient Air Quality Standards. Qualifying events are not reasonably controllable with regulatory techniques. This rule establishes the procedures and criteria that will be used to identify and evaluate data to establish an exceptional events determination.

25.2.2. California air resources board

State governments are responsible for developing SIPs that describe how each state will achieve the requirements of the CAA. In California the SIP is a collection of plans and regulations used to clean up polluted areas. The EPA maintains oversight authority, must approve each SIP, and can take over enforcement action if reasonable progress is not made. The California ARB has set more stringent state air quality standards than many of those established by the U.S. EPA, oversees state and local actions, and implements local programs for toxic air pollutants, heavy-duty trucks, locomotives, ships, aircraft, off-road diesel equipment, and some types of industrial equipment. ARB supports over 200 air-monitoring stations and maintains the statewide emissions inventory. ARB also oversees the regulatory activity of 35 local and regional air districts.

In addition, Assembly Bill (AB) 32, the California Global Warming Solutions Act, was passed in September 2006. AB 32 requires that the ARB adopt regulations for reporting and verification of statewide GHG emissions. AB 32 also requires that ARB adopt a statewide GHG emissions limit equivalent to the statewide GHG limit set in 1990, which should be achieved by the year 2020.

25.2.3. Regional and county air quality regulatory agencies

There are 35 local air quality regulatory agencies in California. The agencies develop plans and implement control measures in their areas of jurisdiction. These plans collectively contribute to California's SIP. These controls primarily affect stationary sources but do include sources of dust and smoke. Air pollution control districts are classified as attainment (meeting the standard) or nonattainment (not meeting the standard) for each criteria pollutant including ozone.

25.3. Emerging regulatory issues

FLMs of forested ecosystems will always need to address the role of fire. General types of fire include wildfires, wildland fire use, and prescribed fire. Wildfires usually fall into a full suppression category, whereas wildland fire use and prescribed fire warrant management attention at different levels.

25.3.1. Prescribed and wildland fire use

Prescribed fires are ignited by management to achieve resource objectives, most often a combination of ecosystem restoration or habitat maintenance objectives, and reduction of high hazard fuel loadings. These objectives are not mutually exclusive and usually all prescribed fire operations contain a combination of them.

Wildfire use is the management of unplanned wildland fires, such as lightning-ignited fires, to accomplish specific resource management objectives. Lighting-caused wildland fires will receive appropriate management responses that give consideration to values, hazards, and risks. They are a preferred means for achieving resource management objectives in designated zones where restoration and ecological values dominate considerations.

There is a perceived conflict between clean air goals and wildland fire use and/or prescribed fire goals. The main concern is smoke and its related air quality and visibility impacts. For FLMs in the southern Sierra Nevada, the problem is more complex. FS and NPS lands in the southern Sierra Nevada are located within the San Joaquin Valley Air Pollution Control District. This air district is classified as serious and severe nonattainment for particulate matter (PM) and ozone, respectively. Best Available Control Measures (BACM) are implemented in the air basin by requiring federal fire programs within the basin to comply with a series of emission control measures that are some of the most stringent in the nation.

As wildland areas are treated and maintained with prescribed fire, fire use projects, and mechanical treatments, the potential amount of smoke emissions can be reduced. Smoke emissions released during unwanted wildfires usually produce more serious air quality impacts, potential harm to life and property, and an unnatural alternation to protected ecosystems than do controlled management fires.

25.3.2. Regional haze rule

The 1977 amendments to the CAA provided a national visibility goal of "the prevention of any future, and the remedying of any existing, impairment of visibility in mandatory Class I federal areas in which impairment results from manmade air pollution." The 1977 amendments required the EPA to issue regulations that would ensure "reasonable progress" towards meeting the national visibility goal. Congress placed additional emphasis on regional haze in the 1990 amendments to the CAA, requiring the EPA to establish the Grand Canyon Visibility Transport Commission to address visibility in 16 Class I areas on the Colorado Plateau. Regional haze is generally considered visibility impairment from a multitude of sources and activities over a broad geographic region. Haze usually consists of fine particles and precursors broadly categorized as sulfates, nitrates, organic carbon, elemental carbon, and dust. The final Regional Haze Rule was passed in July 1999. The regulations require states to develop coordinated strategies and programs to make "reasonable progress" towards the national visibility goal. Each state was required to submit a SIP by December 17, 2007. Preparation of the SIP should have included consultation with FLMs. However, most states have not met this deadline. The goal of the planning effort is to reduce human-caused emissions nationwide to improve visibility in 156 federal Class I wilderness areas and National Parks. Twenty-nine Class I areas are in California. Natural conditions are to be achieved by 2064 with an interim assessment in 2018. California will be required to submit coordinated SIPs for PM2.5 and ozone on the same planning schedule as regional haze, providing an opportunity for FLMs to collaborate on control strategies for those pollutants as well. Although the Regional Haze Rule emphasizes control strategies on industrial and mobile sources, it does require consideration of smoke management techniques for agricultural and forestry management practices in the development of a SIP. It also requires determination of natural background for regional haze prior to setting reduction goals. Natural background must take into consideration the fire histories of the respective ecosystems. Wildland fire and agricultural smoke will be important due to its significance in organic carbon inventories but will be a challenge to project into future inventories because timing and location is uncertain.

25.3.3. Climate change effects on air and forest resources

Managing air resources surrounding forest lands will become more difficult in the future. Most climate change projections (California Climate Action Team, 2006) indicate higher annual average daily temperatures and increased numbers of days conducive to air pollution formation. Future scenarios predict that California will have an increased number of very hot days and fewer cold days. Climate change may increase the number of days conducive to pollution formation by as much as 75–85% in high ozone areas such as Los Angeles and the San Joaquin Valley. Background ozone is projected to increase 4–25% by 2100 (Kleeman & Cayan, 2006). The increase in hot days is projected to increase large wildfire risk by 35% and cost by 30% over the next 50 years (Westerling & Bryant, 2006). Moderate to high ambient ozone reduces net carbon uptake, and high ozone and N deposition alter carbon sequestration, its distribution, and its residence time in the ecosystem (Grulke et al., 2008). Air pollution and climate change are also reducing winter precipitation and increasing the severity of summer drought stress. Cumulative effects of changing climate is forecasted to exacerbate insect and disease affects on forests by weakening tree defenses and expanding historical ranges of pathogens. Tree mortality from insects and pathogens or directly from physiological stress is expected to increase due to longer and more intense drought periods. Changing climate is also expected to impact natural fire regimes. Recent projections indicate that large wildfires may increase almost 35% by mid-century, 55% by the end of the century under medium-high CO_2 emissions scenarios (Climate Action Report, 2006).

25.4. Changing roles, strategies, and organizations

Management techniques can be categorized into direct and indirect opportunities. Direct opportunities include utilizing the legislated mandates and regulatory mechanisms to evaluate impacts and provide recommendations on permit issuance and mitigations to air regulatory agencies. These are actions that are coordinated with air regulatory agencies to directly reduce emissions from contributing sources. Indirect management opportunities include resource manipulation to slow or reduce effects, such as thinning, prescribed fire, soil treatment, water treatment, and visitor health warnings. These indirect measures are generally applied to monitoring and modeling studies that attempt to understand the complex of stressors impacting forest ecosystems and human health and require long-term commitment of resources (Bytnerowicz et al., 1999).

25.4.1. Regulatory coordination

Two of the most significant environmental and public safety issues in California are air pollution and catastrophic wildfire as a result of unnatural fuel loadings. Dedicated professionals and scientists often champion strategies to prevent both issues, and early attempts at coordination often strained working relationships of the public agencies charged to manage these issues. Recently, communication and relationships have improved through a number of forums leading to a better understanding of both issues. These forums have become institutionalized and are leading to more informed solutions and balanced progress. Improved communication has led to collaboration on policy shifts and partnerships in the development of technical tools for improving smoke management.

Three levels of working groups have evolved in California and have become very effective in resolving issues related to wildland fire:

- Interstate—The Western Regional Air Partnership (WRAP) is an organization of western states, tribes, and federal agencies to coordinate visibility improvement in all western Class I areas by providing technical and policy tools.
- Statewide—The California Interagency Air and Smoke Council (IASC) serves as a forum for sharing information and developing technical tools and processes for improved smoke management. Scientists and managers from EPA, ARB, local/regional air regulatory agencies, and land management agencies attend this quarterly forum. The Air

and Land Managers (ALM) group meets quarterly and consists of executive level staff from ARB and the land management agencies. This group typically addresses policy and unresolved issues raised by IASC.
- Air Basin—Most local air regulatory agencies and land management agency units in California have developed smoke management working groups in common air basins. These groups coordinate the operational procedures of permit issuance, fire and dispersion meteorology, smoke modeling, daily burn allocations, smoke monitoring, public safety, and public health. During periods of prescribed fire, fire use, or wildfire these elements are discussed and decisions made in daily conference calls.

25.4.2. Monitoring

An important component of agency air resource management is to conduct or coordinate a variety of monitoring activities in rural and remote areas. Monitoring allows land management agencies to better understand current conditions and trends. Trends in ambient air quality and the relationship with biological and physical resource condition can be valuable information for policy makers and regulators. Air pollution monitoring is an important activity that supports national programs such as the Interagency Monitoring of Protected Visual Environments (IMPROVE) and the Clean Air Status and Trends Network (CASTNET) and provides air quality data for remote areas lacking continuous air monitors. One important tool for monitoring air pollution in remote areas is the use of passive samplers for monitoring O_3 and other gaseous air pollutant concentrations (Koutrakis et al., 1993). Ozone sampling utilizes cellulose filters coated with nitrite (NO_2^-) that is oxidized by ambient ozone to nitrate (NO_3^-). The rate of NO_3^- formation (amount of NO_3^- formed on a filter over time of exposure) serves as a measure of O_3 concentration. Concentrations of O_3 measured with passive samplers are compared at selected sites with real-time O_3 measurements with the UV absorption Thermo Environmental Model 49 or portable UV absorption 2B Technologies monitors (Bognar & Birks, 1998). The empirically derived coefficients are used for calculating O_3 concentrations from other passive sampler sites. By using this approach, regional monitoring networks that consist of 50–100 sites can be maintained for several growing seasons. Passive samplers provide 2-week averages (or other chosen periods of time) of O_3 or other gaseous air pollutants. Information on real-time concentrations of O_3 can be obtained from existing O_3

monitors (CASTNET, National Acid Deposition Program (NADP), and ARB networks, and portable 2B Technologies monitors). These monitoring efforts allow O_3 distribution surfaces to be estimated using geostatistical estimation.

Various PM monitors are distributed at several National Forests and Parks in California. These monitors consist of BAM 1020, EBAM and E-Samplers (Met One Instruments, Inc.). The BAM 1020 and EBAM instruments work on the principle of beta attenuation. The BAM 1020 is a federal reference instrument that requires ambient temperature control. The EBAM is not a federal reference instrument, but serves as a portable air monitor without a requirement for ambient temperature control. The BAM 1020 is equipped with wind speed/wind direction, air temperature, relative humidity, barometric pressure, solar radiation, and precipitation. The EBAM can be equipped with the same meteorological parameters except for solar radiation and precipitation. The E-Sampler is a portable instrument based on the principle of near-forward light scattering and incorporates a gravimetric filter device that can be used to improve the accuracy of the concentrations. E-Samplers compare reasonably well with the Federal Reference Method (Procter et al., 2003).

PM monitors can be used at fixed locations year around, such as the BAM 1020 instruments located in Kernville, Springville, and Pinehurst (Sequoia National Forest), but the majority of monitors are used just during periods of wildland and prescribed fires. Mobile monitors are distributed over regions at National Forests and Parks that conduct frequent prescribed fires or are prone to severe wildland fires. These instruments are typically operated only during fire seasons or as support for regional monitoring or modeling studies. Networks of PM monitors allow air regulatory agencies and land management agencies to collaborate on burn decisions and improve smoke management strategies that are more effective at protecting public health.

Monitoring forest health and injury have also been important components of air resources management. Beginning in the early 1970s, ozone injury monitoring sites were established in California National Forests and Parks. Some sites were maintained jointly with FS and NPS by research institutes, such as the San Bernardino Mountain sites and some have been maintained by FS Pacific Southwest Region's Air Quality Management unit or the NPS Air Management program. As funding allowed, sites have been evaluated for ozone, insect, and drought damage but few comprehensive evaluations have been conducted since the early 1990s. As a result there is little information on recent regional changes in ozone injury severity or the regional relationships between ozone injury and tree mortality.

25.4.3. Modeling

Air quality models use mathematical techniques to simulate chemical and physical processes that influence air pollution as it disperses and chemically reacts in the atmosphere. Air quality models are a valuable tool to land managers attempting to understand the significance of a proposed source, the effectiveness of proposed control strategies, potential issues related to multiple sources, and the concentration or loading of pollutants ultimately delivered to resources on federal land. In addition, models that can estimate biological damage or impact to physical features, such as visibility, help land managers provide more informed input to regulatory permit decisions. Dispersion models, that estimate the concentration of pollutants downwind, are often used in the analysis of proposed major stationary sources to estimate the concentration or deposition of pollutants transported to Class I areas. This is often the most important data an FLM has to work with in making a recommendation on the issuance of permits to construct stationary sources. Dispersion models are also used in land management agency actions and decisions that may produce regulated emissions. Smoke from wildland fire may be the most common of these activities, but other examples include recreation activities, oil and gas development, and construction activities. These modeling activities provide valuable information to FLMs regarding potential regulatory violations that may directly affect a decision. Additional modeling issues include:

- Increasing the understanding of fire behavior and smoke dispersion.
- Expanding knowledge of the physics of fire–atmosphere interactions on all scales.
- Developing products and transferring new technologies related to national and regional fire-weather and air quality dynamics.
- Enhancing the ability to predict climate change effects on forests.
- Improving the accuracy of carbon accounting.
- Modeling to understand complex emissions trade-off scenarios between wildfire and prescribed fire.

25.4.4. Research partnerships

Air management is no longer just the province of the air resource specialists and regulators. Information and expertise needs have exponentially increased, often beyond either the knowledge of individuals or groups of managers. Air managers increasingly depend on researchers for information, advice, and direction on complex multidisciplinary issues. In the past cooperation has been conducted on a project level, but new and complex issues will require much more routine partnership between managers and researchers. Some research involvement will be limited to overlapping areas of interest, but some will also require joint work-plan development and joint positions.

A variety of research is needed to support air management activities. Understanding the effects of single and multiple pollutants on forest ecosystems is critical to understanding future forest composition changes. Similarly, development and application of air-monitoring equipment and computer models of plume dispersal and transport are also important. The following air pollution research questions represent a partial but not comprehensive list of research needs related to air pollution issues in California:

- What are the mass transport patterns, spatial and temporal distributions, and deposition rates of ecologically significant pollutants to Californias mountains?
- What are the effects of ozone, long-term deposition, and the interactions among nitrogen compounds, sulfur compounds, ozone, drought, and pests on the composition, structure, and function of mountain ecosystems?
- Are models used to examine emissions production and transport adequately representing conditions in California forests?
- What are the transport processes that control air pollutant and smoke concentrations and delivery in the Sierra Nevada?
- How will climate change affect future patterns of air pollution and from downwind sources? Can we project, with effects from climate change, whether these thresholds have meaning in the future? For instance, have thresholds already changed measurably from 1980?
- Are the current critical loads, thresholds, and sensitive receptors sufficient for the protection of wilderness and ecosystem values?
- What are the effects of atmospheric pollutants, smoke, and drought on terrestrial wildlife, insect species, soil invertebrates, and soil microfauna?
- What is the role of global and trans-Pacific transported pollutants in air pollution impacts on U.S. forests?
- Would progress in California emissions reductions be compromised by increased future global transport of air pollutants?
- Has existing research knowledge been effectively implemented in management plans?

25.5. Summary

Forest ecosystems are impacted by a complex of abiotic stressors, including air pollution, smoke, and climate change effects. Moderate to high ambient ozone reduces net carbon uptake, and high ozone and N deposition alter carbon sequestration, its distribution, and its residence time in the ecosystem. Air pollution and climate change are also reducing winter precipitation and increasing the severity of summer drought stress, leading to increased insect and pathogen outbreaks.

Present regulatory requirements for protection of Class I areas and proposed regulations for regional haze and climate change goals for Class I and Class II areas will increase the complexity and difficulty of prescribed fire application in these forests. Despite these challenges it is important to maintain prescribed fire as a management tool to reduce the likelihood of large fire smoke and air pollution events. To maintain prescribed fire as a tool requires increased air pollution monitoring and computer modeling tools. Better understanding, measurement and prediction of smoke plume dispersal and transport will be needed to enable fire managers to minimize the impacts of prescribed fire, wildland fire use, and wildland fire smoke on the heath and welfare of firefighters and nearby communities.

The complexity of multiple forest stressors and increased number and diversity of federal and state regulations are changing the roles and responsibilities of air managers. In addition to understanding the distribution and impacts of urban air pollution transported into wilderness areas, managers are concerned about smoke, regional haze, and climate change impacts. Coordination and facilitation efforts between land managers, air regulators, and researchers will become increasingly important aspects of federal land management. Flexibility and enhanced working relationships within and across agencies will be crucial to implementing a successful fuel management program in air pollution impacted forest areas in the future. Strong interagency partnerships between air regulators, fire managers, and researchers will be critical for successful continuation of prescribed or wildland fire use fires as viable fuel treatment strategies in polluted areas.

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