Toolkit for Planning and Managing Prescribed Fire and Wildland Fire Smoke on Military Ranges

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Abstract

Objectives: The objective of the project is to develop a Toolkit for Planning and Managing Prescribed Fire and Wildland Fire Smoke on Military Ranges that will assist Department of Defense (DoD) installations in the continental United States, Alaska, and Hawaii that manage wildfire and prescribed fire with implementation of the DoD Wildland Fire Management Program (DODI 6055.06) and Natural Resource Management (DODI 4715.3). The project will provide guidance to DoD natural and cultural resource managers in responding to wildfires and the implementation of prescribed burn programs that will directly support uninterrupted testing and training operations, and support installation sustainability for realistic training environments. Smoke management tools are identified that will assist in the preservation of public health and safety, comply with local and regional air quality guidelines; protects installation infrastructure and the private property of surrounding communities; and facilitates the health and maintenance of natural and cultural resources. An important goal of the project is to protect public health and safety in communities that surround DoD installations through the implementation of wildland fire risk reduction management and smoke prediction tools that protect private property and public infrastructure, alerted local law enforcement to close highways due to visibility hazards, and alleviating public health risks by evacuation of sensitive individuals at risk.

Technical Approach: The project identifies DoD smoke management tools and prescribe fire protocols designed to assist the installation natural and cultural resource managers in tracking smoke trajectories and concentrations and making good prescribed and wildland fire management decisions. Emphasis is placed on identifying tools that can be implemented with the available staff and computing resources at installations, and evaluating their effective use on small and large installations. The project includes: reviews and evaluations of fuel, emission, and smoke models for implementation on DoD installations; reviews and evaluates smoke management modeling frameworks; reviews and evaluates smoke management websites; identifies smoke management training opportunities; and tests and evaluates smoke management protocols for DoD installations.

Results:
The Ecology of Fire – Historically wildland fire and more recently prescribed fire have determined the distribution of plants and animals throughout the continental United States, Alaska, and Hawaii. Many plant communities have evolved with fire and are dependent on fire for the germination, growth, competition, and productivity. In turn, animals are dependent on the natural regeneration of plant communities following fire for foraging and their reproductive success. Fire ecology topics are discussed for four regions of the continental United States (Western, Central, Southeast, and North East and North Central), and the states of Alaska and Hawaii. Fire ecology implications for managers are discussed for each region and state.

Fire Behavior Fuel and Effects Toolkit – Wildland fire risk assessment and fuel management planning on DoD installations in the United States are complex problems that require state-of-the-art fire behavior modeling. Current fuel classification models have focused on the rate of spread, resistance to control, and the flame length of fires in surface fuels. The Toolkit identifies and discusses the fire behavior models: Anderson 13 Standard Behavior Fuel Models, Scott and
Burgan 40 Standard Fire Behavior Fuel Models, FuelCalc, FARSITE, FlamMap, FireFamily Plus, FIREMON, FFE-FVS, FOFEM, BehavePlus, NEXUX, LANDFIRE, FCCS, and Browns Transects. Each fire behavior model is discussed and web links are provided as sources of additional information for each of the fuel models.

*Smoke Predictive Toolkit* – The potential health and safety concerns associated with smoke generated from low-intensity prescribed fires, operational predictions of the impacts of prescribed burning on DoD installation missions and local air-quality demand an additional tool for the planning and management of prescribed fires. There are a variety of predictive air quality models and systems currently available to the operational fire and air quality management communities for prescribed fire planning. These include box models (e.g. Atmospheric Dispersion Index, Ventilation Index); Gaussian plume models, puff models, particle models, grid models, and smoke modeling frameworks that include HYSPLIT, VSMOKE, SASEM, CALPUFF, SIS, and BlueSky. Each smoke model is discussed and web links are provided as sources of additional information.

*Regulations for Smoke Management* – Ambient air quality is the primary indicator of public health impacts and is regulated through the EPA’s National Ambient Air Quality Standards program. The Clean Air Act, Regional Haze, NAAQS, Prevention of Significant Deterioration, Conformity, Exceptional Events Rule, and Interim Air Quality Policy on Wildland Fire and Prescribed Fires are described to aid natural resource managers in achieving their goals of: (1) allowing fire to function in its natural role in the wildlands, and (2) protecting public health and welfare by minimizing smoke impacts.

**Benefits:** DoD benefits from the project include providing guidance for the mandatory compliance with air quality regulation across the nation in accordance with the Federal Clean Air Act (CAA), which includes: the Federal Air Pollution Control Act of 1955 (PL 84-159), the Federal Clean Air Act of 1963 (PL 88-206), the Federal Air Quality Act of 1967 (PL 90-148), the Federal Clean Air Act Amendments of 1970 (PL 91-604), Clean Air Act Amendments of 1977 (PL 95-95), Clean Air Act Amendments of 1990 (PL 101-549, and the Regional Haze Regulations, Final Rule (40 CFR Part 51) (1999). This legislation is the principal source of statutory authority for controlling air pollution and establishes U.S. programs for controlling air pollution, promulgates national ambient air quality standards (NAAQS) for particulates, photochemical oxidants (including ozone), hydrocarbons, carbon monoxide, nitrogen dioxide, and sulfur dioxide, and sets the goal for visibility protection and improvement in Class I areas and assigns Federal land managers the affirmative responsibility to protect air quality related values.
Acknowledgements

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This handbook was prepared by Carolina Ecosystem Services LLC. (www.carolinaecosystemservices.com). The principal investigator was Robert A. Mickler (robert.mickler@carolinaecosystemservices.com).
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>ADI</td>
<td>Atmospheric Dispersion Index</td>
</tr>
<tr>
<td>AFB</td>
<td>Air Force Base</td>
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<tr>
<td>AFCEC</td>
<td>Air Force Civil Engineer Center</td>
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<tr>
<td>ATHAM</td>
<td>Active Tracer High-Resolution Atmospheric Model</td>
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<tr>
<td>AZCC</td>
<td>Arizona Conservation Corp</td>
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<tr>
<td>BAER</td>
<td>Burned Area Emergency Rehabilitation</td>
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<tr>
<td>BIA</td>
<td>Bureau of Indian Affairs</td>
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<tr>
<td>BLM</td>
<td>Bureau of Land Management</td>
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<tr>
<td>BlueSky</td>
<td>BlueSky Smoke Modeling Framework</td>
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<tr>
<td>CAA</td>
<td>Clean Air Act</td>
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<tr>
<td>CCC</td>
<td>California Conservation Corp</td>
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<tr>
<td>CIA</td>
<td>Class I Areas</td>
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<tr>
<td>CMAQ</td>
<td>Community Multiscale Air Quality</td>
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<tr>
<td>CO</td>
<td>carbon monoxide</td>
</tr>
<tr>
<td>CO₂</td>
<td>carbon dioxide</td>
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<td>DoD</td>
<td>Department of Defense</td>
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<td>DOI</td>
<td>Department of Interior</td>
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<td>DPS</td>
<td>Digital Photo Series</td>
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<td>FAA</td>
<td>Federal Aviation Administration</td>
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<tr>
<td>FCCS</td>
<td>Fuel Characterization Classification System</td>
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<tr>
<td>FIA</td>
<td>Forest Inventory and Analysis</td>
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<tr>
<td>FLAME</td>
<td>Federal Land Assistance, Management, and Enhancement</td>
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<td>FLM</td>
<td>Fuel Loading Model</td>
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<td>FMSC</td>
<td>Forest Management Service Center</td>
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<tr>
<td>FOFEM</td>
<td>First Order Fire Effect Model</td>
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<tr>
<td>FVS</td>
<td>Forest Vegetation Simulator</td>
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<td>GCM</td>
<td>General Circulation Model</td>
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<tr>
<td>HFI</td>
<td>Healthy Forest Initiative</td>
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<td>HFRA</td>
<td>Healthy Forest Restoration Act</td>
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<tr>
<td>HYSPLIT</td>
<td>Hybrid Single-Particle Lagrangian Integrated Trajectory</td>
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<tr>
<td>ICEMAPs</td>
<td>Installation Complex Encroachment Management Action Plans</td>
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<td>ICRMP</td>
<td>Integrated Cultural Resources Management Plan</td>
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<td>INRMP</td>
<td>Integrated Natural Resource Management Plan</td>
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<td>Integrated Wildland Fire Management Plan</td>
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<tr>
<td>MAFF</td>
<td>Modular Airborne Fire Fighting</td>
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<tr>
<td>MM5</td>
<td>Mesoscale Meteorological Model</td>
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<tr>
<td>NAAQS</td>
<td>National Ambient Air Quality Standards</td>
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<td>National Association of State Foresters</td>
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<td>NCAR</td>
<td>National Center for Atmospheric Research</td>
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<tr>
<td>NEPA</td>
<td>National Environmental Policy Act</td>
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<td>NESDIS</td>
<td>National Environmental Satellite, Data and Information Service</td>
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<tr>
<td>NFDRS</td>
<td>National Fire Danger Rating System</td>
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<tr>
<td>NFIC</td>
<td>National Interagency Fire Center</td>
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NFIRS  National Fire Incident Reporting System
NFP    National Fire Plan
NFPA   National Fire Protection Agency
NH₃    ammonia
NIST   National Institute of Standards and Technology
NOₓ    nitrogen oxide
NPS    National Park Service
NWCG   National Wildfire Coordination Group
NWS    National Weather Service
O₃     ozone
OAR    Office of Air and Radiation
Pb     lead
PFP    Prescribed Fire Plan
PFTC   Prescribed Fire Training Center
PM     particulate matter
PSD    Prevent Significant Deterioration
RHR    Regional Haze Rule
SCA    Student Conservation Association
SFS    Smoke Forecasting System
SIS    Smoke Impact Spreadsheet
SIP    State Implementation Plan
SMOKE  Sparse Matrix Operations Kernel Emissions
SMP    Smoke Management Plan
SO₂    sulfur dioxide
SOₓ    sulfur oxides
TES    Threatened and Endangered Species
TICS   Training Information Communication System
TIP    Tribal Implementation Plan
TNC    The Nature Conservancy
USDA   U.S. Department of Agriculture
USEPA  U.S. Environmental Protection Agency
USFS   U.S. Forest Service
USFWS  U.S. Fish and Wildlife Service
VALBOX Ventilated Valley Box Model
VCIS   Ventilation Climate Information System
VERT   Vertical Ecological Restoration Team
WFLC   Wildland Fire Leadership Council
WFM    Wildland Fire Management
WFMP   Wildland Fire Management Plan
WRF    Weather Research and Forecasting
WUI    Wildland Urban Interface
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Chapter 1 Introduction

Introduction to Wildland Fire
As the United States expanded West during the 19th and 20th Centuries, wildland fire management became an essential part of national policy as wildland fires disproportionately affect the Western United States. In the Eastern United States, the patchwork of agricultural development and expanding road network for the transport of agricultural commodities resulted in smaller wildfires, but with greater damage to rural and urban development. Natural, low-intensity fires were once commonplace across the United States. Native Americans, European settlers, farmers, and hunters, all shaped the land to green up the grasslands to provide new growth for livestock and game animals. A century ago, that changed – in 1929 the American Forestry Association’s “Dixie Crusaders” toured the states to spread the message through rallies, movies, pictures and pamphlets that all fire was bad and natural fires were to be suppressed. Wildfire suppression intensified in 1944 with the creation of the Smokey Bear Wildfire Prevention campaign, the longest running public service as campaign in the U.S. Today the majority of our forests don’t look like the historical forests that European settlers first viewed on their arrival to America. They don’t provide homes for native wildlife, are a breeding ground for non-native pests and plants, and fuel loading and biomass accumulations has put most forests, shrublands, and grasslands at risk of catastrophic wildfires. The good news is that as early as 1912 forestry professionals like Yale’s Dr. H.H. Chapman, the father of prescribed burning (some prefer the term “controlled burning”), were arguing that fire suppression might result in the destruction of forests. Within the last decade, Smokey the Bear has changed his public message, President Obama signed The FLAME Act of 2009, and federal land management agencies have implemented a “let it burn” policy for the management of wildfires.

The U.S. Forest Service (USFS) was established in 1905 and the National Park Service (NPS) was established in 1916, when fire suppression was the only policy for wildland fire management. This policy continued until the 1960s when forests began to be managed as ecosystems. At this time, controlled burns came into use as well as the practice of permitting naturally occurring, but not catastrophic, fires to occur. Since then, fire management techniques have become more advanced and effective. At the same time, wildland fires have also become more prevalent and powerful because of climate change during the 21st Century. Additionally, wildland fires in recent decades have increasingly threatened areas, due to increased urban development along forested areas termed Wildland Urban Interface (WUI). The National Wildfire Coordinating Group (NWCG) was formed in 1973 following several extreme wildland fire years (1970, 1971, and 1973). The mission of the NWCG is to: “coordinate programs of the participating wildfire management agencies so as to avoid wasteful duplication and to provide a means of constructively working together. Its goal is to provide more effective execution of each agency’s fire management program. The group provides a formalized system to agree upon standards of training, equipment, qualifications, and other operational functions.” The NWGC is comprised of The US Department of the Interior (Bureau of Land Management (BLM), U.S. Fish and Wildlife Service (USFWS), NPS, and the Bureau of Indian Affairs (BIA), US Department of Agriculture (Fire and Aviation Management, and the Wildland Fire Management Research), US Department of Homeland Security (Federal Emergency Management Agency), and Non-Federal Entities (National Association of State Foresters, Intertribal Council, and the International Association of Fire Chiefs).
Wildland fires can encroach upon Department of Defense (DoD) installations and their mission, and pose a significant threat to DoD assets and training lands. The DoD recognizes this potential encroachment threat and conducts prescribed burns at installations to reduce wildland fire risk by reducing fuel loads. In addition, DoD signed the Interagency Agreement for the Temporary Support During Wildland Firefighting Operations in 2010 to provide guidelines under which the National Interagency Fire Center (NIFC) may request and DoD will provide temporary support to NIFC in wildland fire emergencies occurring within any State, U.S. Territory or Possession, the District of Columbia, and State and private lands. The agreement provides temporary support through the year 2015 to federal agencies tasked with fighting wildland fires. The BLM acts as the administrator for the interagency agreement and acts on behalf of the other NIFC agencies. Given the challenge of wildland fire management, a more proactive approach is needed. Partnering with other agencies, and taking additional proactive measures, is in the best interests of the DoD in order to protect its assets. Although wildland fires may not start on DoD land, they may spread to DoD installations or remote assets.

**DoD Natural and Cultural Resources Policy**
The principal purpose of DoD lands, waters, airspace, and coastal resources is to support mission-related activities. All DoD natural resources conservation program activities work to guarantee the DoD continued access to its land, air, and water resources for realistic military training and testing and to sustain the long-term ecological integrity of the resource base and the ecosystem services they provide. These principles are embodies in DoD Instruction 4715.03 that state:

- The DoD manages its natural resources to facilitate testing and training, mission readiness, and range sustainability in a long-term, comprehensive, coordinated, and cost-effective manner.
- The DoD demonstrates stewardship of natural resources in its trust by protecting and enhancing those resources for mission support, biodiversity conservation and maintenance of ecosystem services.
- The DoD manages for multiple uses when appropriate, including sustainable yield of all renewable resources, scientific research, education, and recreation demonstrates stewardship of natural resources.
- All DoD natural resources conservation programs are integrated with mission activities, installation planning and programming, and other activities as appropriate.

DoD embraces its stewardship responsibilities for valuable natural and cultural resources. However, DoD lands must first be managed for the continued use of military training and testing. This mission contrasts with other federal and state land management agencies, e.g. the USFS and the USFWS. This is manifested in DoD's three-part conservation goal, which is to support the military mission by:

- Providing for sustained use of its land, sea, and air resources, while protecting valuable natural and cultural resources for future generations;
- Meeting all legal requirements, *e.g.* the Endangered Species Act (ESA); and,
- Protecting compatible multiple use of these resources. The challenge for DoD is to balance the need to maintain its access to air, land, and water resources for current military training with the need to protect and manage these resources in a sustainable manner.

Wildland fire is an important natural resource planning and management tool, a means to ensure uninterrupted testing and training mission support through the reduction of wildfire risk, and an encroachment challenge for the DoD. In FY2013, it was identified as one of the six emerging and most commonly found encroachment issues for Air Force Installation Complex Encroachment Management Action Plans (ICEMAPs). Wildland fire is an additional contributor to another emerging and commonly found encroachment issue, defense access roads.

The Army, Navy, Air Force, and Marine Corps manage 561 at-risk species on approximately 25 million acres on more than 425 major military installations throughout the United States. These installations are the foundation upon which the military services conduct essential training, testing, and basing. Historically, remote location sites for DoD installations limited public access due to security considerations, and the need for range safety buffer zones have delayed encroachment pressures and large-scale habitat losses. Most military lands contain federally and state listed fauna and flora, and terrestrial ecosystems of rare native plant communities, such as old-growth forests, tall-grass prairies, and vernal pool wetlands. Approximately 220 different federally listed species are known to occur on at least one DoD installation - the highest known density per acre of threatened and endangered species (TES) found on any federal agency lands. More than 200 installations provide habitat for at least one candidate or listed species. This total can be broken down into the DoD Services by the following: 76 species on Air Force bases, 173 on Army bases, 56 on Marine Corps bases, and 138 on Naval bases. Defense installations in Hawaii are especially significant; more than one-third of all ESA status species on military lands are Hawaiian. During the past decade, approximately 15 installations have needed to modify or restrict military training or testing to comply with the ESA. Required changes have included actions such as modifications to training schedules, the temporary closing of specific areas, restrictions on the types of activities permitted, and improved environmental awareness training for troops using sensitive areas.

Prescribed fire is one of the major natural resource management tools identified in an installation’s Integrated Natural Resource Management Plans (INRMPs) for use in the conservation and rehabilitation of natural and cultural resources. Prescribed fire is planned and implemented to ensure compliance with the Sikes Act, Section 7(a)(1) of the ESA http://www.fireinthefield.net, and DoD Instructions (DoDI 4715.03, DoDI 4715.05, DoDI 4715.1E, AR 200-3, AFI 32-7064, OPNAVINST 5090.1B, and MCO P5090.2A).

**The Ecology of Fire**

Historically wildland fire and more recently prescribed fire have determined the distribution of plants and animals throughout the continental United States, Alaska, and Hawaii. Many plant communities have evolved with fire and are dependent on fire for the germination, growth, competition, and productivity. In turn, animals are dependent on the natural regeneration of plant communities following fire for foraging and their reproductive success. The result is a sustainable environment in which natural and cultural resources on DoD installations are protected from degradation resulting in realistic DoD testing and training environments without Federal and State restrictions on land use and missions.
One of the most important goals of prescribed fire and other treatments to change or reduce wildland fuels in the reduction in unplanned wildfires. The fuel management activities on DoD installations and the surrounding communities have become increasingly important for reducing the risk of severe wildfires. Many of the lands within DoD installations are characterized a fire-adapted or fire-dependent and these ecosystems require periodic fire to maintain a healthy and sustainable environment. Mechanical treatments, such as forest and understory vegetation thinning, mowing, and the removal of dead vegetation can be implemented to reduce fuels that contribute to destructive wildfires. The benefits of fire often include:

- Reduction in wildland fire risk, protecting installation and adjoining private property and communities from extreme wildfires;
- Controlling the spread of insect pests and diseases that degrade the sustainability of natural resources;
- Management of non-native species that threaten and compete with native plants and animals;
- Restoration of wildlife habitats that have been destroyed, degraded, or fragmented, all of which often lead to species becoming threatened or endangered;
- Maintains cultural landscapes such as historic building, battlefields, native American sites, and homesteads;
- Promoting clean air and water for healthy ecosystems that provide clean air to breath and clean water to drink; and
- Supports the DoD mission of uninterrupted testing and training on installation.

Ecosystem management emphasizes an ecological approach to resource stewardship and sustainability. It is a holistic approach to natural and cultural resource management that attempts to manage the aquatic and terrestrial resources. It focuses on long-term landscape management of installations and the surrounding wildlands and urban development within the INRMP 5-year planning cycles. The premise is that, in managing for whole, healthy ecosystems, natural resource managers are better able to sustain resource outputs for the future. Instead of emphasizing short-term resource extraction, ecosystem management attempts to manage for the healthy, long-term functioning of the entire system, with the expectation that, in doing so, DoD installations testing and training missions will follow on a sustainable basis.

The biological effects of fire have a profound influence on composition, structure, and function of forests, shrublands, grasslands, and aquatic ecosystems on DoD installations. The effects of fire are particularly apparent in short interval fire-adapted ecosystems in which fires resulting from lightning or burning by Native Americans generally occurring at 5- to 25-year intervals. These ecosystems were the first to manifest adverse biological consequences because of fire exclusion. Fire-related ecological problems are most immediate in short interval fire-adapted ecosystems where over-accumulation of fuels results in extreme wildfire behavior and ecosystem degradation. In the prolonged absence of periodic, low-intensity surface fire, stands undergo relatively rapid changes in species composition and structure that often become predisposing factors to epidemic insect and disease outbreak and severe forest stand replacement wildfires. Natural resource planning in these systems requires the integration and understanding of fire history, fire behavior, past management practices, land-use change, watershed management, aquatic and terrestrial species viability, and the relative risk to installation staff and infrastructure, and the public.
Significant forest health problems appear to be most concentrated in short interval fire-adapted tree species, commonly represented by long-needle pine species (e.g. ponderosa, Jeffrey, eastern and western white, red, loblolly, short-leaf, long-leaf, and slash pine). The Blue Mountains in northeastern Oregon and southeastern Washington, the mountains in south-central Idaho, the Colorado Front Range west of Denver, and the central Sierra in California are examples of conifer-dominated short interval fire-adapted ecosystems that are plagued by serious forest health problems. They are also areas where severe wildfires have recently occurred and will reoccur.

Invasive species such at cheatgrass (*Bromus tectorum*), also know as downy brome, are also producing increased wildfire risk on DoD installations. The early-season growth habits of cheatgrass provide a competitive advantage by allowing it to grow tall and abundant before native grass species emerge. Cheatgrass turns brown and dies by early summer leaving thick, continuous, dry, 1-hour fuels that create extreme wildfire risks.

Sustaining short interval fire-adapted ecosystems is expected to be a difficult challenge. In order to better prepare the USFS’s Fire and Aviation Management Staff made five recommendations that were adopted as prescribed fire management goals:

- Communicate the ecological roles of fire to decision-makers and the public. In short interval fire-adapted ecosystems, complex issues are inherent and the risks that surround wildfire threats and prescribed fire applications increase the potential for conflict in the social arena.
- Display the long-term effects of prescribed fire and wildfire suppression options. The land management planning process affords the means to display trade-offs, assess benefits and consequences, and determine costs among a full range of alternative natural resource management approaches.
- Maintain strong wildfire suppression capability and continue to strengthen prescribed fire expertise. Fire suppression capability will remain a vital cornerstone as fire-adapted ecosystems continue to approach high-risk conditions and as private development continues to expand at the wildland/urban interface. Prescribed fire, despite the concerns that surround its use, remains an important, ecologically appropriate management tool.
- Manage prescribed fire risk: assess it, mitigate it, and seek partners to share it. Risk management will become a fundamentally important component of the prescribed fire program. A risk assessment process will become the basis for ignition decisions. Managers will be better apprised of high-risk prescribed burning treatments and avoid them, unless they can be adequately mitigated or risks can be shared among partners.
- Align fire management programs to better complement one another. Although fire policies are sound, program areas (prevention, pre-suppression, suppression, fuel management, and prescribed fire use) will be fully integrated, better reflect a common purpose, and complement one another toward an ecosystem management objective.

These goals and actions signal important changes for fire management. They require that natural resource managers take a proactive role in explaining the consequences of both the presence and absence of prescribed burning and wildfire suppression and fully integrate these considerations into the decision-making process. They also require an improved, more balanced fire management approach to land and resource management in support of DoD missions.
The Role of Fire

The role of fire in North American ecosystems has been undergoing change since people began to play a more active role in managing their natural resources. Native Americans actively used fire to manipulate the landscape to improve hunting, gathering, and farming. Prior to European settlement, fire played a natural role as a necessary disturbance phenomenon, reducing fuel density, controlling the insects and diseases, thereby maintaining healthy North American forests, shrublands, and grasslands. Since European settlement and the introduction of grazing herds of cattle and sheep, and the practice of fire suppression, public land management agencies have recognized that not allowing fire to play its natural role in United States wildlands has had unintended effects. When forests, shrublands, and grasslands are not allowed to burn naturally with a mosaic of low intensity wildfires the result can be heavy accumulation of dead vegetation which provides fuel for extreme wildfires that resulted in forest death and declines, damage to soils from heat and erosion, and reductions in water quantity and quality in watersheds. Because of this unhealthy build-up of fuels, the risk of catastrophic wildfires is much greater as evidenced by several large recent fires. These fires put DoD installation staff, infrastructure, firefighters, and the general public in danger while destroying natural and cultural resources and costing millions of dollars for fire suppression and land rehabilitation. The lack of fire also has unintended ecological effects, leading to the loss of habitat for rare species, the decline of ecosystems, and the listing of new threatened and endangered species on DoD installations that place restrictions on land use and testing and training missions. Fire exclusion can lead to an alteration in natural community types, and an important loss of biodiversity. Many plant and animal species are on the decline because they exist in fire-dependent habitats that haven't burned in decades. This situation has led to a rethinking of Federal land management and fire management policy.

Changes in Fire Management Policy

In 1995, a Federal Wildland Fire Management Policy and Program Review was conducted in response to the unhealthy condition of our public wildlands, and the increase in unplanned fires that occurred in 1987, 1988, 1992, and 1994. As a result of this review, the five principal Federal fire/land management agencies the USFS under the Department of Agriculture; and the Bureau of Land Management (BLM), National Park Service (NPS), USFWS, and the Bureau of Indian Affairs (BIA) under the Department of Interior agreed on the need for several changes to existing fire/land management practices. Their recommendations include the reintroduction of fire as a natural process into Federal land management programs in “an ongoing and systematic manner, consistent with public health and environmental quality considerations.” The goals of this change in land management policy are to reduce unnatural fuel densities that contribute to increasing unplanned fire hazards, and to restore wildland ecosystems to their healthy natural states. The Federal agencies previously mentioned began increasing the use of fire in their most vulnerable wildlands in 1997. Today, prescribed fire is used on private, State, and Federal lands to restore fire dependent ecosystems and reduce the wildland fire risk of extreme fire events.

Air Quality Considerations

Burning wildland vegetation results in the release of emissions of many chemical compounds and small particles. The components and quantity of fire emissions are dependent on the types of fuel burned, the moisture content of the fuels, the temperature of the combustion, and
meteorological conditions during the burn. Many volatile organic compounds and aldehydes may be absorbed into and onto condensed smoke particles. On average, 90 percent of smoke particles from wildland and prescribed fire are particulate matter (PM) of 10-micron size and 70 percent are PM particles with 2.5-micron size.

Historically, the EPA has focused on control efforts for the larger “coarse” particles and on “total suspended particles” as large as 100-micron size. These standards were revised based on science that showed the smaller size particles were capable of transport into lungs and were associated with adverse human health effects. Recent reviews of health studies have focused attention on PM$_{2.5}$. These studies have provided consistent and coherent, “evidence that serious health effects (mortality, exacerbation of chronic disease, increased hospital admissions, etc.) are associated with exposures to ambient levels of PM found in contemporary urban airsheds even at concentrations below current U. S. PM standards”. PM concentrations currently found in many communities are associated with adverse health effects in the general population, including increased mortality and morbidity, altered lung function, increased respiratory symptoms, aggravated respiratory and cardiovascular disease. Sensitive sub-populations, such as children, the aged and those with existing cardiopulmonary or infectious respiratory disease, may experience effects at lower levels of PM than the general population, and the severity of effects might be greater. In addition, the PM 2.5-micron size particles are a source of visibility impairment on state and federal lands.

Visibility Impairment
Visibility impairment is an important consideration on all wildfires and prescribed burns. Smoke transported at the ground surface present a public safety concern for roads and highways, especially when combined with morning and evening fog creating “super fog” events that cause white out conditions. Smoke columns and their downwind transport are also an air traffic hazard. Visibility impairment is caused by the scattering and absorption of light by PM particles and emission gases from fires. The fine particles most responsible for visibility impairment are sulfates, nitrates, organic compounds, carbon, and soil dust. Fine particles are more efficient per unit mass than coarse particles at scattering light. Light scattering efficiencies also go up as humidity rises, due to water adsorption on fine particles, which allow the particles to grow to sizes comparable to the wavelength of light.

Visibility is an important public welfare consideration because of its significance to enjoyment of daily activities in all parts of the country. Protection of visibility as a public welfare consideration is addressed nationally through the National Ambient Air Quality Standards (NAAQS) secondary standard for PM. Visibility protection is particularly important in the 156 mandatory Class I Federal areas, “Areas of Great Scenic Importance,” and is addressed for these areas by the special provisions of Sections 169A and 169 B of The Clean Air Act (CAA).

Smoke Management
Natural resource managers planning and implementing prescribed fires and responding to wildfire suppression must understand the management for minimizing the negative impacts of smoke and associated fire emissions. Managers know that the protection of DoD installation personal and the surrounding communities and public are the priority in all aspects of fire and smoke management. Protecting natural and cultural resources and ensuring that there is no interruption of testing and training missions are secondary priorities.
The legal foundation of smoke management is the CCA that establishes the primary standard (public health) and the secondary standard (welfare and environmental quality) for controlling smoke and emission gases from fire. The CCA requires the U.S. Environmental Protection Agency (EPA) to set the NAAQS to control pollution and protect the public health, safety, and welfare. The EPA has set NAAQS for six criteria pollutants: ozone, particulate matter, carbon monoxide, nitrogen dioxide, sulfur dioxide, and lead. The law also requires EPA to periodically review the standards to ensure that they provide adequate health and environmental protection, and to update those standards as necessary. Many of the specific requirements for smoke management are found in State Implementation Plans (SIP) and Smoke Management Plans (SMP).

Prescribed fire emissions are subject to the State and Federal laws, regulations, and policies. The major components of fire emissions are water vapor and carbon dioxide, and to a lesser amount carbon monoxide, nitrogen oxide, hydrocarbons, and particulate matter (PM). In addition to the CAA and the NAAQS, smoke and gaseous emissions from fire are regulated by EPA through the Interim Air Quality Policy on Wildland and Prescribed Fires, the Exceptional Events Rule, the Determining General Conformity of General Federal Actions to State or Federal Implementation Plans, and the Regional Haze Rule.

Web Links:
http://www.epa.gov/ttn/oarpg/t1/memoranda/firefnl.pdf
http://www.epa.gov/ttn/analysis/docs/exceptevents_guidememo_130510.pdf
http://www.epa.gov/ttn/oarpg/conform/genconf_00001.pdf
http://www.epa.gov/visibility/program.html

The Importance of Smoke Management on DoD Installations
Management of smoke from wildfires and prescribed burns is a concern for both DoD installation operations and compliance with State and Federal regulatory statutes. DoD installation natural resource managers must consider the short-term needs that include impacts on the day’s missions, determining suitable times for prescribed burning, responding to wildfires on the installation caused by testing and training activities, and estimating the impact of smoke on neighboring communities, as well as on crews working the fire. These operational considerations of smoke have received extensive attention within State and Federal agencies and tools have been developed to assist natural resource managers in planning prescribed burns and conducting wildfire suppression operations.

Fire has an impact on local and regional air quality. The EPA has set NAAQS for pollutants considered to be harmful to public health and the environment. These include primary standards, which protect public health, and secondary standards, set to protect human welfare such as visibility and ecosystem effects. Fires, both wildfires and prescribed burning, can contribute significantly to levels of ozone (O_3) and fine PM, causing nonattainment of both the primary and secondary NAAQS in communities and regions throughout the U.S. Regulations set limits on ambient concentrations allowed for hourly, daily and annual average values.

Smoke from prescribed fires can also contribute to haze in National Parks and in wilderness areas, collectively known as Class I areas (CIA). In these areas, haze is regulated using EPA’s
Regional Haze Rule (RHR), which requires each state to set “reasonable progress” goals to return visibility to natural conditions on the 20 percent of haziest days by 2064, while preventing degradation of visibility on the 20 percent of least-hazy days. Progress towards these goals is tracked using five-year-average values. Further, fire emissions also contain substantial levels of reactive nitrogen, and it is anticipated that there will be a secondary total reactive nitrogen deposition NAAQS standard.

Natural resource managers must also plan and implement goals for the long-term needs of the installation, its future sustainability, and the continuance of realistic testing and training environments that are free from State and Federal restrictions on missions.

The “Toolkit for Planning and Managing Prescribed and Wildland Fire Smoke on Military Installations” was developed with the goals of:

- Providing DoD natural resource managers with a fundamental understanding of fire policy, state and federal regulatory objectives, fire ecology, and the tools for the management of wildland fire, and wildfire and prescribed fire smoke, and
- Providing natural resource managers with background information on the use of fire as a tool toward the goal of achieving the sustainability of terrestrial and aquatic resources on military installations that supports the mission while ensuring for the safety of the installation staff, infrastructure, and the surrounding public and private lands.
Chapter 2 Regulations for Smoke Management

Introduction
Ambient air quality is the primary indicator of public health impacts and is regulated through the EPA’s NAAQS program. The CAA requires EPA to set NAAQS for the protection of health and welfare (40 CFR Part 50) and to review these standards every five years. There are NAAQS for six criteria pollutants that are regulated by developing human health-based and/or environmentally-based criteria for setting permissible levels. The NAAQS limits based on human health are called primary standards. Whereas NAAQS limits intended to prevent environmental and property damage are called secondary standards.

A geographic area that meets or has air quality better than the primary standard is called an attainment area. Areas that do not meet the standards, or that contribute pollution to nearby areas that do not meet standards, are called nonattainment areas. In some instances where there is insufficient information an area may be designated unclassifiable until such time as more information becomes available. Maintenance areas are former nonattainment areas where air quality has improved to be in compliance with the relevant NAAQS. An area may be designated attainment for some pollutants and non-attainment for others.

The CAA requires states and national air quality standards, prevent significant deterioration of air quality and remedy existing and prevent future visibility impairment in mandatory Class I Federal areas caused by man-made sources of pollution. Air quality managers accomplish this by developing either State Implementation Plans (SIPs) or Tribal Implementation Plans (TIPs) that include all programs and rules required by the CAA to meet and assure maintenance of Federal air quality standards. If a state or tribe does not adopt an implementation plan to address air quality protection, the EPA has the authority to adopt and implement a Federal Implementation Plan (FIP). Development of a SIP, TIP or FIP is done through a public process involving all stakeholders. During the development of an implementation plan, stakeholders are invited to provide input on the technical components of the plans including:

- Emission inventories,
- Modeling analyses,
- Attainment demonstrations,
- Transportation and general conformity emission budgets,
- Analyses of air quality data, and
- Control strategy development.

When fire emissions impact air quality, effective management of these emissions is an important component of an implementation plan to attain and maintain the NAAQS. In addition to public health impacts, emissions from fire may have public welfare impacts, including visibility impairment and contributions to regional haze, both of which are regulated under the Regional Haze Rule. Where fire causes or contributes to violations of the NAAQS or impairs visibility in mandatory Class I federal areas, states and tribes are required to address this source of emissions through their SIP or TIP.

Clean Air Act
For common pollutants, the law requires EPA to establish health-based national air quality
standards to protect people with an "adequate margin of safety." The CCA requires EPA to set NAAQS for the six common air pollutants. These commonly found "criteria pollutants" are found all over the United States. They are particle matter (PM), ground-level ozone (O_3), carbon monoxide (CO), sulfur oxides (SO_x), nitrogen oxides (NO_x), and lead (Pb). These pollutants can harm health and the environment, and cause property damage. Of the six pollutants, PM and ground-level ozone are the most widespread health threats. EPA calls these pollutants "criteria" air pollutants because it regulates them by developing human health-based and/or environmentally-based criteria for setting permissible levels. The set of limits based on human health is called primary standards. Another set of limits intended to prevent environmental and property damage is called secondary standards. States are responsible for developing enforceable SIPs to meet the standards. In some states such as California, local air pollution districts work with the State to produce air quality plans. Each State plan also must prohibit emissions that significantly contribute to air quality problems in a downwind State.

EPA provides guidance and technical assistance to assist State planning, issues national emissions standards for new stationary sources, and reviews state plans to ensure that they comply with the CAA. Preconstruction permits are required for major new and modified stationary sources. In most areas, state or local air agencies serve as the CAA permitting authority. Elsewhere, EPA is the permitting authority.

Toxic Pollutants: National Standards with a Role for States - Congress directed EPA to issue national limits for toxic air emissions from each category of major sources, and for certain categories of smaller, area sources. These standards ensure that facilities throughout the nation control their toxic emissions. States have the option of adopting a program that provides for partial or complete delegation of EPA's authorities to implement and enforce toxic emissions standards; State programs can be no less stringent than the Federal requirements.

Acid Rain: A Federal Program - Congress established a Federal acid rain program to cut acid-rain forming emissions from power plants that cross state lines. The law required EPA to issue the implementing rules, track the trading of emissions allowances, and monitor compliance.

The Role of Tribal Governments - Tribal governments can play important roles implementing the CAA in their areas. If a tribe has the desire and capability to administer one or more CAA program and meets certain criteria, the law authorizes EPA to approve the tribe as eligible to implement programs under the Act. The tribe can then develop and obtain approval of particular CAA programs from EPA. Otherwise, EPA generally implements the law in Indian country. EPA's Office of Air and Radiation (OAR) works closely with tribal governments and tribal environmental professionals to increase their capacity to develop and manage their air quality programs by providing training, grants, and technical support.

Regional Haze
Congress requires States to adopt enforceable plans to reduce pollutants that damage visibility in national parks and other protected areas. EPA issues guidance on State planning and required controls, and reviews State plans to ensure that they comply with the CAA. EPA and other Agencies have been monitoring visibility in National Parks and Wilderness Areas since 1988. In 1999, the EPA announced a major effort to improve air quality in National Parks and Wilderness Areas. The Regional Haze Rule calls for state and federal agencies to work together
to improve visibility in 156 National Parks and Wilderness Areas such as the Grand Canyon, Yosemite, the Great Smokies, and Shenandoah. The rule requires the States, in coordination with the EPA, the National Park Service (NPS), USFWS, the USFS, and other interested parties, to develop and implement air quality protection plans to reduce the pollution that causes visibility impairment.

Table 1. List of 156 Mandatory Class I Federal Areas

<table>
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<tr>
<th>Area Name</th>
<th>Acreage</th>
<th>Federal Land Manager</th>
<th>Public Law</th>
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<td>81.401 Alabama.</td>
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<td>Sipsey Wilderness Area</td>
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<td>USDA-FS</td>
<td>88-577</td>
</tr>
<tr>
<td>Mokelumme Wilderness Area</td>
<td>50,400</td>
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<tr>
<td>Pinnacles Wilderness Area</td>
<td>12,952</td>
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<tr>
<td>Point Reyes Wilderness Area</td>
<td>25,370</td>
<td>USDI-NPS</td>
<td>94-544</td>
</tr>
<tr>
<td>Redwood NP</td>
<td>27,792</td>
<td>USDI-NPS</td>
<td>90-545</td>
</tr>
<tr>
<td>San Gabriel Wilderness Area</td>
<td>36,137</td>
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<td>90-318</td>
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<tr>
<td>San Gorgonio Wilderness Area</td>
<td>34,644</td>
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<td>88-577</td>
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<tr>
<td>San Jacinto Wilderness Area</td>
<td>20,564</td>
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<td>88-577</td>
</tr>
<tr>
<td>San Rafael Wilderness Area</td>
<td>142,722</td>
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<td>90-271</td>
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<tr>
<td>Sequoia NP</td>
<td>386,642</td>
<td>USDI-NS</td>
<td>(11)</td>
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<tr>
<td>South Warner Wilderness Area</td>
<td>68,507</td>
<td>USDA-FS</td>
<td>88-577</td>
</tr>
<tr>
<td>Thousand Lakes Wilderness Area</td>
<td>15,695</td>
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<td>88-577</td>
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<tr>
<td>Ventana Wilderness Area</td>
<td>95,152</td>
<td>USDA-FS</td>
<td>91-58</td>
</tr>
<tr>
<td>Yolla-Bolly-Middle-Eel Wilderness Area</td>
<td>109,091</td>
<td>USDA-FS</td>
<td>88-577</td>
</tr>
<tr>
<td>Yosemite NP</td>
<td>759,172</td>
<td>USDI-NPS</td>
<td>58-49</td>
</tr>
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</table>

### 81.406 Colorado.

<table>
<thead>
<tr>
<th>Wilderness Area</th>
<th>Size</th>
<th>Agency</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black Canyon of the Gunnison Wilderness Area</td>
<td>11,180</td>
<td>USDI-NPS</td>
<td>94-567</td>
</tr>
<tr>
<td>Eagles Nest Wilderness Area</td>
<td>133,910</td>
<td>USDA-FS</td>
<td>94-352</td>
</tr>
<tr>
<td>Flat Tops Wilderness Area</td>
<td>235,230</td>
<td>USDA-FS</td>
<td>94-146</td>
</tr>
<tr>
<td>Great Sand Dunes Wilderness Area</td>
<td>33,450</td>
<td>USDA-FS</td>
<td>94-567</td>
</tr>
<tr>
<td>La Garita Wilderness Area</td>
<td>48,486</td>
<td>USDA-FS</td>
<td>88-577</td>
</tr>
<tr>
<td>Maroon Bells-Snowmass Wilderness Area</td>
<td>71,060</td>
<td>USDA-FS</td>
<td>88-577</td>
</tr>
<tr>
<td>Mesa Verde NP</td>
<td>51,488</td>
<td>USDA-NPS</td>
<td>59-353</td>
</tr>
<tr>
<td>Mount Zirkel Wilderness Area</td>
<td>72,472</td>
<td>USDA-FS</td>
<td>88-577</td>
</tr>
<tr>
<td>Rawah Wilderness Area</td>
<td>26,674</td>
<td>USDA-FS</td>
<td>88-577</td>
</tr>
<tr>
<td>Rocky Mountain NP</td>
<td>263,138</td>
<td>USDA-NPS</td>
<td>63-238</td>
</tr>
<tr>
<td>Weminuche Wilderness Area</td>
<td>400,907</td>
<td>USDA-FS</td>
<td>93-632</td>
</tr>
<tr>
<td>West Elk Wilderness Area</td>
<td>61,412</td>
<td>USDA-FS</td>
<td>88-577</td>
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</table>

### 81.407 Florida.

<table>
<thead>
<tr>
<th>Wilderness Area</th>
<th>Size</th>
<th>Agency</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chassahowitzka Wilderness Area</td>
<td>23,360</td>
<td>USDI-FWS</td>
<td>94-557</td>
</tr>
<tr>
<td>Everglades NP</td>
<td>1,397,429</td>
<td>USDI-NPS</td>
<td>73-267</td>
</tr>
<tr>
<td>St. Marks Wilderness Area</td>
<td>17,745</td>
<td>USDI-FWS</td>
<td>93-632</td>
</tr>
</tbody>
</table>

### 81.408 Georgia.

<table>
<thead>
<tr>
<th>Wilderness Area</th>
<th>Size</th>
<th>Agency</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cohutta Wilderness Area</td>
<td>33,776</td>
<td>USDA-FS</td>
<td>93-622</td>
</tr>
<tr>
<td>Okefenokee Wilderness Area</td>
<td>343,850</td>
<td>USDA-FWS</td>
<td>93-429</td>
</tr>
<tr>
<td>Wolf Island Wilderness Area</td>
<td>5,126</td>
<td>USDA-FWS</td>
<td>93-632</td>
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</table>

### 81.409 Hawaii.

<table>
<thead>
<tr>
<th>Wilderness Area</th>
<th>Size</th>
<th>Agency</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haleakala NP</td>
<td>27,208</td>
<td>USDI-NPS</td>
<td>87-744</td>
</tr>
<tr>
<td>Hawaii Volcanoes NP</td>
<td>217,029</td>
<td>USDI-NPS</td>
<td>64-171</td>
</tr>
<tr>
<td>State</td>
<td>Area Name</td>
<td>Acres</td>
<td>Agency</td>
</tr>
<tr>
<td>---------</td>
<td>-----------------------------------------------------</td>
<td>--------</td>
<td>------------</td>
</tr>
<tr>
<td>Idaho</td>
<td>Craters of the Moon Wilderness Area</td>
<td>43,243</td>
<td>SDI-NPS</td>
</tr>
<tr>
<td></td>
<td>Hells Canyon Wilderness Area{1}</td>
<td>83,800</td>
<td>USDA-FS</td>
</tr>
<tr>
<td></td>
<td>Sawtooth Wilderness Area</td>
<td>216,383</td>
<td>USDA-FS</td>
</tr>
<tr>
<td></td>
<td>Selway-Bitterroot Wilderness Area{2}</td>
<td>988,770</td>
<td>USDA-FS</td>
</tr>
<tr>
<td></td>
<td>Yellowstone NP{3}</td>
<td>31,488</td>
<td>USDI-NPS</td>
</tr>
</tbody>
</table>

{1} Hells Canyon Wilderness, 192,700 acres overall, of which 108,900 acres are in Oregon and 83,800 acres are in Idaho.
{2} Selway Bitterroot Wilderness, 1,240,700 acres overall, of which 988,700 acres are in Idaho and 251,930 acres are in Montana.
{3} Yellowstone National Park, 2,219,737 acres overall, of which 2,020,625 acres are in Wyoming, 167,624 acres are in Montana, and 31,488 acres are in Idaho.

<table>
<thead>
<tr>
<th>State</th>
<th>Area Name</th>
<th>Acres</th>
<th>Agency</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kentucky</td>
<td>Mammoth Cave NP</td>
<td>51,303</td>
<td>USDI-NPS</td>
<td>69-283</td>
</tr>
<tr>
<td>Louisiana</td>
<td>Breton Wilderness Area</td>
<td>5,000+</td>
<td>USDI-FWS</td>
<td>93-632</td>
</tr>
<tr>
<td>Maine</td>
<td>Acadia National Park</td>
<td>37,503</td>
<td>USDI-NPS</td>
<td>65-278</td>
</tr>
<tr>
<td></td>
<td>Moosehorn Wilderness Area.</td>
<td>7,501</td>
<td>USDI-FWS</td>
<td>91-504</td>
</tr>
<tr>
<td></td>
<td>(Edmunds Unit)</td>
<td>(2,782)</td>
<td>USDI-FWS</td>
<td>93-632</td>
</tr>
<tr>
<td></td>
<td>(Baring Unit)</td>
<td>(4,719)</td>
<td>USDI-FWS</td>
<td>93-632</td>
</tr>
<tr>
<td>Michigan</td>
<td>Isle Royale NP.</td>
<td>542,428</td>
<td>USDI-NPS</td>
<td>71-835</td>
</tr>
<tr>
<td></td>
<td>Seney Wilderness Area</td>
<td>25,150</td>
<td>USDI-FWS</td>
<td>91-504</td>
</tr>
<tr>
<td>Minnesota</td>
<td>Boundary Waters Canoe Area Wilderness Area</td>
<td>747,840</td>
<td>USDA-FS</td>
<td>99-577</td>
</tr>
<tr>
<td></td>
<td>Voyageurs NP</td>
<td>114,964</td>
<td>USDI-NPS</td>
<td>99-261</td>
</tr>
<tr>
<td>Missouri</td>
<td>Hercules-Glades Wilderness Area</td>
<td>12,315</td>
<td>USDA-FS</td>
<td>94-557</td>
</tr>
<tr>
<td></td>
<td>Mingo Wilderness Area</td>
<td>8,000</td>
<td>USDA-FWS</td>
<td>95-557</td>
</tr>
<tr>
<td>Montana</td>
<td>Anaconda-Pintlar Wilderness Area</td>
<td>157,803</td>
<td>USDA-FS</td>
<td>88-577</td>
</tr>
<tr>
<td></td>
<td>Bob Marshall Wilderness Area</td>
<td>950,000</td>
<td>USDA-FS</td>
<td>88-577</td>
</tr>
<tr>
<td></td>
<td>Cabinet Mountains Wilderness Area</td>
<td>94,272</td>
<td>USDA-FS</td>
<td>88-577</td>
</tr>
<tr>
<td></td>
<td>Gates of the Mtn Wilderness Area</td>
<td>28,562</td>
<td>USDA-FS</td>
<td>88-577</td>
</tr>
<tr>
<td></td>
<td>Glacier NP</td>
<td>1,012,599</td>
<td>USDI-NPS</td>
<td>61-171</td>
</tr>
<tr>
<td></td>
<td>Medicine Lake Wilderness Area</td>
<td>11,366</td>
<td>USDA-FWS</td>
<td>94-557</td>
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<tr>
<td></td>
<td>Mission Mountain Wilderness Area</td>
<td>73,877</td>
<td>USDA-FS</td>
<td>93-632</td>
</tr>
<tr>
<td></td>
<td>Red Rock Lakes Wilderness Area.</td>
<td>32,350</td>
<td>USDA-FWS</td>
<td>94-557</td>
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<tr>
<td></td>
<td>Scapegoat Wilderness Area</td>
<td>239,295</td>
<td>USDA-FS</td>
<td>92-395</td>
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<tr>
<td></td>
<td>Selway-Bitterroot Wilderness Area{1}</td>
<td>251,930</td>
<td>USDA-FS</td>
<td>88-577</td>
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<tr>
<td></td>
<td>U. L. Bend Wilderness Area</td>
<td>20,890</td>
<td>USDA-FWS</td>
<td>94-557</td>
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<tr>
<td></td>
<td>Yellowstone NP{2}</td>
<td>167,624</td>
<td>USDI-NPS</td>
<td>(13)</td>
</tr>
</tbody>
</table>

{1} Selway-Bitterroot Wilderness, 1,240,700 acres overall, of which 988,770 acres are in Idaho and 251,930 acres are in Montana.
{2} Yellowstone National Park, 2,219,737 acres overall, of which 2,020,625 acres are in Wyoming, 167,624 acres are in Montana, and 31,488 acres are in Idaho.
### 81.418 Nevada.
- Jarbidge Wilderness Area 64,667 USDA-FS 88-577

### 81.419 New Hampshire.
- Great Gulf Wilderness Area 5,552 USDA-FS 88-577
- Presidential Range-Dry River Wilderness Area 20,000 USDA-FS 93-622

### 81.42 New Jersey.
- Brigantine Wilderness Area 6,603 USDI-FWS 93-632

### 81.421 New Mexico.
- Bandelier Wilderness Area 23,267 USDI-NPS 94-567
- Bosque del Apache Wilderness Area 80,850 USDI-FWS 93-632
- Carlsbad Caverns NP 46,435 USDI-NPS 71-216
- Gila Wilderness Area 433,690 USDA-FS 88-577
- Pecos Wilderness Area 167,416 USDA-FS 88-577
- Salt Creek Wilderness Area 8,500 USDI-FWS 91-504
- San Pedro Parks Wilderness Area 41,132 USDA-FS 88-577
- Wheeler Peak Wilderness Area 6,027 USDA-FS 88-577
- White Mountain Wilderness Area 31,171 USDA-FS 88-577

### 81.422 North Carolina.
- Great Smoky Mountains NP 273,551 USDI-NPS 69-268
- Joyce Kilmer-Slickrock Wilderness Area 10,201 USDA-FS 93-622
- Linville Gorge Wilderness Area 7,575 USDA-FS 88-577
- Shining Rock Wilderness Area 13,350 USDA-FS 88-577
- Swanquarter Wilderness Area 9,000 USDI-FWS 94-557

### 81.423 North Dakota.
- Lostwood Wilderness 5,557 USDI-FWS 93-632
- Theodore Roosevelt NP 69,675 USDI-NPS 80-38

### 81.424 Oklahoma.
- Wichita Mountains Wilderness 8,900 USDI-FWS 91-504

### 81.425 Oregon.
- Crater Lake NP 160,290 USDA-NPS 57-121
- Diamond Peak Wilderness 36,637 USDA-FS 88-577
- Eagle Cap Wilderness 293,476 USDA-FS 88-577
- Gearhart Mountain Wilderness 18,709 USDA-FS 88-577
- Hells Canyon Wilderness 108,900 USDA-FS 94-199
- Kalmiopsis Wilderness 76,900 USDA-FS 88-577

---

[{1} Great Smoky Mountains National Park, 514,758 acres overall, of which 273,551 acres are in North Carolina, and 241,207 acres are in Tennessee.

[{2} Joyce Kilmer-Slickrock Wilderness, 14,033 acres overall, of which 10,201 acres are in North Carolina, and 3,832 acres are in Tennessee.]
<table>
<thead>
<tr>
<th>Wilderness Area</th>
<th>Acres</th>
<th>Management Agency</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mountain Lakes Wilderness</td>
<td>23,071</td>
<td>USDA-FS</td>
<td>88-577</td>
</tr>
<tr>
<td>Mount Hood Wilderness</td>
<td>14,160</td>
<td>USDA-FS</td>
<td>88-577</td>
</tr>
<tr>
<td>Mount Jefferson Wilderness</td>
<td>100,208</td>
<td>USDA-FS</td>
<td>90-548</td>
</tr>
<tr>
<td>Mount Washington Wilderness</td>
<td>46,116</td>
<td>USDA-FS</td>
<td>88-577</td>
</tr>
<tr>
<td>Strawberry Mountain Wilderness</td>
<td>33,003</td>
<td>USDA-FS</td>
<td>88-577</td>
</tr>
<tr>
<td>Three Sisters Wilderness</td>
<td>199,902</td>
<td>USDA-FS</td>
<td>88-577</td>
</tr>
<tr>
<td>Mount Hood Wilderness</td>
<td>14,160</td>
<td>USDA-FS</td>
<td>88-577</td>
</tr>
<tr>
<td>Mount Jefferson Wilderness</td>
<td>100,208</td>
<td>USDA-FS</td>
<td>90-548</td>
</tr>
<tr>
<td>Mount Washington Wilderness</td>
<td>46,116</td>
<td>USDA-FS</td>
<td>88-577</td>
</tr>
<tr>
<td>Strawberry Mountain Wilderness</td>
<td>33,003</td>
<td>USDA-FS</td>
<td>88-577</td>
</tr>
<tr>
<td>Three Sisters Wilderness</td>
<td>199,902</td>
<td>USDA-FS</td>
<td>88-577</td>
</tr>
<tr>
<td>Three Sisters Wilderness</td>
<td>199,902</td>
<td>USDA-FS</td>
<td>88-577</td>
</tr>
<tr>
<td>- Hells Canyon Wilderness, 192,700 acres overall, of which 108,900 acres are in Oregon, and 83,800 acres are in Idaho.</td>
<td></td>
<td></td>
<td></td>
</tr>
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</table>

81.426 South Carolina.
Cape Romain Wilderness 28,000 USDA-FWS 93-632

81.427 South Dakota.
Badlands Wilderness 64,250 USDA-NPS 94-567
Wind Cave NP 28,060 USDA-NPS 57-16

81.428 Tennessee.
Great Smoky Mountains NP{1}. 241,207 USDA-NPS 69-268
Joyce Kilmer-Slickrock Wilderness{2} 3,832 USDA-FS 93-622

81.429 Texas.
Big Bend NP. 708,118 USDA-NPS 74-157
Guadalupe Mountains NP 76,292 USDA-NPS 89-667

81.43 Utah.
Arches NP. 65,098 USDA-NPS 92-155
Bryce Canyon NP. 35,832 USDA-NPS 68-277
Canyonlands NP. 337,570 USDA-NPS 88-590
Capitol Reef NP. 221,896 USDA-NPS 92-507
Zion NP 142,462 USDA-NPS 68-83

81.431 Vermont.
Lye Brook Wilderness 12,430 USDA-FS 93-622

81.432 Virgin Islands.
Virgin Islands NP. 12,295 USDA-NPS 84-925

81.433 Virginia.
James River Face Wilderness. 8,703 USDA-FS 93-622
Shenandoah NP 190,535 USDA-NPS 69-268

81.434 Washington.
Alpine Lakes Wilderness. 303,508 USDA-FS 94-357
Glacier Peak Wilderness. 464,258 USDA-FS 88-577
Goat Rocks Wilderness. 82,680 USDA-FS 88-577
Mount Adams Wilderness 32,356 USDA-FS 88-577
Mount Rainer NP. 235,239 USDA-NPS (11)
North Cascades NP. 503,277 USDA-NPS 90-554
Olympic NP 892,578 USDA-NPS 75-778
Pasayten Wilderness 505,524 USDA-FS 90-544

81.435 West Virginia.
Dolly Sods Wilderness. 10,215 USDA-FS 93-622

[1] Hells Canyon Wilderness, 192,700 acres overall, of which 108,900 acres are in Oregon, and 83,800 acres are in Idaho.


[3] Joyce Kilmer Slickrock Wilderness, 14,033 acres overall, of which 10,201 acres are in North Carolina, and 3,832 acres are in Tennessee.

[44 FR 69124, Nov. 30, 1979; 45 FR 6103, Jan. 25, 1980]

[30 Stat. 993 (55th Cong.).]
National Ambient Air Quality Standards (NAAQS)
The Clean Air Act, which was last amended in 1990, requires EPA to set NAAQS (40 CFR part 50) for pollutants considered harmful to public health and the environment. The CAA identifies two types of national ambient air quality standards. Primary standards provide public health protection, including protecting the health of "sensitive" populations such as asthmatics, children, and the elderly. Secondary standards provide public welfare protection, including protection against decreased visibility and damage to animals, crops, vegetation, and buildings. EPA has set NAAQS for six principal pollutants, which are called "criteria" pollutants. They are listed below. Units of measure for the standards are parts per million (ppm) by volume, parts per billion (ppb) by volume, and micrograms per cubic meter of air (µg/m$^3$).

Fires can contribute significantly to levels of ozone and fine PM, causing nonattainment of both the primary and secondary NAAQS in communities and regions throughout the U.S. Regulations set limits on ambient concentrations allowed for hourly, daily and annual average values. Smoke from prescribed fires can also contribute to haze in national parks and in wilderness areas, collectively known as Class I areas (CIA). In these areas, haze is regulated using EPA’s Regional Haze Rule (RHR), which requires each state to set “reasonable progress” goals to return visibility to natural conditions on the 20 percent of haziest days by 2064, while preventing degradation of visibility on the 20 percent of least-hazy days. Progress towards these goals is tracked using five-year-average values. Currently, both PM and ozone NAAQS are violated in a number of areas, and virtually all CIAs have haze levels above natural background levels. State and federal agencies are working to implement plans to reduce and manage emissions that contribute to this problem.
Table 2. National Ambient Air Quality Standards for Six Principle Pollutants

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Primary/Secondary</th>
<th>Averaging Time</th>
<th>Level</th>
<th>Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Monoxide</td>
<td>primary</td>
<td>8-hour</td>
<td>9 ppm</td>
<td>Not to be exceeded more than once per year</td>
</tr>
<tr>
<td>[76 FR 54294, Aug 31, 2011]</td>
<td></td>
<td>1-hour</td>
<td>35 ppm</td>
<td></td>
</tr>
<tr>
<td>Lead</td>
<td>primary and secondary</td>
<td>Rolling 3 month average</td>
<td>0.15 μg/m³ (1)</td>
<td>Not to be exceeded</td>
</tr>
<tr>
<td>[73 FR 66964, Nov 12, 2008]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrogen Dioxide</td>
<td>primary</td>
<td>1-hour</td>
<td>100 ppb</td>
<td>98th percentile of 1-hour daily maximum concentrations, averaged over 3 years</td>
</tr>
<tr>
<td>[75 FR 6474, Feb 9, 2010]</td>
<td></td>
<td>Annual</td>
<td>53 ppb (2)</td>
<td>Annual Mean</td>
</tr>
<tr>
<td></td>
<td>primary and secondary</td>
<td>Annual</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ozone</td>
<td>primary and secondary</td>
<td>8-hour</td>
<td>0.075 ppm (3)</td>
<td>Annual fourth-highest daily maximum 8-hr concentration, averaged over 3 years</td>
</tr>
<tr>
<td>[73 FR 16436, Mar 27, 2008]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>primary</td>
<td>Annual</td>
<td>12 μg/m³</td>
<td>annual mean, averaged over 3 years</td>
</tr>
<tr>
<td></td>
<td>secondary</td>
<td>Annual</td>
<td>15 μg/m³</td>
<td>annual mean, averaged over 3 years</td>
</tr>
<tr>
<td></td>
<td>primary and secondary</td>
<td>24-hour</td>
<td>35 μg/m³</td>
<td>98th percentile, averaged over 3 years</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>primary and secondary</td>
<td>24-hour</td>
<td>150 μg/m³</td>
<td>Not to be exceeded more than once per year on average over 3 years</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>primary</td>
<td>1-hour</td>
<td>75 ppb (4)</td>
<td>99th percentile of 1-hour daily maximum concentrations, averaged over 3 years</td>
</tr>
<tr>
<td>Sulfur Dioxide</td>
<td>secondary</td>
<td>3-hour</td>
<td>0.5 ppm</td>
<td>Not to be exceeded more than once per year</td>
</tr>
<tr>
<td>[75 FR 35520, Jun 22, 2010]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>PM₂₅</td>
<td>Annual</td>
<td>12 μg/m³</td>
<td>annual mean, averaged over 3 years</td>
</tr>
<tr>
<td></td>
<td>secondary</td>
<td>Annual</td>
<td>15 μg/m³</td>
<td>annual mean, averaged over 3 years</td>
</tr>
<tr>
<td></td>
<td>primary and secondary</td>
<td>24-hour</td>
<td>35 μg/m³</td>
<td>98th percentile, averaged over 3 years</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>PM₁₀</td>
<td>24-hour</td>
<td>150 μg/m³</td>
<td>Not to be exceeded more than once per year on average over 3 years</td>
</tr>
</tbody>
</table>

(1) Final rule signed October 15, 2008. The 1978 lead standard (1.5 μg/m³ as a quarterly average) remains in effect until one year after an area is designated for the 2008 standard, except that in areas designated nonattainment for the 1978, the 1978 standard remains in effect until implementation plans to attain or maintain the 2008 standard are approved.

(2) The official level of the annual NO₂ standard is 0.053 ppm, equal to 53 ppb, which is shown here for the purpose of clearer comparison to the 1-hour standard.

(3) Final rule signed March 12, 2008. The 1997 ozone standard (0.08 ppm, annual fourth-highest daily maximum 8-hour concentration, averaged over 3 years) and related implementation rules remain in place. In 1997, EPA revoked the 1-hour ozone standard (0.12 ppm, not to be exceeded more than once per year) in all areas, although some areas have continued obligations under that standard (“anti-backsliding”). The 1-hour ozone standard is attained when the expected number of days per calendar year with maximum hourly average concentrations above 0.12 ppm is less than or equal to 1.

(4) Final rule signed June 2, 2010. The 1971 annual and 24-hour SO₂ standards were revoked in that same rulemaking. However, these standards remain in effect until one year after an area is designated for the 2010 standard, except in areas designated nonattainment for the 1971 standards, where the 1971 standards remain in effect until implementation plans to attain or maintain the 2010 standard are approved.

Prevention of Significant Deterioration
The CAA requires SIPs/TIPs to include provisions to prevent the significant deterioration (PSD) of air quality in areas designated as attainment or unclassifiable for any NAAQS. “Significant deterioration” for any pollutant is an unacceptable change in air quality measured as an incremental increase in ambient pollutant concentrations above the baseline concentration for that pollutant in an area. Thus, PSD “increments” define the maximum allowable increase in an ambient pollutant concentration above the baseline concentration existing in a particular area.

The SIPs/TIPs are required to contain emission limits and such other measures as may be necessary to prevent significant deterioration of air quality. In addition, SIPs/TIPs are required to include a preconstruction review permit program for new and modified major stationary sources.
The SIPs/TIPs must ensure that increases in actual emissions from all types of air pollution sources do not cause changes in air quality that exceed the increment for a particular pollutant. While fires managed for resource benefits generally are not subject to a preconstruction review and the issuance of a PSD permit, the emissions from such activities may affect the air quality in a PSD area. Under adverse conditions, the combined PM emissions from increased date when the first application for a PSD permit is submitted in an attainment or unclassifiable area for that pollutant. Prior to that date, increment is consumed only by construction-related increases in actual emissions from major sources. Fire activities and from other sources could possibly result in ambient concentrations that exceed the allowable PSD increments for PM. Historically, however, EPA has often regarded fires managed for resource benefits as temporary activities. In addition, the PM emissions resulting from fire activities differ from the PM emissions generated by most other sources because they are generally short-lived. That is, the burning generally is carried out infrequently at a specific location (once every five to 20 years) and the duration tends to be short (approximately one to two days).

The CAA authorizes States with approved PSD programs to exclude (with the EPA Administrator’s approval) concentrations of PM caused by “construction or other temporary related activities” when determining compliance with the PSD increments. The EPA generally supports the concept of allowing States and Tribes with approved SIPs/TIPs to exclude emissions caused by temporary managed fire activities from increment analyses, provided the exclusion does not result in permanent or long-term air quality deterioration. The decision as to whether PM emissions from fire activities should be counted against the PSD increments for PM is a decision to be made by individual States and Tribes. The EPA expects States and Tribes to consider the extent to which a particular type of prescribed burn activity is truly temporary, as opposed to those activities which can be expected to occur in a particular area with some regularity over a period of time.

Conformity
Actions undertaken, permitted or funded by Federal agencies, including DoD, must meet the requirements of the CAA, including the provisions of section 176(c), which requires that such activities “conform” to the purpose of the applicable SIP to eliminate or reduce the severity and numbers of NAAQS violations and achieve expeditious attainment of those standards. The EPA’s Conformity rules, implementing the provisions of section 176(c), only apply to Federal actions taken within a designated nonattainment or maintenance area. The Transportation Conformity rules govern transit-related activities, and all other activities are governed by the General Conformity rules. The Conformity rules require a Federal agency to demonstrate, prior to initiating a project, that an action conforms to all applicable requirements in a SIP and will not cause or contribute to NAAQS violations. The General Conformity rules provide Federal agencies with several options for demonstrating conformity. The following methods are most typically followed:

- A modeling demonstration to show that emissions from the project will not increase the frequency or severity of a NAAQS violation,
- Obtaining emission reductions that offset the new project emissions, or
- Showing that the project’s emissions are already included in, or accommodated by, the emissions inventory of an EPA-approved SIP that assures attainment or maintenance of the NAAQS.
In addition, where an action is designated as presumed to conform, Federal agencies do not have to conduct a conformity determination, unless it is demonstrated that the emissions from a specific action would in fact cause or contribute to NAAQS violations, interfere with maintenance of a NAAQS, increase the frequency or severity of an existing NAAQS violation, or delay achievement of NAAQS attainment or milestones. Federal activities occurring in Indian country will be addressed by EPA consistent with its Tribal Authority Rule (40 CFR Part 49) and the requirements of the CAA.

When addressing emissions from fire projects, a Federal agency can make a conformity demonstration on an annual basis for all burns within the airshed of a specific nonattainment or maintenance area. Alternatively, a Federal agency should make the demonstration for each individual fire project conducted at the administrative unit. In addition, EPA has finalized revisions to the General Conformity rules that add an alternative compliance method for some federal fire actions. EPA believes that it is reasonable to presume that any fire action taken in compliance with a SMP would conform to the applicable SIP. Wildland fire use and prescribed burn actions are presumed to conform when conducted in compliance with approved SMPs, and Federal agencies would not have to conduct a conformity determination for those actions. While the final revisions to the General Conformity rules do not include a presumption of conformity for wildland fire use and prescribed burn actions employing basic smoke management practices, the preamble explains that such fires may be able to meet a presumption of conformity if the required actions to establish such a presumption have been taken by an agency under 40 C.F.R. § 93.153(g) or by a State under 40 C.F.R. § 51.851(f).

**Exceptional Events Rule**

On March 22, 2007, EPA published its final rule on the Treatment of Data Influenced by Exceptional Events 72 FR 13560. The EER establishes procedures and criteria for identifying, evaluating, interpreting, and using air quality monitoring data affected by exceptional events. Section 50.1(j) of the rule defines an exceptional event as an event that:

- Affects air quality;
- Is not reasonably controllable or preventable;
- Is an event that is caused by human activity that is unlikely to recur at a particular location, or is a natural event; and
- Is determined by the EPA Administrator through the process established in the rule to be an exceptional event.

It excludes stagnation of air masses or meteorological inversions, meteorological events involving high temperatures or a lack of precipitation or air pollution relating to source noncompliance. While not specifically excluded from the definition of exceptional events, EPA anticipates that fire used to manage non-forestry resources (e.g., crops) is not likely to satisfy the statutory definition of exceptional events.

In addition to meeting the required procedures and criteria specified in the rule for qualifying as an exceptional event, the rule at 40 CFR 50.14(b)(3) requires that States must certify that they have either (1) adopted and implemented a SMP, or (2) they have ensured that the burner employed basic smoke management practices. This rule provision further specifies that if a prescribed burn managed by employing basic smoke management practices nonetheless causes...
or contributes to an exceptional event, the state must consider whether it is necessary to develop a SMP (if one is not already in place) to ensure that public health is protected.

The EER contains mitigation requirements for States, including public notification, public education, and appropriate measures to protect public health from exceedances or violations of the NAAQS caused by exceptional events, including prescribed fires. These mitigation requirements apply to all States experiencing exceptional events, and are not preconditions for EPA approval to exclude data affected by specific exceptional events. The inclusion of public notification, public education, and appropriate measures to protect public health is consistent with several of the EPA recommendations for “Smoke Management Components of Burn Plans”.

Although a general rule, the EER currently applies to and provides for the discounting or exclusion of air quality data because these NAAQS contain provisions that allow for the special handling of data affected by exceptional events. During the NAAQS reviews for the other pollutants EPA will consider, as appropriate, including provisions for the rule to apply to those pollutants. In the meantime, if exceptional events cause violations of NAAQS for pollutants other discretion in determining the impact of these events on an area’s attainment status.

Interim Air Quality Policy on Wildland and Prescribed Fires
The EPA’s policy regarding wildland and prescribed fires managed for resource benefits is that owners/managers of public, private and Indian wildlands should collaborate with State/tribal air quality managers to achieve their goals of: (1) allowing fire to function in its natural role in the wildlands, and (2) protecting public health and welfare by minimizing smoke impacts. The EPA urges air quality managers to participate in public land use planning activities which involve selecting appropriate resource management treatments, including the use of fire, and to help identify air quality criteria for fire management plans. Air quality managers are urged to help evaluate the potential impacts of alternative resource treatments and assure that air quality concerns that include visibility and regional haze concerns, are adequately addressed in the public land use planning process. They are urged to solicit information from private and Indian wildland owners/managers on plans to use fire for resource management, to encourage them to consider appropriate alternative treatments, and to assist them in evaluating the potential air quality impacts of alternatives to meet particular management objectives.

Wildland owners/managers are urged to: (1) notify air quality managers of plans to significantly increase their future use of fire for resource management, (2) consider the air quality impacts of fires and take appropriate steps to mitigate those impacts, (3) consider appropriate alternative treatments, (4) and participate in the development and implementation of State/tribal SMP’s.

The EPA will allow States/tribes flexibility in their approach to regulating fires managed for resource benefits. They are not required to change their existing fire regulations if those regulations adequately protect air quality. However, there are incentives for States/tribes to certify to EPA that they have adopted and are implementing a SMP that includes the basic components identified in this policy. The main incentive is that, as long as fires do not cause or significantly contribute to daily or annual PM$_{2.5}$ and PM$_{10}$ NAAQS violations, States and Tribes may allow participation by burners in the basic SMP to be voluntary and the SMP does not have to be adopted into the SIP. Another incentive is the commitment by EPA to use its discretion not to redesignate an area as nonattainment when fires cause or significantly contribute to PM NAAQS violations, if the State and Tribe required those fires to be conducted within a basic
SMP. Rather, if fires cause or significantly contribute violations, States and Tribes will be required to review the adequacy of the SMP, in cooperation with wildland owners/managers, and make appropriate improvements.

If States and Tribes do not certify that a basic SMP is being implemented, no special consideration will be given to PM violations attributed to fires managed for resource benefits. Rather, EPA will call for a SIP revision to incorporate a basic SMP and/or will notify the governor of the State or the tribal government that the area should be redesignated as nonattainment. The SMP adopted in response to the SIP and Tribal Implementation Plan (TIP) call must require mandatory participation for greater than de minimis fires, and must be adopted into the SIP/TIP so that it is Federally enforceable. Also, the SIP/TIP must meet all other CAA requirements applicable to nonattainment areas.

Fire data requirements for SIP’s/TIP’s are addressed in section VIII of this policy. Guidance for meeting CAA requirements to show conformity of Federal fire activities with SIP’s, to address visibility/regional haze impacts, and to address prevention of significant deterioration of air quality are addressed in section IX. The following are guiding principles for implementing this policy:

- Air quality and visibility impacts from fires managed for resource benefits should be treated equitably with other source impacts.
- Land and vegetation management practices should be promoted that are best for wildland ecosystems, yet protect public health and avoid visibility impairment.
- States/tribes should foster collaborative relationships among wildland owners/managers, air quality managers and the public to develop and implement SMP’s.
- States/tribes will be allowed the flexibility (prior to measuring violations of the PM$_{2.5}$ or is needed and how the program will be designed to prevent adverse air quality impacts. This does not preclude wildland owners/managers from including smoke management components in burn plans for fires they conduct in the absence of an applicable State/tribal program.
- All parties (wildland owners/managers, air quality managers and the public) are expected to act in good faith and will be held accountable for implementing their respective parts of fire and SMP’s.
Chapter 3  DoD Wildland Fire Policy

History of Fire Policy in the United States

Federal wildland fire management began in 1886 when the U.S. Army began patrolling the newly created National Parks. The Army's early fire responsibilities included patrolling fire suppression. In 1891, the Congress established the National Forests and Gifford Pinchot became the first Chief of the USFS. Under his direction the first national forest fire policies were developed which were dominated by a policy of fire suppression. During the early 20th Century, when fire management was dominated by fire suppression, the "AM Policy" of 1935 which stipulated that all wildfires should be controlled by 10 o’clock on the morning following their discovery.

The policy of fire suppression was debated in the southeast United States because the use of fire was culturally accepted in this area for farmland clearing and wildlife habitat improvement for hunting. Several large wildfires in this region reinforced the need to consider policies that utilized prescribed burning to reduce fuel hazards. Eventually, a change in fire policy allowed the first use of prescribed fire on federal lands, with burning taking place in Florida’s Osceola National Forest in 1943.

Research initiated in the Southeast and the Western United States began to identify landscape conditions that could be attributed to fire suppression. Changes in the structure, composition, and fuel loads were documented in forests that had historically experienced frequent, low-to-moderate-intensity fire regimes. The policy of fire suppression that had been adopted decades earlier was producing forests with high fire hazards, and these forests were being burned by high-severity wildfire. In 1962, the Leopold Report identified fire suppression as a policy that was adversely affecting wildlife habitats. The first use of prescribed fires on Federal lands in the West occurred in California in 1968 at Sequoia-Kings Canyon National Parks, followed two years later by Yosemite National Park. The NPS continued to suppress unwanted wildfires, but fire was also used to meet resource objectives.

In 1968, the first prescribed natural fire program in Sequoia-Kings Canyon National Parks was created, a result of earlier research on the effects of prescribed fire in mixed conifer forests and because of the recent change in NPS fire policy. Creation of the National Wilderness System in 1964 also advanced the philosophy of wildland fire use in remote forested areas. Some USFS wilderness areas such as the Selway-Bitterroot (Idaho and Montana) and Gila (New Mexico) began a program of prescribed natural fire in the late 1960s, but similar management philosophies were rare on other National Forest lands. By the 1970s, attitudes toward wildland fire management began to shift as scientists discovered that immediate suppression of all fires would actually increase the likelihood that a future severe wildfire. The reason is that smaller, more frequent wildfires clear out dead vegetation that could become fuel for larger, more destructive wildland fires.

In the 1980s Federal funding began to support prescribed burning. In 2001, the U.S. government implemented the National Fire Plan (NFP) and increased the budget from $108 million to $401 million for the reduction of hazardous fuels. Along with prescribed burns, mechanical methods such as chippers or other machinery are also used to remove hazardous fuels.

The current philosophy of fire management according to the U.S. Department of Agriculture’s Guidance for Implementation of Federal Wildland Fire Management Policy (Feb. 13, 2009), is that “fire, as a critical natural process, will be integrated into land and resource
management plans and activities on a landscape scale, and across agency boundaries. Response to wildfire is based on ecological, social and legal consequences of fire. The circumstance under which a fire occurs, and the likely consequences and public safety and welfare, natural and cultural resources, and values to be protected dictate the appropriate management response to fire”.

DoD and Service-Specific Policies

DoD Manual 4715.03, Natural Resources Conservation Program

It is DoD policy to implement and maintain natural resources conservation programs to ensure access to land, air, and water resources for realistic military training and testing while ensuring that the natural resources under the Secretary of Defense’s stewardship and control are managed to support and be consistent with the military mission. Responsibilities include:

Integrate natural resources conservation program requirements with mission activities. This includes preparing, maintaining, and implementing INRMPs in coordination with the U.S. Fish and Wildlife Service (USFWS), appropriate State fish and wildlife agencies, and National Oceanic and Atmospheric Administration National Marine Fisheries Service (NOAA Fisheries), when relevant, as part of overall installation planning consistent with military training or test mission requirements.

Develop policies requiring installations with significant natural resources to develop: (1) INRMPs pursuant to section 670a(a) of the Sikes Act, and (2) Procedures for coordinating plans at the military installation level.

INRMPs provide for the management of natural resources, including fish, wildlife, and plants; allow multipurpose uses of resources; and provide public access where appropriate for those uses, without any net loss in the capability of an installation to support its military mission. Wildland fire management is a required section of the plan.

- Per the 2001 Federal Wildland Fire Management Policy, DoD installations with wildland fire risk or planning to conduct prescribed burns must develop a Wildland Fire Management Plan (WFMP) and/or a Prescribed Fire Plan.
- An Emergency Response Plan should be prepared for the installation.

DoDI 6055.6 – DoD Fire and Emergency Services

DoDI 6055.6 – DoD Fire and Emergency Services establishes the DoD Wildland Fire Management Program. Authorizes the publication of Guides, Handbooks, and Manuals to provide specific information on DoD fire fighter qualifications, fire and emergency services programs, and fire incident reporting.

INRMPs provide for the management of natural resources, including fish, wildlife, and plants; allow multipurpose uses of resources; and provide public access where appropriate for those uses, without any net loss in the capability of an installation to support its military mission. Wildland fire management is a required section of the plan.

- Per the 2001 Federal Wildland Fire Management Policy, DoD installations with wildland fire risk or planning to conduct prescribed burns must develop a Wildland Fire Management Plan (WFMP) and/or a Prescribed Fire Plan.
- An Emergency Response Plan should be prepared for the installation.
The Interagency Agreement, “Provision of Temporary Support during Wildland Firefighting Operations”, (Valid FY10-FY15)

The Agreement stipulates that the DoD will provide assistance in the form of trained personnel, Modular Airborne Firefighting (MAFF) capable aircrafts, and rotary aircrafts. In addition, it states that the DoD will be reimbursed for their services by the necessary agencies and that requests for support are at the discretion of the Assistant Secretary of Defense for Homeland Defense and Americas’ Security Affairs.

In 2004, a strategic plan was developed for implementing a DoD Wildland Fire Policy. The plan notes that some recommendations of its working group were incorporated into the revision of Department of Defense Instruction DoDI 6055.6 in 2000. under Section E2.5.9, Wildland Fire Preparation and Response:

- Fire department and natural resources preparedness and response to wildland fires shall be in accordance with the Federal Wildland Fire Management Policy and Program Review of 1995 and the Interagency Fire Management Agreement (reference (l)), except as covered under DoD Directive 3025.15 (reference (m)).
- The DoD shall establish and maintain voting membership in the National Wildfire Coordinating Group to facilitate the development of policy, standards, and training with the Federal wildland agencies.
- The DoD shall establish and maintain a fire protection specialist position at the National Interagency Fire Center to represent DoD wildland fire requirements, coordinate the use of military assets through the Director of Military Support, and manage the wildland fire qualification system for the Department of Defense.

In order to implement the DoDI, the strategic plan made the following recommendations:

- Designate the Marine Corps as Executive Agent for DoD wildland fire policy. The Marine Corps would staff a billet at the National Interagency Fire Center to represent DoD on the National Wildfire Coordinating Group.
- DoD would sign an interagency agreement for fire management and become a NWCG voting member.

Branch-Specific Policies

Air Force
- AFI 32-2001 provides fire emergency services policy for fire prevention and protection, firefighting, rescue, and HazMat response capabilities.
- AFI 90-2001 details encroachment management guidance that is mandatory for the planning, operations, management, safety, and security of Air Force Bases. Wildfires are listed as an example of a severe weather encroachment.

Army
- AR 200-1, Environmental Quality: Environmental Protection and Enhancement (2007)

The Army’s environmental vision is for sustainable operations, installations, systems, and
communities enabling the Army mission. Under the strategy, the Army’s environmental mission is to sustain the environment to enable the Army mission and secure the future. In doing so, all Army organizations and activities will—

1) Foster an ethic within the Army that takes us beyond environmental compliance to sustainability.
2) Strengthen Army operational capability by reducing our environmental footprint through more sustainable practices.
3) Meet current and future training, testing and other mission requirements by sustaining land, air, and water resources.
4) Minimize impacts and total ownership costs of Army systems, materiel, facilities, and operations by integrating the principles and practices of sustainability.
5) Enhance the well being of our soldiers, civilians, families, neighbors, and communities through leadership in sustainability.
6) Use innovative technology and the principles of sustainability to meet user needs and anticipate future Army challenges.
7) The policy requires that garrison commanders, “designate an installation wildland fire program manager and approve the integrated Wildland Fire Management Plan.”

• AR 420-90 10 Sep 97, Fire and Emergency Services require the Director of Environmental Programs with the assistance from the U.S. Army Environmental Center to provide wildland fire policy and guidance to the F&ES Functional Manager.

1) Installations with unimproved grounds that present a wildfire hazard and/or installations that use prescribed burns as a land management tool will develop and implement an Integrated Wildland Fire Management Plan (IWFMP) that is compliant and integral with the Integrated Natural Resources Management Plan (INRMP), the installation’s existing fire and emergency services program plan(s) and the Integrated Cultural Resources Management Plan (ICRMP).
2) The IWFMP must consider availability and use of military personnel and equipment, specialized firefighting apparatus, and other specialized requirements.
3) The Real Property Services is responsible for wildland control and prescribed burning that is needed to reduce fuels.
4) The Environmental Program (Conservation) would fund wildland fire activities in support of ecosystem management efforts.
5) The G-3 is only responsible for firebreak establishment during range construction (MILCON).

• AR 200-3, 28 Feb 95, Natural Resources – Land, Forest and Wildlife Management Sets forth responsibilities, policies, and procedures to wisely use, scientifically manages and systematically restore renewable natural resources existing on Army lands consistent with the local military mission, national security, and current Federal laws pertaining to renewable resources and the quality of the environment.
1) Installation land and facilities will be mitigated of fire hazards and the vegetative growth controlled to the degree essential to the safety of the installation and its natural and cultural resources.

2) Prescribed burning is recognized as an effective and efficient means to reduce or prevent the accumulation of hazardous fuels, where permitted, and will be used as a recognized land management practice for natural resources management and fire protection. The decision to use prescribed burning will be based on the safety hazard involved, the hazard that will develop if burning is not accomplished, the type of natural habitat involved, the impact on the areas total ecosystem, and applicable State and local regulations and coordination with installation fire departments.

**Marine Corps**
- Marine Corps Order (MCO) 11000.11, Marine Corps Fire Protection and Emergency Services Program, (2010) has the following stated mission: “This Order provides policy to protect Marine Corps personnel and the public from loss of life, injury and illness due to fires and other emergencies as a result of installation activities, aircraft operations, disasters or terrorist incidents. This Order also encourages measures to prevent or minimize damage to Marine Corps property and the environment.” The MCO addresses wildland fire response by requiring that, “sufficient emergency response personnel are trained for their expected level of involvement in the wildland fire mission.”

**Navy**
- Executive Agent for DoD National Fire Incident Reporting System (NFIRS)
- OPNAV Instruction 1132.23G – Navy Fire and Emergency Services
- According to Chief of Naval Operations Instruction 5090.1C, Environmental Readiness Program Manual, Navy forest management “shall maintain and improve the economic and ecological value, health and diversity of forest resources and related ecosystems.”

**Wildland Fire Management Organization**

**Federal**
Wildland Fire Management (WFM) has been a responsibility of the federal government for over a century. The USFS and the DOI are the primary federal agencies receiving WFM appropriations. There are five federal regulatory agencies tasked with managing forest fire response and planning for the 676 million acres in the United States: the Department of the Interior (BLM, BIA, NPS, USFWS, and the USFS). The BLM and the USFS have the lead role in wildland fire management, but all five agencies signed the Interagency Agreement for (WFM) in 2010 that is valid through 2015.

**DoD Role**
While the DoD is not a member of the National Wildfire Coordination Group (NWCG), DoD is a signature to an interagency agreement, “Provision of Temporary Support During Wildland Firefighting Operations” in 2010, which is valid through 2015. This provision states that the Assistant Secretary of Defense has the authority to approve certain requests for firefighting assistance, generally as a last resort. The primary forms of physical DoD firefighting support are
trained personnel, and Modular Airborne Firefighting System’s air tankers and rotary support. However, there is a clause in the interagency agreement that stipulates the DoD will be reimbursed for any assistance provided.

As noted in its mission statement, in order to coordinate between the multiple Federal regulatory agencies tasked with Wildland Fire Management, the NWCG was formed, “to coordinate programs of the participating wildfire management agencies so as to avoid wasteful duplication and to provide a means of constructively working together. Its goal is to provide more effective execution of each agency’s fire management program. The group provides a formalized system to agree upon standards of training, equipment, qualifications, and other operational functions.” The NWCG is comprised of the BIA, BLM, USFWS, NPS, USFS (Fire and Aviation Management), the Federal Emergency Management Agency (U.S. Fire Administration), the National Association of State Foresters, USFS Fire Systems Research, and the Intertribal Timber Council.

There have been attempts in recent legislation to allow the DoD to play a more substantial role in wildland fire management. Most notably, former Representative Elton Gallegly (R-CA) proposed legislation several times during the last decade, which would have equipped Air National Guard units with preposition C-130 aircraft with MAFFs. However, attempts to pass this bill and similar legislation have not succeeded because the DoD opposes this plan without language requiring the USFS to utilize all industry operated air tanker assets before utilizing DoD assets. Other recent wildfire management legislation that does not involve DoD firefighting has been successful. Senator Udall (D-CO) passed legislation increasing the federal firefighting budget by $100 million in 2014. Senator Wyden (D-OR) passed S. 3261, a bill to allow the Chief of the USFS to award certain contracts for large air tankers which allowing the USFS to expedite its acquisition of at least seven next-generation large air tankers.

Federal Land Assistance, Management and Enhancement (FLAME) Act
In 2009, a highly diverse group of interests came together for the specific purpose of advocating a fix for the fire suppression funding challenge. The Partner Caucus on Fire Suppression Funding Solutions—a coalition of 114 environmental, industry, outdoor recreation, and forestry organizations led by National Association of State Foresters (NASF), The Wilderness Society and American Forests, believed that the establishment of a Federal Land Assistance, Management, and Enhancement (FLAME) fund would help to move the USFS and the DOI toward a sustainable suppression funding mechanism better suited to deal with the escalating costs of fighting emergency fires. The USFS and DOI are required to produce forecasts of annual suppression expenditures three times during each fiscal year: March, May, and July, with a September outlook for the next fiscal year required when the next fiscal year budget is not approved by Congress and the President by that date. In past years, when the cost of managing Federal wildfires exceeded the funds appropriated by Congress, monies were often shifted from non-fire programs to cover the cost. Over the past decade, the USFS fire program has gone from encompassing less than 20 percent of the Agency’s budget to nearly 50 percent. With the enactment of the FLAME Act funding is available to cover the cost of large or complex fire events or for use when the incident meets certain criteria (300 acres, threat to life and property, or when the cumulative cost of suppression exceeds appropriated amounts). Fires that do not meet the criteria are funded through the traditional agency suppression budgets. Once a declaration is made by the appropriate Secretary, the eligible wildfire suppression event can be funded through the FLAME fund.
DoD Fire and Emergency Services Certification Program (F&ESCP)
This program, managed by the Air Force Civil Engineer Center (AFCEC), is accredited by the both the International Fire Service Accreditation Congress and the National Professional Qualifications Board. As noted in the DoD F&ESCP Certification Program (6055.06-M, September 16, 2010), the purpose of the program is to enhance the training process, improve employee performance reliability, and strengthen the professionalism of all DOD Fire and Emergency Services personnel. The program effectively measures the competence of DoD Fire and Emergency Services personnel and provides a quality control element for the training process. These measurements and quality control elements shall be accomplished through the administration of standardized written or computer-based tests and performance evaluations. This comprehensive program uses the National Fire Protection Association's (NFPA) professional qualifications standards. The Administration Center shall develop standards when NFPA standards do not exist.

DoD Organizational Structures
Organizational structures pertaining to wildland fire management in the DoD include the Air Force Wildland Fire Center at Eglin Air Force Base (AFB), officially established in 2012. The Center is a part of AFCEC and assists with prescribed burns, as well as research. The center emphasizes the base’s strength and ability in providing training for firefighters. The base has one of the largest prescribed fire programs in the country and since the FAA does not regulate their airspace, they have the ability to gather Unmanned Aerial Vehicle (UAV) infrared imagery of the area controlled burn area. In addition to the Fire Center at Eglin AFB, Vandenberg Air Force Base (VAFB), on the Central California Coast has strong wildland fire management program.

The DoD Northern Command (USNORTHCOM) provides “unique military support to firefighting efforts when requested by the NIFC and approved by the secretary of defense. These diverse mission assets are prepared to respond quickly and effectively to protect lives, property, critical infrastructure, and natural resources. This capability can include but is not limited to MAFFS, military helicopters and ground forces capable of supporting firefighting efforts.” MAFFS capable aircrafts continue to prove to be one of the most valuable assets the DoD can provide in wildland firefighting efforts.

State Policy
The main responsibilities for wildland fire management fall upon the Federal government; however there is some involvement at the State level. In response to the FLAME Act, the Wildland Fire Leadership Council developed the National Cohesive Fire Management Strategy (Cohesive Strategy). “The Cohesive Strategy is a collaborative process with active involvement of all levels of government and non-governmental organizations, as well as the public, to seek national, all-lands solutions to wildland fire management issues. Many states also have their own departments that handle wildland fire protection.

National Policy
National Fire Plan
Though wildland fires play an integral role in many forest and rangeland ecosystems, decades of efforts directed at extinguishing every fire that burned on public lands have disrupted the natural
fire regimes that once existed. Moreover, as more and more communities develop and grow in areas that are adjacent to fire-prone lands in what is known as the wildland/urban interface, wildland fires pose increasing threats to people and their property.

The National Fire Plan (NFP) was developed in August 2000, following a landmark wildland fire season, with the intent of actively responding to severe wildland fires and their impacts to communities while ensuring sufficient firefighting capacity for the future. The NFP addresses five key points: Firefighting, Rehabilitation, Hazardous Fuels Reduction, Community Assistance, and Accountability.

The National Fire Plan continues to provide invaluable technical, financial, and resource guidance and support for wildland fire management across the United States. Together, the USFS and the DOI are working to successfully implement the key points outlined in the National Fire Plan by taking the following steps.

1. Assuring that necessary firefighting resources and personnel are available to respond to wildland fires that threaten lives and property
2. Conducting emergency stabilization and rehabilitation activities on landscapes and communities affected by wildland fire
3. Reducing hazardous fuels (dry brush and trees that have accumulated and increase the likelihood of unusually large fires) in the country's forests and rangelands
4. Providing assistance to communities that have been or may be threatened by wildland fire
5. Committing to the Wildland Fire Leadership Council, an interagency team created to set and maintain high standards for wildland fire management on public lands

Healthy Forests Initiative
The Healthy Forests Initiative (HFI) was launched in August 2002 by President Bush with the intent to reduce the risks severe wildfires pose to people, communities, and the environment. By protecting forests, woodlands, shrublands, and grasslands from unnaturally intensive and destructive fires, HFI helps improve the condition of our public lands, increases firefighter safety, and conserves landscape attributes valued by society.

In 2002, Arizona, Colorado, Oregon and New Mexico, each had their largest timber fire in a century. The most devastating series of wildland fires in state history swept Southern California during October 2003. These fires killed 24 people, destroyed more than 3,700 homes, and burned 750,000 acres. Alaska set a record for acres burned in 2004. And, while fire has always helped shape our landscape, today's fires are not those of the past; they are often hotter, more destructive, and more dangerous to fight.

Today's forests often have unprecedented levels of flammable materials including among other materials: underbrush, needles, and leaves. In the interior West, Ponderosa pine forests range from Arizona and New Mexico northward into Idaho. A century ago such a forest may have had 25 mature trees per acre and be easily traversed on horseback or by a horse-drawn wagon. Today that same forest may have more than 1,000 trees on the same acre creating conditions that are much too thick for the passage of a hiker. The increase in stems per acre result in weaker and disease prone, and more susceptibility to insect attack. Such forests form huge reservoirs of fuel awaiting ignition, and pose a particularly significant threat when drought is also a factor.
Wildfire requires three elements: heat, oxygen, and fuel. We can manage neither heat nor oxygen, but we can remove hazardous fuels and make them unavailable for fire's inevitable appearance. HFI helps make that happen by reducing unneeded paperwork and processes thus shortening the time between when a hazardous fuels project is identified and when it is actually implemented on the ground. HFI accomplishes its goals through administrative reforms and legislative action.

Three areas where changes have had a positive impact are: 1) Streamlined compliance with the National Environmental Policy Act, 2) Amended rules for project appeals, and 3) Improved Endangered Species Act consultation to expedite decisions.

Two key actions streamlined compliance with the National Environmental Policy Act (NEPA). For a given project, a federal land manager can comply with the NEPA in one of three ways. Complex projects or those likely to have significant impacts on the human environment require the preparation of an environmental impact statement. An action, where preliminary analysis shows there were similar projects done in the past that did not have significant impact, can be categorically excluded from further examination for NEPA purposes. When a manager is unsure of likely impacts, preparation of an environmental assessment that will result in a finding that either an environmental impact statement is needed or the project will not have a significant impact.

With direct respect to removing hazardous fuels the Healthy Forest Restoration Act (HFRA):

- Provides authority for expedited vegetation treatments on certain types of USFS and BLM lands that: (a) are at risk of wildland fire, (b) have experienced windthrow, blowdown, or ice-storm damage, (c) are currently experiencing disease or insect epidemics, or (d) are at imminent risk of such epidemics because of conditions on adjacent land.
- Provides expedited environmental analysis of HFRA projects.
- Provides administrative review before decisions are issued on proposed HFRA projects on USFS lands
- Contains requirements governing the maintenance and restoration of old-growth forest stands when the Forest Service and Bureau of Land Management carry out HFRA projects in such stands.
- Requires HFRA projects on USFS and BLM land to maximize retention of larger trees in areas other than old-growth stands, consistent with the objective of restoring fire-resilient stands and protecting ‘at-risk' communities and Federal lands
- Requires collaboration between Federal agencies and local communities, particularly when Community Wildfire Protection Plans are prepared
- Requires using at least 50 percent of the dollars allocated to HFRA projects to protect areas adjacent to communities at risk of wildland fire
- Requires performance to be monitored when agencies conduct hazardous fuel reduction projects and encourages multiparty monitoring that includes communities and other diverse stakeholders (including interested citizens and Tribes)
- Encourages courts to expedite judicial review of legal challenges to HFRA projects
• Directs that when courts consider a request for an injunction on an HFRA-authorized project, they balance the short and long-term environmental effects of undertaking the project against the effects of taking no action.

In addition HFRA:

• Encourages biomass removal from public and private lands
• Provides technical, educational, and financial assistance to improve water quality and address watershed issues on non-Federal lands.
• Authorizes large-scale silvicultural research
• Authorizes the acquisition of Healthy Forest Reserves on private land to promote recovery of threatened and endangered species, and improve biodiversity and carbon sequestration.
• Directs the establishment of monitoring and early warning systems for insect or disease outbreaks

The National Strategy
In 2009, Congress passed the Federal Land Assistance, Management, and Enhancement Act (FLAME Act), which directs the USDA and the DOI to develop a national cohesive wildland fire management strategy to comprehensively address wildland fire management across all lands in the United States. Under the direction of the intergovernmental Wildland Fire Leadership Council (WFLC), the National Cohesive Wildland Fire Management Strategy effort (Cohesive Strategy) was initiated in 2010 through a three-phased approach to planning, risk analysis, and collaboration by Federal, state, local and tribal governments and non-governmental partners and public stakeholders. This report, The National Strategy, The Final Phase in the Development of the National Cohesive Wildland Fire Management Strategy (National Strategy), and the companion National Action Plan culminate the third phase of the Cohesive Strategy effort. The National Strategy recognizes and accepts fire as a natural process necessary for the maintenance of many ecosystems, and strives to reduce conflicts between fire-prone landscapes and people. By simultaneously considering the role of fire in the landscape, the ability of humans to plan for and adapt to living with fire, and the need to be prepared to respond to fire when it occurs, the Cohesive Strategy takes a holistic approach to the future of wildland fire management.

The Wildland Fire Leadership Council (WFLC) adopted the following vision for the next century: To safely and effectively extinguish fire, when needed; use fire where allowable; manage our natural resources; and as a Nation, live with wildland fire. The primary, national goals identified as necessary to achieving the vision are: Restore and maintain landscapes: Landscapes across all jurisdictions are resilient to fire related disturbances in accordance with management objectives. Fire-adapted communities: Human populations and infrastructure can withstand a wildfire without loss of life and property. Wildfire response: All jurisdictions participate in making and implementing safe, effective, efficient risk-based wildfire management decisions. Early in the planning process, stakeholders collaboratively established the following guiding principles and core values for wildland fire management to guide fire and land management activities:

• Reducing risk to firefighters and the public is the first priority in every fire management activity.
• Sound risk management is the foundation for all management activities.
• Actively manage the land to make it more resilient to disturbance, in accordance with management objectives.
• Improve and sustain both community and individual responsibilities to prepare for, respond to, and recover from wildfire through capacity-building activities.
• Rigorous wildfire prevention programs are supported across all jurisdictions. Wildland fire, as an essential ecological process and natural change agent, may be incorporated into the planning process and wildfire response.
• Fire management decisions are based on the best available science, knowledge, and experience, and used to evaluate risk versus gain.
• Local, state, tribal, and Federal agencies support one another with wildfire response, including engagement in collaborative planning and the decision making processes that take into account all lands and recognize the interdependence and statutory responsibilities among jurisdictions.
• Where land and resource management objectives differ, prudent and safe actions must be taken through collaborative fire planning and suppression response to keep unwanted wildfires from spreading to adjacent jurisdictions.
• Safe aggressive initial attack is often the best suppression strategy to keep unwanted wildfires small and costs down.
• Fire management programs and activities are economically viable and commensurate with values to be protected, land and resource management objectives, and social and environmental quality considerations.

**International Policy**
In January of 2013, Canada signed the “Canada / United States Reciprocal Forest Fire Fighting Arrangement”. The agreement facilitates mutual assistance in wildland fire between Canada and the U.S. The Wildfire Suppression Assistance Act permits the U.S. government to request assistance from foreign fire agencies. Australia and New Zealand share a similar command structure and training and physical requirements to the U.S., making it easy for them to blend into American wildland fire organizations.
Chapter 4  Ecological Effects of Wildfire and Prescribed Fire

Introduction
Prescribed burning is a land management tool for reducing wildland fire fuels and lowering wildfire risk, and an ecosystem restoration process to landscapes that historically experienced fire but have in recent history have been managed for wildfire suppression. While the effects of prescribed burning are thought to mimic those of natural fires, several decades of wildfire suppression have altered the landscape resulting in increased fuel loading of dead and live vegetation. In most landscape in the United States, our grasslands, shrublands, and forests do not resemble the plant and animal communities that evolved with natural fire regimes or Native American burning. Because of prescribed fire operational and liability constraints, a significant proportion of prescribed burning is not conducted when the majority of the landscape burned historically. Rather it is conducted during the colder, dormant season when fire behavior is easier to manage and prior to when federal, state, and local firefighting contingency resources are deployed and positioned to respond to wildfires. This has brought into question the extent to which prescribed fire mimics effects of the historical fire-disturbance regime, and whether prescribed fire can restore fire dependent ecosystems to their pre-fire suppression structure and function.

Most plant and animal species that co-exist in landscapes with a history of frequent low- to moderate-intensity fires that burn in a patchy mosaic are resilient to wildfire effects. However, the seasonal timing of prescribed burns will influence the goals for fuel reduction and the ecological structure and function endpoints for the landscape. For example, many plant species respond quickly from fire, through increased growth from reductions in plant competition, changes in shrub and herb species and abundance, and mortality of fire sensitive species. When aboveground parts are consumed or killed by the fire, resprouting of shrubs and small trees depends on stored carbohydrate resources in the roots. These carbohydrates are typically at their highest levels during the dormant season and at their lowest annual levels following leaf growth early in the growing season. Plants will have more fire related death or delayed regrow following fires that occurs during the active growing season rather than fires that occurs after plants have gone dormant. Animal species can often avoid the flames; however, they may be more vulnerable to fire at times of reduced mobility, such as during nesting or breeding season. The influence of fire season can also be indirect, through differences in habitat created, or competitive release of some species owing to damage to or mortality of others. In some areas of the United States, most fires historically occurred when plants were dormant and animals had reproduced and dispersed. This includes the Western United States, where fires were historically most abundant during the months of the year with the driest fuels and after senescence of surface vegetation, and the forests of the Northeast, where fallen leaves of deciduous trees are the main carrier of fire. In the Southwestern United States, the main historical fire season was toward the end of the dry season (late spring/early summer), in association with the first thunderstorms, which ignited the fires but also provided moisture for plants to initiate growth. In the Southeastern United States, historical fires were once common throughout the summer and peaked in May at the transition from the dry spring period to the wet summer period, when lightning incidence was at its highest, vegetation was growing, and animals were active.

Prescribed fires may not only differ from natural fires in their timing relative to phenology (seasonal growth or life history stage) of organisms that live in the ecosystem, but may also often differ in their intensity. For example, in the Western United States, prescribed burns are
increasingly conducted in the spring, when many of the larger surface fuels are still somewhat moist from the winter and spring precipitation. Because of the higher moisture, prescribed burns at this time of year tend to consume less fuel and therefore release less heat. Thus, to evaluate the effect of burn season, both the role of differences in intensity and timing between prescribed fire and natural fire need to be considered. Although burn season research results that have controlled for fire intensity have often shown an effect of fire timing, the latest research suggests that, in many cases, variation in fire intensity exerts a stronger influence on the ecosystem than variation in fire timing.

Given the potential importance of fire intensity to fire effects, a useful means of evaluating the outcome of prescribed burn season relative to what might have been expected under a natural fire regime would be to consider the amount of fuel consumed by prescribed burns and the intensity of those burns at different times of the year, in relation to the amount of fuel that was likely consumed by and the intensity of historical fires (both lightning ignited and anthropogenic) (Table 3-1).

### Table 3. Historical and Prescribed Fire Seasons Plus Potential Fuel Consumption Differences Between Dormant- and Growing-Season Prescribed Burns

<table>
<thead>
<tr>
<th>Region</th>
<th>Main historical fire season</th>
<th>Main prescribed fire season</th>
<th>Typical potential fuel consumption difference between dormant and growing season burns</th>
</tr>
</thead>
<tbody>
<tr>
<td>Western forests</td>
<td>Dormant</td>
<td>Dormant/Growing</td>
<td>Very high</td>
</tr>
<tr>
<td>Southwestern forests</td>
<td>Growing/Dormant*</td>
<td>Dormant</td>
<td>High</td>
</tr>
<tr>
<td>Central grasslands</td>
<td>Dormant/Growing</td>
<td>Dormant</td>
<td>Low</td>
</tr>
<tr>
<td>Southeastern pine forests</td>
<td>Growing</td>
<td>Dormant/Growing</td>
<td>Moderate</td>
</tr>
<tr>
<td>Eastern hardwood forests</td>
<td>Dormant</td>
<td>Dormant/Growing</td>
<td>Low to moderate</td>
</tr>
<tr>
<td>Alaska</td>
<td>Summer Dry Season</td>
<td>Dormant/Growing</td>
<td>Moderate</td>
</tr>
<tr>
<td>Hawaii</td>
<td>Summer Dry Season</td>
<td>Dormant/Growing</td>
<td>High</td>
</tr>
</tbody>
</table>

In forest ecosystems of the Western United States, prescribed burns are often conducted in areas with very heavy fuel loads resulting from decades of fire exclusion. Although spring prescribed burns typically consume less fuel than those that are ignited in other seasons, prescribed burns in any season can conceivably consume more fuel than historical burns would have under a natural fire regime. Several recent papers have shown that late summer or fall prescribed burns often lead to higher tree mortality and set back herbaceous understory vegetation more than spring burns, even though late summer and early fall fire was the historical norm. The difference in fuel consumption and fire intensity between the prescribed burn seasons apparently overwhelmed the effect of phenology of the organisms. Many coniferous forest ecosystems of the Southwest also typically have unnaturally high fuel loads, but times of the year with lower fuel moisture and higher consumption differs, owing to monsoon rains in the summer. Until fuels are reduced to historical levels, any prescribed burn under higher fuel moisture conditions may have effects more similar to historical burns, because the amount of fuel consumed, and fire intensity are closer to that noted for historical burns. A different situation exists in chaparral shrub lands of the West, where prescribed burns are usually conducted under
more benign conditions in the winter or spring, and are therefore often less intense and consume less fuel than historical fires. With organisms in these shrub ecosystems presumably adapted to high-severity stand-replacing fire, reduced intensity over what might have been experienced historically also means that the outcomes sometimes have not met objectives. For example, several authors have noted that shrubs and herbs requiring intense heat to stimulate germination emerge in lesser numbers following spring burns.

Grasslands are composed of fine fuels that dry readily and are likely to be nearly completely consumed with prescribed fire in any season. Grass thatch also breaks down relatively rapidly, so there is not a large buildup of fuels relative to historical levels. Because the difference in total fuel consumption and fire intensity between burn seasons is relatively low, the effect of timing of the fire is generally more evident in grasslands than in other vegetation types. Numerous examples of alterations to grassland plant communities with prescribed burning in different seasons are found in the literature.

In the Southeastern United States, prescribed burns are typically conducted in late winter/early spring when many plants and other organisms are dormant, and in the late spring/early summer, during the historical peak period of lightning-ignited fire. Burning during the dormant season became standard practice in order to reduce direct impacts to nesting birds and other wildlife species. However, in many cases, the prescribed burns during the late spring/early summer growing season have been shown to better meet longer term management objectives for pine forests by reducing competition from competing hardwoods. Furthermore, concerns about negative effects to wildlife from late spring/early summer growing-season burns have generally not been supported by research.

In eastern forests, burn intensity does not generally vary predictably with season, with fuel consumption influenced more by time since previous rainfall and year-to-year climatic variability. Differences in fuel consumption among burning seasons is often much less in eastern forests (particularly deciduous forests) than in western forests, where because of a long history of fire exclusion and a slower decomposition rate, surface fuel loads are typically much higher. Therefore, differences among burn seasons related to fire intensity are expected to be considerably less in eastern forests than in western forests.

Many species show strong resilience to fire in either season, with the majority of studies reporting relatively minor differences. Differences in the timing of a single or even several applications of prescribed fire do not appear likely to substantially change the plant or animal community. In most ecosystems studied, the change associated with either burning or not burning is much greater than differences in the outcome with burning in different seasons. This should not be interpreted as burning season not mattering. Burning season has been shown to affect community composition, particularly with repeated application of fire in the same time of year. Many authors have therefore stressed the importance of incorporating variability in prescribed fire timing (along with variability in other aspects of the fire regime) into long-term burn management plans. Because response to burning season differs a great deal among species, a heterogeneous fire regime is likely to maximize biodiversity.

**Wildland Fire in Ecosystems: Effects on Fire on Flora**

An understanding of the effects of fire on plant communities can assist land managers with ecosystem and fire management planning and in their efforts to inform others about the role of fire. Fire is an ecosystem management practice for the management of plant communities. The geographic area covered in the following publication includes Canada, the United States, and
adjoining Caribbean areas. The contents focus on principles, generalities, and broad scale fire effects on flora rather than on detailed site-specific responses. Vegetative response to individual fires can vary substantially depending on a host of factors involving characteristics of the fire, existing vegetation, site conditions, and post-fire weather. The following reference volume and web link provides a summary of fire effects that was meaningful over broad areas even in view of highly variable responses.


Web Link: [http://www.fs.fed.us/rm/pubs/rmrs_gtr042_2.pdf](http://www.fs.fed.us/rm/pubs/rmrs_gtr042_2.pdf)

**Wildland Fire in Ecosystems: Effects of Fire on Fauna**
The effects of fire on animals is based on the premises that fire regimes strongly influence animal response to fire and that fire affects animals at every level of ecosystem organization. The publication cited below describes the fundamental concepts of fire regimes and their effects on vegetation structure, and the role of fire in several North American vegetation communities prior to settlement by European Americans. Because the vegetation provides habitat for fauna, the publication provides background for understanding examples cited in the publication. Additional information describes animal response to fire at four levels of organization: individual, population, community, and landscape. Fire effects on wildlife foods, and the management implications of fire-fauna relationships, particularly in light of past fire exclusion, and identifies information gaps and research needs. The following reference volume and web link provides a summary of fire effects on fauna.


Web Link: [http://www.fs.fed.us/rm/pubs/rmrs_gtr042_1.pdf](http://www.fs.fed.us/rm/pubs/rmrs_gtr042_1.pdf)

**Wildland Fire in Ecosystems: Wildland Fire Effects on Air**
First published in 1985, the wildfire effects on air guide was intended to provide national guidance for the planning and managing of smoke from prescribed fires to achieve air quality requirements through better smoke management practices. The guide has been widely distributed within the fire community and air quality regulatory agencies, and to private and Tribal land managers, providing a single comprehensive source of information on fire and air quality issues. Much has changed since 1985 in prescribed burning practices, smoke management programs, and air quality regulatory requirements. These changes are reflected in the 2001 edition of the guide referenced below, which includes expanded sections on fire and emissions processes, smoke impacts on health, welfare, safety, and nuisance; regulations for smoke management; and the fundamentals of responsible smoke management. These fundamentals include: fire planning, use of smoke management meteorology, techniques to reduce emissions, smoke dispersion prediction systems, air quality monitoring methods, and program assessment. The most significant change in the guide is the expanded and updated section on techniques to reduce
emissions and impacts. The 2001 guide has a great deal more information on the latest developments in national air quality regulations that affect fire programs including the regional haze and visibility protection programs, Clean Air Act’s conformity requirements, EPA’s Interim Air Quality Policy on Wildland and Prescribed Fires, and NEPA planning guidance. The following reference volume and web link provides a summary of fire effects air quality.


Web Link: http://www.fs.fed.us/rm/pubs/rmrs_gtr042_5.pdf

Wildland Fire in Ecosystems: Effects of Fire on Soils and Water
Information on the effects of fire on soils and water is provided to assist land managers with ecosystem restoration and fire management planning responsibilities in their efforts to inform others about the impacts of fire on these ecosystem resources. The geographic coverage is North America, but the principles and effects can be applied to any ecosystem in which fire is a major disturbance process. The publication is divided into three major parts: a description of the nature of the soil resource, its importance, characteristics and the responses of soils to fire, and the relationship of these features to ecosystem functioning and sustainability; the basic hydrologic processes that are affected by fire, including the hydrologic cycle, water quality, and aquatic biology; and the effects of fire on the hydrology and nutrient cycling of wetland ecosystems along with management concerns, the use of models to describe heat transfer throughout the ecosystem and erosional response models, watershed rehabilitation and implementation of the Federal Burned Area Emergency Rehabilitation (BAER) program. The following reference volume and web link provides a summary of fire effects soil and water.


Regional Overview of Ecological Effects of Fire
Because of differences in historical and prescribed fire regime (timing, intensity, vegetation type, spatial scale), fire management from studies conducted in one area or vegetation type may not apply to others. In the following regional summaries, broad regions of the continental United States are adapted roughly from groupings of eco-regional divisions outlined by Bailey’s ecoregions, which are based on both climatic zones and potential natural vegetation. Regions consider differences in vegetation with the strongest influence on fuel loading and the fire regime. The Western region is everything west of the central grasslands, and consists of both a humid temperate division along the Pacific Coast as well as the non-grassland portions of the dry interior division. The Central region is composed of both dry temperate to subtropical steppe (shortgrass prairie) and humid temperate prairie (tallgrass). The Eastern region consists of mainly a warm continental and a hot continental division (boreal and deciduous forest, respectively), plus a subtropical division, dominated by pine and mixed pine-oak forests, and a savanna division in south Florida. Alaska and Hawaii are covered with historical and seasonal differences of prescribed fire for these two areas. (Adapted from: Boucher, 2003; Knapp, Estes, Skinner, 2009; Smith, Tunison, 1992; Kasischke, et al., 2010.)

Western Region

Humid Temperate Historical Fire Regime
Prior to fire exclusion, the historical fire-return interval averaged across all forest types in Washington was 71 years, whereas the fire-return interval in Oregon forests was estimated to be 42 years. A great deal of variability existed among forest types, with mesic cedar/spruce/hemlock forests burning in mixed to stand replacing fire every 400 to 500+ years, whereas drier ponderosa pine forests burned in low- to mixed-severity fires every 15 years. Many forested regions in California burned even more frequently in low- to mixed-severity fires at approximately 8- to 30-year intervals, depending on forest type. In general, the shorter the interval, the less fuel accumulated between fires, and the lower severity the average fire. This gradient in fire regime from north to south is a function of precipitation and temperature patterns. Chaparral shrublands found in central and southern California typically burned in high-severity stand replacing events at moderate interval. Owing to the lack of historical records, actual number of years between fires in chaparral shrub ecosystems is somewhat uncertain, but estimated to have typically ranged from 50 to 100 years. The wildfire season generally lasts from June until September in the north, with this period expanding as one moves south. Although wildfires in southern California are most common from May through November, they can occur in nearly every month of the year when conditions are dry. In forested regions throughout the Humid Temperate zone, growth ring records from fire-scarred trees indicate that the majority of acres historically burned late in the growing season or after trees had ceased growth for the year and were dormant. Late growing season would correspond approximately to late July through August, whereas dormancy typically occurs by September in most years. Early to mid growing-season fires (approximately May through July) also occurred, but mainly in unusually dry years. It is believed that Native Americans made use of spring burns to manage vegetation, but such fires were likely less extensive than later lightning-ignited fires under drier conditions.
Humid Temperate Prescribed Fire Regime
Prescribed burns are typically conducted in two seasons either before or after the main period of summer drought. Early season burns are ignited after the cessation of winter and spring precipitation or snowmelt, as soon as the fuels have dried enough to burn (typically mid April until about July 1), until conditions become too dry and wildfire season begins in the summer. At lower elevations below the snowline, prescribed burning can sometimes also be successfully done during dry periods within the winter and early spring rainy season. In black oak (Quercus kelloggii) dominated forests below the snowline, periods during tree dormancy when the leafless canopy allows sunlight to dry the leaf litter on the forest floor are often ideal for burning. Spring or early summer prescribed burning can be problematic because surface fuels are drying and temperatures warming. Thus, fires may continue to creep and smolder, sometimes for months. The second prescribed fire season typically occurs in the fall, after temperatures have cooled and often after the fuels have moistened with the first rains. In many areas of the West, the fall prescribed fire season coincides with inversions and poor air quality. The spring and early summer prescribed burning period is generally earlier than the main historical fire season, and the fall prescribed burning period is often later than the historical fire season. Few prescribed burns are conducted in mid to late summer, the main historical fire season, because of fire control concerns that can result from the heavy fuels that characterize many contemporary forest landscapes. In addition, the summer wildfire season uses a significant proportion of available firefighting resources, meaning that fire crews are often unavailable for prescribed burns at this time of year.

The range of ecological conditions under which prescribed burns occur is quite broad. In the coniferous forest zone, early spring prescribed burns (prior to May) usually happen prior to active tree and plant growth as well as other significant biological activity. Burns conducted in late spring (May to June) occur during the main period of seasonal growth of vegetation and significant wildlife activity such as bird nesting. Late summer and fall prescribed burns (September to October) typically occur during the dormant season after biological activity has slowed or ceased for the year. Because of the nearly precipitation-free summers, soils are typically drier in the late summer and early fall than in the spring or early summer. However, this is not always the case, and much depends upon rainfall patterns for that year in relation to the prescribed burning period. Concerns about prescribed burning conducted outside of the historical season include (1) less-than-desired fuel consumption owing to high fuel moisture levels, and (2) potentially detrimental impacts to organisms if burns coincide with periods of peak growth/activity.

Dry Interior Historical Fire Regime
In the western and northern areas of this zone, such as the Great Basin, the lightning fire season generally starts in June and runs through September or October. The main fire season is somewhat earlier in areas influenced by the monsoon, with area burned historically peaking in May and June. These fires are typically ignited by dry high-based thunderstorms that are common this time of year. As the summer progresses, thunderstorms begin to be accompanied by more rainfall, limiting fire spread. Although the fall may be dry enough for fire as well, thunderstorms are less common and thus sources of ignition are fewer. Native Americans contributed to the historical fire regime, and may have burned at times that did not necessarily coincide with peak lightning activity.

The peak of the historical fire season in parts of the Dry Interior zone not strongly affected
by the summer monsoon was similar to the Humid Temperate zone to the west, with most of the fire occurring when most plants were past the peak of growth or dormant, and animals presumably less active. The peak of the historical fire season in areas strongly influenced by the summer monsoon was approximately the time at which trees begin growth for the year. Cool-season grasses in the understory are often actively growing at this time. May and June fires also coincide with bird nesting.

Dry Interior Prescribed Fire Regime
Prescribed burns in juniper or pinyon-juniper woodlands of Nevada, as well as forested areas farther east and north, are generally conducted either in the spring or fall. More days of weather and fuel conditions within the usual prescription conditions occur during the spring. Cool conditions in either season moderate fire behavior and reduce crown scorching. However, such prescribed burns typically occur before or well after the typical historical fire season. In areas influenced by the monsoon in the Southwest, the majority of prescribed burns are conducted in the cool conditions of fall (mid-September into December or even later in years without early snow). Fuels at this time of year are usually fairly dry, but moister conditions may also occur in some years. Prescribed burns can also be ignited when the weather is cool in early spring. Little prescribed burning is done during the peak historical fire season (late spring to early summer), because windier and drier weather make fire more difficult to control, especially when fuel loading is high.

Fall is recommended for the initial prescribed burn after a long period of fire exclusion and fuel accumulation. Once fuels have been reduced to near historical levels, the prescribed burning window of opportunity is a bit broader, with good results even when conditions are warmer, such as in the late spring, early fall, or even the summer. Summer prescribed burns are possible depending on weather conditions, but ignition is generally limited by the availability of firecrews, which are often on assignment this time of year.

Both early spring and fall prescribed burns occur during the period of plant dormancy for many species. One of the main issues with prescribed burns during these times is that because of the cool conditions, they are often milder and therefore result in less ecological change than historical fires.

Ecological Effects of Burning Season in Forested Ecosystem

Trees
Differential tree mortality among burning seasons has been attributed to both phenology (seasonal growth stage) and variation in fire intensity. A study of ponderosa pine in southwestern Colorado reported mortality of trees in different crown scorch categories after spring (June) and summer (August) prescribed fires conducted during the active growth period, and fall prescribed fires (October) conducted when the trees were already dormant. By comparing trees that experienced similar fire intensity, the effect of phenology could be isolated. Trees with >90 percent of crown scorched were more likely to die after the spring (54 percent) and summer fires (42 percent) than after the fall fires (13 percent). Mortality in trees with crown scorch less than 90 percent was quite low in all seasons. For example, mortality of trees with 67 to 89 percent of the crown scorched was 12, 11, and 0 percent, for spring, summer, and fall burns, respectively. When crown scorch was 66 percent or less, the differences in mortality between seasons was not statistically significant. Because the goal of operational prescribed burns is generally to avoid high levels of scorching of larger trees, any difference in mortality between burning seasons may
end up not being biologically meaningful. Indeed, ponderosa pines greater than 12 in diameter, which managers are most likely to want to retain, had equally low (< 8 percent) mortality rates after fires in all three seasons. Differential mortality among seasons was only witnessed for small size classes. Younger trees of shorter stature are more likely to have high levels of crown scorch, and as the objective of prescribed burns is often to thin the forest of younger or suppressed trees, greater mortality of this size class with early or mid-season burns may be advantageous.

A study of interior Douglas fir noted that overall mortality was nearly the same for spring and fall prescribed burns (53 percent vs. 47 percent, respectively), although the spring burns were more intense. Fire damage measures (proportion of cambium killed and crown scorch) were predicted to contribute much more strongly to mortality than the burning season.

Several recent prescribed fire studies all reported at least a tendency for higher tree mortality after fall burns. Most of the sites studied had not burned in some time, and common to all was greater fuel consumption in the fall. Although the spring and early summer burns were conducted during the active growth phase when loss of living material is expected to be more detrimental, it appears that when the difference in fuel consumption between spring and fall burns is substantial (such as after a period of fire exclusion and fuel buildup), the effect of fire intensity may overwhelm the effect of phenology.

Higher mortality after fall burns (October) than spring burns (late June) has been reported in mixed-conifer forests of Crater Lake National Park without a recent history of fire. Fall burns were conducted when fuels were drier, with burn coverage averaging 76 percent and fuel consumption averaging 52 percent, as compared to 37 percent and 18 percent, respectively, for the spring burns. The study concluded that the higher mortality was best explained by the greater intensity of the fall burns, which may have overwhelmed seasonal vulnerabilities. Interestingly, an earlier less controlled study of prescribed burning season nearby showed the opposite results. Mortality of large ponderosa pine after prescribed fires in June, July, and September was reported to be 38 percent, 32 percent, and 12 percent, respectively. Although the effect of burning season was significant, the relative importance of variables showed fire severity measures (scorch height and ground char) explained more of the variation in mortality than burning season. The prescribed fires in this study were conducted over a period of two decades, with all but one of the late- season burns occurring in the 1970s and most of the early- season burns occurring in the 1980s. Therefore, mortality results could have been confounded with longer-term climatic patterns. It is also possible that fuel consumption differences among seasons were not as great.

In a large replicated study of burning season in mixed-conifer forests of the Southern Sierra Nevada, no significant differences in tree mortality were found between early season (June) and late season (September to October) prescribed burns. The June burns were conducted shortly after trees had initiated growth (bud break), whereas the September/October burns were conducted after visual evidence suggested growth had ceased for the year. The historical fire-return interval in the study area was approximately 27 years, but as a consequence of fire exclusion, hadn't burned for over 125 years, and fuel loading was therefore very high. Because of higher moisture levels, the June burns consumed less of the available fuel; however, total amount of fuel available and consumed was likely far above historical levels for burns in both seasons. There was a tendency for higher mortality in the small tree size classes with the late-season burns (greater fuel consumption) than the early-season burns (less fuel consumption), although the differences were not statistically significant. Despite variation in fuel consumption, average crown scorch height and bole char height did not differ between seasons. For each tree size
category, differences in mortality appeared to be largely a result of local variation in fire intensity, with little effect of fire season.

In a study conducted in eastern Oregon, ponderosa pine trees experienced less mortality after spring (June) burns (11 percent) than after fall (October) burns (32 percent). The amount of fuel consumed was not quantified. However, the fuel at the base of the trees burned more completely, and a higher proportion of trees experienced crown scorch with the fall burns than spring burns. The apparently greater fire intensity with fall burns appeared to have a stronger impact than effects of phenology, which would have been expected to cause greater mortality with the spring burns. A tree mortality model developed using data from this study and burns in northern California did not find burn season to be a predictor variable, with approximately the same level of delayed mortality expected for a given level of fire damage, regardless of the burn timing. The studies have found that physiological performance (net photosynthetic rate, stomatal conductance, and xylem water potential) and wood growth of ponderosa pine did not differ between trees in units burned in the spring or the fall. As is often the case with prescribed burns in the Western United States, the spring burns consumed less fuel than the fall burns.

Comparing the outcome of a spring wildfire (May), a summer wildfire (late June), and a fall prescribed fire (September) in Arizona it was reported that mortality in all seasons was greatest on trees most heavily damaged by fire. Total tree mortality averaged 32.4 percent, 13.9 percent, and 18.0 percent in spring, summer, and fall, respectively. Although the spring wildfire occurred prior to bud break, conditions were dry and crown scorch was also greater than for the other fires (55.3 percent). The summer fire burned during the active growth phase of trees but scorched the least canopy of the three fires (27.3 percent). Crown scorch for the fall prescribed fire was intermediate, as was the mortality. Total crown damage and bole char explained much more of the variation in tree mortality than season of the fire.

Secondary mortality in many western conifer species is often attributed to bark beetles. Bark beetle attack probability is usually correlated to degree of tree injury, which may differ among burning seasons as a result of differences in fire intensity. The timing of fire may also influence bark beetle populations directly. Bark beetles are known to be attracted to volatiles released from tissues injured by heat. Bark beetle activity had likely already ceased for the season by the time of the fall prescribed burning period. By the time bark beetles become active again the following spring, volatiles produced by injured tissue may have already subsided. Early-season burns, on the other hand, typically coincide with increasing bark beetle flight activity and there is some concern that this could lead to a buildup of bark beetle numbers.

One study did not find any difference in bark beetle attack probability between June and September/October prescribed burns on pine species, but did note an increase in bark beetle attacks on smaller diameter firs with the earlier burns. Because of the overabundance of small firs in many mixed-conifer forests following logging and fire exclusion, favoring pines over firs is a management goal of many prescribed fire projects. Thus, if causing greater mortality of small firs relative to small pines is an objective, early-season burns may prove advantageous.

In a survey of bark beetle populations following fires in ponderosa pine forests in Arizona, differences in attack probabilities were found among seasons, with a May wildfire leading to greater probability of attack (41 percent), compared to a June wildfire (19 percent), or a September prescribed burn (11 percent). The May wildfire also was the most intense, causing the most crown scorch, and overall attack probability was associated with degree of fire-caused damage. However, attack probability was somewhat greater for the June fire than the September prescribed burn although crown scorch was less. This suggests that the timing of fire relative to
periods of bark beetle activity may play a role. Still, studies to date all point to degree of crown damage being the overriding contributing factor to bark beetle attack, regardless of season of burn.

**Understory Vegetation**

No important differences in the cover of understory vegetation between areas treated with either early- or late-season broadcast burning treatments were found in Montana. In southwestern ponderosa pine systems, fall prescribed burns often lead to a greater abundance of understory vegetation such as cool-season perennial grasses. Some have suggested that burning during the natural fire season (May through early July) might lead to an even greater increase in grass production, because grasses that are growing and green are less readily consumed by such fires. In addition, seed heads are possibly less likely to be consumed with late spring/early summer burns than with fall burns. Certain species that grow later in the year, such as the warm-season grass mountain muhly (*Muhlenbergia montana*) appear to be negatively affected by repeated fall burns.

One study reported much higher shrub mortality after early fall burns (high fuel consumption), than after spring burns (low fuel consumption). Overall, the greater the consumption of fuel, the greater mortality of shrubs, regardless of burning season. Variability in mortality was also seen among sites within a burn season treatment, with lesser mortality at sites that contained the least fuel, and therefore experienced lower total heat flux upon burning. It was hypothesized that shrub phenology at the time of fire may have also played a role, albeit a lesser one. At one site, mortality of black oak was 31 percent following early spring burns conducted prior to bud break and initiation of growth, and 55 percent following late spring burns conducted during the period of rapid growth following bud break, although fuel consumption with these two burn treatments was nearly identical (77 percent for early spring vs. 79 percent for late spring burns, respectively). Differences in plant carbohydrate storage among seasons may have been one mechanism for this observed difference. However, variation in mortality between seasons could also be attributed to factors other than phenology. For example, soil moisture at the time of early spring burns was nearly double that of the late spring burns, which may have also reduced the heat flux into the soil.

For fire-following species, differential response among burning seasons is also sometimes evident in the seed germination phase. Enough heat is required to scarify the seed, but not so much that the seeds are killed. Depth of lethal heating, which is affected by both the amount of fuel consumed and the moisture content of the soil, may determine how many seeds are available to germinate. One study found that wet heat, simulating a heat pulse under moist soil conditions, was more effective for scarifying seeds of shrubs than dry heat, simulating fire in the fall when soils were dry. The dry heat actually resulted in higher seed mortality. In another study in an area with low fuel loading (10 years after a fire), it was found that fall burns resulted in germination of long-sepaled globe mallow (*Iliamna longisepala*), while spring burns did not. It is possible that the soil heating generated by spring burns was, in this case, insufficient.

It has been reported that understory vegetation in a mixed-conifer forest in the Sierra Nevada of California was resilient to prescribed fire conducted in either late spring/early summer (June) when plants were in the midst of active growth, or in the fall (September/October) when most plants were nearly to fully dormant. Several years after treatment, total plant cover and species richness in the spring/early summer- and fall-burned plots did not differ significantly from each other or from an unburned control. However, there was a difference in the rate of vegetation recovery between burn season treatments. In the season immediately following the burns, cover
was initially reduced relative to the control in the fall burn treatment, but not the spring/early summer burn treatment. Furthermore, certain species, particularly ones most common under the forest canopy where surface fuel loading is expected to be the highest, such as white veined wintergreen (*Pyrola picta*), were reduced in frequency by late-season burns but not early-season burns. Because the late-season burns were conducted when the fuels and soils were drier, the greater fuel consumption and heat penetration into the soil may have killed more of the underground structures than the late spring/early summer burns. Late-season burns also covered a larger proportion of the forest floor, leaving fewer undisturbed patches. Vegetation change was associated with variation in fire severity, and the authors concluded that effects on vegetation suggested a greater dependency on amount of fuel consumed and fire intensity than on plant phenology.

In a longer term study of understory vegetation response to burning season in a ponderosa pine forest of eastern Oregon, it was reported that there were no significant difference in native perennial forb cover 5 years after early-season (June) and late-season (September/October) prescribed burns. The June burns occurred during the active growth phase of many understory plant species, whereas the September/October burns occurred when most species were dormant. Few effects were found of either spring (May) or fall (October) prescribed burns on mature individuals of two native herbaceous perennial plant species. Exotic species, which often thrive with disturbance, were more frequent following the higher severity (as evidenced by greater bole char and higher tree mortality) late-season burning treatments. Exotic species were also concentrated in patches within burns where local severity was the highest. This study is another example of plants responding more strongly to fire intensity and degree of environmental change than the plant phenology at the time of the fire. A similar trend, with greater numbers of exotic species in plots that burned at higher severity in the fall was noted in another study.

By timing prescribed burns for when plants are most vulnerable, fire can be used to control vegetation or target certain species. A Gambel oak (*Quercus gambelii*) understory of a ponderosa pine forest resprouted vigorously following single prescribed burns conducted in the spring (June), summer (August), or fall (October). The spring burns occurred 3 to 4 weeks after bud break and leaf emergence, the summer burns occurred while vegetation was still actively growing, and the fall burns occurred after plants had gone dormant and leaves had fallen. A second summer fire 2 years later significantly reduced the frequency of resprouting stems, whereas spring and fall fires did not. However, differences in sprout number among treatments were relatively small. The effect was attributed to reduced root carbohydrate reserves in the summer following a second flush of growth, which suppressed the energy available for resprouting following fire.

Several studies have been conducted to investigate whether burning in different seasons might be used to control bear clover (*Chamaebatia foliolosa*), a vigorous highly flammable shrub with rhizomatous roots that can compete strongly with conifer seedlings. Fires in May (prior to the growing season) and October (after the growing season) stimulated growth of *C. foliolosa* relative to the control, whereas prescribed burn in July (mid growing season) resulted in growth comparable to the control after 2 years. A single prescribed burn in any season (May through October) was ineffective for reducing the cover of this plant, but a second treatment during the growing season, where all tops were removed, simulating the effect of a follow-up prescribed burn, did slow regrowth. Studies on chamise (*Adenostoma fasciculatum*) also have shown top removal during the growing season to slow regrowth compared to top removal during the dormant season. Carbohydrate reserves at the time of treatment may play a role in regrowth.
Burning in different seasons has been attempted as a means of controlling shrubs with seed banks stimulated to germinate by fire (such as *Ceanothus* sp. or Manzanita (*Arctostaphylos* sp.)). Hotter burns that consumed the entire duff layer under dry soil conditions in the fall killed more seeds by pushing critical temperatures deeper into the soil than burns in the spring that consumed less fuel. However, so many seeds were found in the soil that sufficient seeds remained to regenerate a vigorous shrub layer no matter the burn season.

**Soils**

Soil heating during the process of combustion can cause biological and physical changes such as root mortality or increased water repellency. The magnitude of change depends at least partially on three factors that may differ with burning season: amount of fuel consumed, duration of combustion (residence time), and soil moisture at the time of burning.

Fuel moisture largely dictates how much organic material is consumed, and therefore the residence time of combustion. Likewise, the extent to which the heat penetrates into the soil is determined by soil moisture. Water has a high specific heat and therefore substantial energy is required to drive off the moisture before the temperature of that soil will exceed 212 °F, the boiling point of water. Because of this, moist soils are much less likely to heat up than dry soils. Soils are largely protected from excessive heating, even under high fuel loading conditions if they contain sufficient moisture. Plant roots are killed starting at soil temperatures between 118 and 129 °F, microbes are killed between 122 and 250 °F, and buried seeds have been reported to die at temperatures between 158 and 194 °F. The temperature at 1-inch depth in the soil below a laboratory burn that consumed a very high load of masticated wood chips (69.9 tons/ac) reached a maximum of 595 °F in dry soils and only 241 °F in moist soils.

Effects on soil physical properties and soil biota largely mirror the intensity and severity of the fire. In a study in mixed-conifer forest of the Southern Sierra, California, soil temperature, moisture and pH, plus mineral soil carbon levels and microbial activity following late spring/early summer (June) prescribed burns were reported to be generally intermediate between fall (September/October) prescribed burns and unburned controls. A similar result was reported from ponderosa pine forests in eastern Oregon, with October prescribed burns decreasing soil carbon and nitrogen, whereas June burns had little impact. The magnitude of effects was in line with the greater fuel consumption and intensity of the late-season burns. In the same study plots October prescribed burns significantly reduced fine root biomass to a depth of 4 in and depressed the number of ectomycorrhizal species, relative to units burned in June. Fine root biomass and ectomycorrhizal species richness following the June burns did not differ from the unburned control. Soil moisture values were not provided, but given the rainfall patterns, it was likely considerably higher at the time of the June burns. Other studies corroborate findings of a greater loss in soil microbes following burns when soils were dry than when soils were moist, corresponding to the amount of soil heating. One study reported a reduction in root disease causing fungi following fall burns but not spring burns; however, soil moisture and fuel consumption were not reported.

In addition to changes within the soil, other variables that frequently differ with burning season may influence soils indirectly through erosion. Such variables include the percentage of the soil surface burned, and the depth of burn (how much of the duff layer is removed). Burns when soils and the fuels in contact with those soils are moist tend to be patchier. These unburned patches may act as refugia from which fire-sensitive organisms such as soil ectomycorrhizae can recolonize burned areas, or act as barriers to soil erosion. A study reported an exponential...
increase in the amount of erosion once the percentage of the forest floor burned exceeded 60 to 70 percent, presumably because as the percentage increases, burned patches coalesce into larger and larger areas, leaving fewer unburned patches at a scale necessary to capture sediment. Under the high fuel loading and high fuel continuity in landscapes common today, many prescribed burns cover a greater percentage of the landscape than this, particularly ones conducted when fuel conditions are dry.

Whether changes to soils as a result of fire are beneficial or detrimental will depend on the burn objectives. Burns at times of the year when soils (and fuels) are still moist may limit the amount of soil heating and leave a greater amount of duff unconsumed, which could reduce the threat of erosion. However, burns at drier times of the year may be necessary if bare mineral soil exposure is desired to produce an adequate seedbed for species that don't germinate well through a layer of organic material, or if the objective is to heat scarify deeply buried seeds of fire-following species.

Wildlife
Wildlife populations may be affected by fire either directly by heat and flames, or indirectly through modification of the habitat. In environments where fire was historically common, there is little evidence that fires falling within the range of historical intensities cause much direct mortality of wildlife. Most animals have presumably developed behavioral adaptations for escaping fire that enable population persistence, and many, in fact, benefit from the habitat modifications resulting from fire. In the Western United States, most species have already successfully produced young by peak fire season in late summer to early fall. There has been some concern that prescribed fires ignited outside of the season when historical fires were common might do harm to wildlife populations, especially for species with poor dispersal or species that raise offspring in locations that are most likely to burn. For example, small mammal young may be more vulnerable to early-season fire, because of lack of mobility prior to maturity. Many of these species have high reproductive rates, however, and recovery is likely rapid.

Ground-nesting birds could be killed prior to fledging and forest floor arthropods in the egg or larval stages may be more vulnerable to loss. Amphibians are also likely to be more active with the moister conditions under which prescribed fires are typically conducted. On the other hand, amphibians tend to live in the moister microsites that are least likely to burn in prescribed fires, especially in the early season. In the Southwestern United States, the peak historical fire activity occurred earlier, during the spring and early summer, when effects on wildlife might be more severe. In this case, the impact of prescribed fires in the spring or fall would be expected to be less than those in the main historical fire season.

Much of the information about effects of season of prescribed fire on wildlife in the Western United States is anecdotal or has lacked a direct comparison among seasons. For example, many studies compared early-season fire with no fire, or late-season fire with no fire. What has been written generally has found very little influence of fire season on populations. Wildlife may be affected by fire both through direct mortality or habitat alterations, the latter appears to play a larger role. In some cases, the magnitude of change in populations or communities has been associated with measures of fire severity, which may differ with burning season. For example, dark-eyed juncos (Junco hyemalis) often choose nest sites in unburned patches within prescribed fire units, and burns in early season when fuels are moist are more likely to create such unburned islands.

One of the most rigorous evaluations of burning season to date reported similar effects of
early (June)- and late (September/October)-season prescribed burns on small mammal populations in a mixed-conifer forest of the Southern Sierra Nevada. Although the June burns occurred during the small mammal breeding season, the burns consumed less fuel and were therefore less intense than later burns under dryer conditions. June burns were also patchier, leaving more potential refuges and habitat such as coarse woody debris where animals could have escaped fire. Most of the variation in population numbers was attributed to year-to-year differences in food availability tracking the yearly seed production cycles of the overstory trees. This further suggests that small mammals respond more strongly to habitat conditions, including those created by the fires, than to the burning season.

As is the case with small mammals, the effect of early season prescribed fire on forest floor arthropods might also be expected to differ with the life cycle of the organisms because of seasonal vulnerabilities. Fire influenced the arthropod community, reducing abundance but increasing diversity, but changes appeared to be mediated by habitat alteration (amount of litter and duff, coarse woody debris, vegetation), and these habitat variables differed much more strongly between the control and burn units than between the June and September/October burning treatments. Changes in the June burn treatment were generally intermediate between the control and September/October burn treatments.

Adult birds are highly mobile and easily escape prescribed burns. Early-season burns may cause some direct mortality of young, particularly for species nesting on the ground, but the ultimate impact on bird populations requires a longer-term view. When nests are lost, many species will renest. In addition, like many wildlife species, bird populations are capable of responding rapidly, with population size limited by food availability and shaped by habitat changes.

Unfortunately, experimental design flaws limit the inference of many studies of the response of birds to fire. Published literature comparing the effects of prescribed burns in different seasons on birds is not available for the Western United States. Preliminary data from the Sequoia National Park study on burning season suggest that effects one to three seasons after the burns were minimal. Population sizes of the eight most common species observed with point counts and bark foraging surveys did not differ significantly between burning season treatments. Too few nests could be located to investigate direct mortality from the June burns.

Besides direct mortality, another possible short-term impact of spring or early-summer prescribed burns is a temporary drop in food availability or cover because understory vegetation in these systems may not resprout until the following year. It is possible that lack of food could reduce reproductive success. The longer-term responses of many bird species are thought to be due primarily to structural changes of vegetation or changes to food resources, as affected by fire severity. For example, foliage gleaners typically decline in abundance when more of the tree crowns are lost to scorch, and woodpeckers increase in abundance when fire-damaged trees are attacked by bark beetles, an important food source. Variation in outcomes among prescribed burns early or late in the season would therefore mainly be expected if crown scorch or mortality of vegetation differed.

Ecological Effects of Burning Season in Chaparral and Grasslands

Chaparral
Extensive chaparral shrublands are found in non-desert areas of central and southern California and historically burned over a range of intervals, from every few decades in montane sites with more frequent lightning, to 100 years or more in areas closer to the coast. Most of the acres were burned in late summer through the fall, often in high intensity stand-replacing events. Because
of frequent human-caused ignitions and seasonal hot and dry winds, the fire regime remains similar today, despite fire-suppression efforts. Plant species have evolved means of persisting under such burning conditions, from resprouting of lignotubers, to seeds requiring substantial heating or exposure to chemicals found in char for germination.

Prescribed burns are sometimes used to reduce fire hazard in chaparral, but such burns are controversial. To avoid burning during times when the vegetation is most volatile and conditions are conducive to rapid fire spread, many prescribed burns are conducted in the winter or spring, outside of the historical fire season. Live fuel moisture is typically higher and soils considerably wetter at such times of the year, than would have been the case for historical fires. As a result, prescribed burns are usually considerably less intense than the wildfires. Observations suggest that vegetation response to such prescribed burns often differs from response to natural wildfires, with reduced germination of certain herbs and potentially altered species composition. For example, *Ceanothus* l. seeds require heat for germination, and abundance of seedlings has been shown to be greater following fall prescribed burns than spring burns.

Some studies have attributed the reduced germination of some obligate seeding chaparral species following spring prescribed burns to higher seed mortality upon heating. It was thought that seeds are particularly vulnerable when soils are moist and seeds full of water, compared to when seeds are dry. Interestingly, species producing hard seed with dormancy (such as *Ceanothus* spp.) that do not imbibe water until dormancy is broken, were not differentially affected by heating under moist or dry conditions. Given that heat penetration is limited when soils are moist, it is also possible that the soil heating under prescribed burning conditions typical for this vegetation type may be insufficient to scarify seeds of hard-seeded species. However, one study reported no decline in numbers of shrub seedlings or herbaceous species germinating from seed following late spring prescribed burns (May) as compared to fall (October) wildfire. The late spring prescribed burns reported were likely of higher intensity, closer to the fire intensity expected with historical wildfires. Soil moisture was likely also less.

Out-of-season burns have the potential to reduce the length of the growing season, and this could also potentially influence seedling survival/ Chaparral shrubs are typically actively growing throughout the winter rainy season—a seedling might have 6 months to grow after germination following a typical fall wildfire, whereas a winter or spring burn would considerably shorten the time to establish prior to the summer dry period. With less time to grow and put down deep roots, smaller seedlings may be less likely to survive.

Reported responses of mature shrubs to burning season have been variable. Shoot growth for resprouting chamise (*Adenostoma fasciculatum*) was not found to be affected by prescribed burn season. The study also did not note differences in mortality of resprouting shrubs with spring or fall burns. Conversely, one study found that more than 70 percent of chamise plants had died one or two years after spring burns, while nearly all plants successfully resprouted after early fall burns. Higher mortality with spring burns was thought to have been due to the timing of fire in relation to periods during which carbohydrate storage is lowest.

The bottom line is that the potential for shifts in the plant community exists when the heat generated by prescribed burning is dissimilar to what would have been experienced with the fire regime that species evolved with. Seeds of species requiring heat to germinate are dependent on receiving enough to break dormancy, but not so much that they are killed. Seeds of species requiring chemical cues rather than heat to germinate should not be as strongly affected by fire season, unless they are killed by excess heat. Excess heat is likely to be less in the winter or spring, when soils are moist. Thus, winter or spring burning might be expected to favor species
with charate stimulated seeds, whereas late summer or early fall burning may create opportunities for a greater mix of species with different strategies. One study suggested that some fall management burns, during the natural fire season, may be necessary to perpetuate *Ceanothus*, the seeds of which require heat to germinate.

**Western Grasslands**

Many western grasslands are highly altered as a result of nonnative species invasion. Rather than fuel reduction, the objective of prescribed burning is frequently to reduce the cover of nonnative species so that more desirable native species may flourish. Such burns are usually timed for periods where the nonnative species targeted may be more vulnerable to fire than the native species. Prescribed burns are likely to be most effective at reducing a target species if the seeds of that species are still immature and on the plant, whereas seeds of desirable species have dispersed to the ground where they may more readily escape the heat of fire. For example, early summer prescribed burns have been effective for controlling yellow star-thistle (*Centaurea solstitialis*) burns occurred when this late-flowering annual still contained immature seeds, but much of the associated vegetation had senesced. Controlling target herbaceous species with fire is likely to be more effective in grasslands than many other vegetation types found in the West, because of the relatively high importance of annuals in this vegetation type. Herbaceous perennial species that emerge from underground structures are typically more difficult to kill with fire.

One study followed vegetation in grasslands dominated by nonnative species that had been burned one, two, and three times in successive years in the spring (mid June, when grass had dried enough to burn, but prior to the period when such grasslands would have normally burned historically), and in the fall (late October or early November, at the very end of the historical fire season). Although fire in both seasons reduced the number of nonnative grass species and increased the number of forb species, fire in the fall favored nonnative forbs, whereas fire in the spring favored native and nonnative forbs equally. Another study compared late spring (June), fall (September), and winter (February) burns, and reported that late spring fires suppressed nonnative annual grasses more so than fall burns, presumably because grass seeds were not completely mature at the time of the late spring burns and therefore more vulnerable to being killed by fire. Winter burns were less intense and much less effective at altering nonnative grass cover than either spring or fall burns. Therefore, both phenology and intensity differences among burning seasons appeared to have played a role in how grassland vegetation was affected.

Owing to the presence of nonnative species, the amount of fuel consumed and the nature of the fire may differ from historical fires in some cases. However, because grassland fuels are fine and dry quickly, the difference in moisture and therefore consumption and aboveground fire intensity between different burning seasons may not often be as substantial as in forested ecosystems. Thus, with the confounding effect of fire intensity lessened, differences among seasons may more readily be attributed to timing of the fire in relation to plant phenology.

**Implications for Managers**

The published literature on season of burning in western ecosystems indicates that most species are quite resilient to fire in any season. The majority of plants in forested vegetation types here are perennial; loss of one season’s growing structures in long-lived or readily resprouting herbaceous species appears to have limited effects over the long term. In wildlife studies, the large amount of year- to-year variability in population sizes caused by non-fire factors makes detecting seasonal effects particularly difficult.
All else being equal (fuel consumption, fire intensity, etc.), evidence suggests that certain organisms might be somewhat more affected by burns during times of peak growth or during the breeding season. In many areas of the Western United States, fall prescribed burns are generally conducted when fuels and soils are drier, more fuel is consumed, and resulting fire intensity is greater than at the time of spring or early summer burns. Thus phenology or life history stage and fire intensity can be seriously confounded. When the difference in fuel consumption between burns in different seasons is substantial, response of many ecological variables appears to be influenced more by fire-intensity differences than by phenology or life history stage at the time of the fire. When differences in fuel consumption between fires in varying seasons are small or nonexistent, the influence of phenology or life history stage may become more apparent. Another factor that needs to be considered is the fire intensity in relation to likely historical intensity.

Most prescribed fire studies in western forest ecosystems have been conducted in areas where fire has long been suppressed and surface fuel loading is uncharacteristically high. Therefore, prescribed burns in many cases consume more fuel than wildfires burning every 10 to 15 years once did. As a result, fire intensity and resulting severity may be somewhat unnatural. In addition, when the total amount of fuel consumed is large, the magnitude of potential differences in fuel consumption among seasons as a result of fuel moisture variation is also substantial. If fire effects are driven by differences in intensity among seasons, burning when fuels are moister may be one means of limiting consumption and producing fire effects more similar to those found historically. Higher fuel moisture is more common in the spring or early summer. Limiting consumption may be especially advantageous under conditions of unnaturally high fuel loading. Once fuels have been reduced to closer to historical levels, burning at times of the year with higher fuel moisture may lead to less fuel consumed than was historically the norm. In this case, prescribed burning may result in less ecological change than desired. Also, once fuels are reduced, the difference in consumption between seasons will likely not be as high, and the effect of phenology or life history stage may become more apparent.

In contrast to forested ecosystems that historically experienced frequent low- to moderate-intensity fire, vegetation types where high-severity stand-replacing fire was the historical norm (chaparral shrublands, for example) may require hotter prescribed burns than is currently common. Prescribed burns conducted under benign weather conditions of the late fall, winter, or spring likely consume less fuel and are less intense than historical fires. In addition, soils at the time of many of these burns are generally moist, and heat penetration into moist soils could possibly be insufficient to trigger germination of heat-stimulated seeds of certain hard-seeded fire-following species. The take-home message is that early-season burns may be a valuable tool for more gradually reducing high fuel loads, especially for the first restoration burn(s) after a period of fire exclusion. Once fuels are reduced to historical levels, early-season burns might then be followed by late-season or a mix of late- and early-season burns. To mimic the historical highly variable fire regime, timing of prescribed burns should ideally also be variable. Shifting the fire regime to entirely spring/early summer growing season prescribed burning when the historical regime consisted of predominantly late summer/early fall dormant season fire (much of the Western United States), or shifting the fire regime to entirely fall dormant-season burning, when the historical regime consisted of late spring/early summer growing-season fire (as in areas of the Southwestern United States influenced by a monsoonal climate), may eventually lead to demonstrable ecological change, even if such change is not apparent today. Areas of the Western United States have generally seen at most three cycles of prescribed burning, and data from other
Table 4. Key Points - Western Region

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<td>• The effect of prescribed burning season appears to be relatively minor for many of the species that have been studied.</td>
</tr>
<tr>
<td>• Although stage of plant growth (phenology) at the time of prescribed fire may have some influence on the community trajectory in forested vegetation types, it appears that the intensity and resulting severity of the fire often has a greater impact. This is likely to be especially the case in forests that contain heavy surface fuel loads, where fuel moisture differences among seasons can lead to substantial differences in consumption.</td>
</tr>
<tr>
<td>• In chaparral vegetation, prescribed burns conducted at times of the year with higher soil and fuel moistures are often considerably less intense and may not stimulate the germination and growth of some species that are adapted to the historical regime of high-severity fire.</td>
</tr>
<tr>
<td>• In predicting outcomes of prescribed burning, it may be useful to compare the prescribed fire intensity and severity to historical intensity and severity. Burning prescriptions for producing historical or near-historical intensity and severity could then be developed.</td>
</tr>
<tr>
<td>• Until heavy fuels are reduced to historical levels, out-of-season burns that consume less fuel may be useful for reintroducing fire without causing severe effects.</td>
</tr>
<tr>
<td>• A single prescribed burn outside of the historical fire season appears unlikely to have major detrimental impacts. However, the effect of multiple sequential out-of-season burns remains poorly understood.</td>
</tr>
<tr>
<td>• Variation in the timing of prescribed burns will reduce chances of selecting for certain species, thereby helping to maintain biodiversity.</td>
</tr>
</tbody>
</table>

parts of the United States with a longer history of prescribed fire show that numerous burn cycles may be required to dramatically shift community composition. Some of the heterogeneity in the prescribed fire regime will be produced from year-to-year variation in climate alone. A prescribed burn in one year may have entirely different effects than a fire on the same date in another year, as climatic differences can influence the phenology or life history stage.

Central Region

Historical Fire Regime
The central grasslands have developed and flourished in an environment with recurrent fire from lightning ignitions and Native American activity. Without physical evidence such as fire scars, understanding how often grasslands burned historically is mostly anecdotal. Rate of fuel accumulation in some grasslands is sufficient to carry fire every year, but in others at least 1 year between fires may be necessary for dead fuels to build up, particularly if the grassland is grazed. Historical timing of fire in the central grasslands was dictated by phenology of the
vegetation, sources of ignition, and other weather events such as precipitation and wind. Grassland vegetation typically starts growing in spring (March/April), senescing in late summer and fall, or earlier if summer moisture is not available. In the dormant season (fall and winter through early to mid spring), the grassland consists of a higher dry component as thatch. This thatch is more flammable than actively growing vegetation, at least at times without recent precipitation. In northern climates, snow cover limits drying of thatch, and thus the duration of the fire season. In the more mesic grasslands, fuels may also be too moist to burn during the summer growing season, especially during wet years, because of the low ratio of dead to live fuels. However, one study reported that grasslands with 1 year of accumulated thatch could burn anytime during a March-to-November study of flammability and consumption.

The majority of thunderstorms occur from April to October, and the months in between comprise the typical fire season. Of lightning-ignited fires in grasslands of the Northern Great Plains from 1940 to 1981, nearly all occurred during the growing season from May through September, with 73 percent occurring in July and August alone. It was noted that over two-thirds of lightning fires in grasslands of Nebraska during the years 1971 to 1975 occurred in July and August. Lightning strikes may have ignited fires in advance of precipitation during thunderstorms, but could also have occurred in conjunction with precipitation in areas of higher fuel loading and thatch buildup. Native Americans also set fire to grasslands to clear vegetation and to aid with hunting and may have done so anytime the vegetation was dry enough to burn, i.e., during both the growing season and the dormant season for vegetation. One historian wrote that Native Americans “did not pattern their use of fire with the seasonal patterns of lightning fires,” burning both in the spring and fall dormant seasons, when lightning ignitions were infrequent. In Illinois, the preferred time for igniting grassland fires for hunting purposes was apparently during warm dry spells in the fall, following the first killing frosts.

**Prescribed Fire Regime**
Recognition that fire plays an important role in maintaining grasslands has led to widespread use of prescribed fire, initially to promote livestock forage and later for restoration goals such as reduction of woody vegetation. The season of prescribed burning differs, but for operational ease, the majority of burns are typically conducted when vegetation is dormant in the early spring or late fall. Spring burning (often late April) is the norm in tallgrass prairie remnants such as the Flint Hills, which extends from Kansas into northeastern Oklahoma. Fire at this time of year is thought to be most beneficial to warm-season perennial grass species that are important for grazing. Prescribed burning of grasslands farther south may be conducted earlier (January to March). Overall, the majority of prescribed burns occur either earlier or later in the season, and at a time of greater plant dormancy than the majority of natural lightning-ignited fires. Greater use of growing-season burns has been advocated in order to mimic historical timing of lightning ignitions. However, there is some debate whether the goal with grassland burning should be to re-create grassland conditions representative of 30 million years of grassland evolution (predominantly growing-season lightning fires), or whether the goal should be to re-create conditions as they existed immediately prior to Euro-American settlement, which is thought to have been a mixture of growing- season lightning fires augmented by growing- and dormant-season fires, ignited by Native Americans.
Ecological Effects of Burning Season

Grassland Vegetation
In a review of the literature, researchers concluded that prairies are far more resilient to burning in any season than previously thought. For example, it was noted that most prairie forbs are resilient to burning in any season, with 75 of 92 species studied unaffected by burns in different seasons. However, timing of fire can alter certain grassland species directly through injury or mortality, especially during vulnerable phenological stages. Fire during the period of most active growth is thought to be most damaging, because new plant tissues are more sensitive to heat and because carbohydrate reserves are lower this time of year. One study compared fire in June, July, and August on four bunchgrass species and found plants to be most resistant to fire later in the season, presumably when carbohydrate reserves were again replenished.

Needle and thread (Hesperostipa comata) was damaged most by June fires, when plants were greenest. Squirreltail (Elymus elymoides), which was still green to partially green in both June and July was damaged most by July fires, when outside temperatures were the hottest. Data from this study demonstrated that depending on the species, both timing in relation to plant phenology, as well as the total heat experienced (from fire plus starting air temperature) may play a role in the response. In a different grassland type, mesquite savannah, the yield of Texas wintergrass (Nassella leucotricha) was reported to be nearly twice as high after summer fires than after winter fires. This cool-season grass species grows in the early season (February to June). The winter fires (February/early March) therefore coincided with growth, whereas the summer fires (September) were ignited after the species had finished growth. In a study of burning season on a rare forb, either spring (mid April) or fall burns (mid September) increased the germination of Spalding’s catchfly (Silene spaldingii), which grows from May through September (flowering in July and setting seed in August), but response was greater after spring burns. One study noted significant differences in response of big bluestem (Andropogon gerardii) to burns just 4 days apart, with fires shortly after initiation of spring growth increasing subsequent stem height and numbers of flowering culms compared to fires prior to initiation of spring growth. All of these studies highlight the importance of evaluating the effect on individual species in context of the timing of fire in relation to phenology of the plant at the time of the fire.

Much of the research on season of burning in grasslands has looked at the impact on the plant community. In addition to direct effects of fire on certain species, grassland vegetation can also be altered indirectly through changes in competitive relationships that occur when injury or mortality to some species is greater than to others. Prairies are typically composed of varying amounts of two groups of grass species: the cool-season grasses that experience peak growth from approximately March through May and the warm-season grasses that have peak grow from approximately April through October. Prescribed burns in the spring can kill, damage, or inhibit growth of early cool-season species that are active at this time of year, thereby favoring later warm-season species that have not yet started to grow. Conversely, prescribed fire during the middle of the summer at the peak of lightning and historical fire frequency are more detrimental to the dominant warm-season grass species, thereby favoring early-flowering cool-season species, many of which have already finished growth and dropped seed by this time. For example, population size of the early perennial forb Golden zizia (Zizia aurea), a species that sets seed in early summer, was greater following August burns than May burns. The summer burns more effectively suppressed the canopy of the taller dominant warm-season grasses, creating an environment free from shading by thatch.
Altering the fire regime of the Central and Northern Great Plains from lightning-ignited summer wildfire to spring prescribed fire has possibly shifted species composition toward a greater proportion of warm-season grasses. The warm-season grasses favored by spring (dormant season) prescribed fire are generally taller and outcompete other species for light; burning at this time of year is therefore thought to have contributed to rarity of formerly abundant species, and reduced overall diversity. Conversely, summer burns, by reducing competition by dominant warm-season grasses, have been shown to favor early-flowering cool-season grasses and forbs. In a study comparing midsummer (July 15) and early spring (March 31) burns, it was reported that early-cool-season flowering species such as black-eyed Susan (*Rudbeckia hirta*) and quack-grass (*Agropyron repens*) increased in abundance after the mid-summer burns, whereas the spring burns caused both to decline or disappear. One census of unburned prairies found that the guild of early-flowering species covered only 2 to 15 percent of the ground; after a single mid-July burn, the cover of early-flowering species rose to 46 percent. Because lightning fires historically occurred most often during the summer, it is believed that such early-flowering species were once more abundant. With more early-flowering species in place of a few dominant warm-season grasses, tallgrass prairies managed with summer (growing season) burns have higher species diversity than prairies managed with spring or fall (dormant season) burns. The greater heterogeneity in intensity and effects with growing-season burns may be another reason for higher plant diversity. If biodiversity management in tallgrass prairies is the goal, burning during the summer active phase of the dominant grasses may be preferred. One study suggested that greater biodiversity could be maintained with a “chaotic array” of burn seasons, such as what might have occurred historically.

The extent of community shifts caused by different burning seasons is largely dependent upon the mix of species present. For example, major changes in the plant community have not been noted for tallgrass prairies dominated by warm-season species. In a study of burning at Konza prairie in Kansas where cool-season species are only a minor component, researchers noted a high degree of resilience to fire in any season. Canopy cover of warm-season grasses increased with burning in the fall, winter, or spring. Whereas some cool-season grasses did decline with repeated spring burning, low initial abundance apparently did not lead to differences in the competitive relationships between cool- and warm-season species among burning season treatments. Even repeated growing season (summer) burning, which was expected to suppress warm-season grasses and increase cool-season species, had few strong effects, possibly because watershed-scale burns in this season were patchy and incomplete. That repeated burning in different seasons led to few and slow changes of most species suggests that in this grassland type, the impact of one or a few out-of-season burns is likely to be relatively minor.

Studies in shortgrass prairies have also not demonstrated dramatic shifts in species composition with burning season. One study found that grass population size and forb composition in a shortgrass savanna did not differ after fires in the growing season (July through August) or dormant season (January through February). Based on data showing few changes in species composition, but large reductions in grass cover and biomass production, dormant-season burning (April) was deemed less likely to put the shortgrass prairie at risk than growing-season (September) burning.

Another common goal of burning in grasslands is to increase forage for livestock. In one study, forage production of a tallgrass prairie was greater after late-spring burning (May 1) than after early-spring burning (March 20), with mid-spring burning (April 10) intermediate. Late-spring burns were timed for the start of growth of dominant warm-season grasses and
preferentially killed or reduced cool-season species that initiated growth earlier. Similar results were reported by others from the same site 20 years later, with greater forage production after late spring burns (May 1), than after winter (December 1), early-spring burns (March 20) or mid-spring burns (April 10). These plots had been burned annually since 1928. It was thought that the earlier fires led to greater duration of bare mineral soil exposure, with evaporation drying out the soil and reducing plant growth. In some grasslands, higher productivity with late-spring burns is likely partially the result of species shifts. The dominant warm-season grasses that are favored by such a fire regime are generally more robust and taller than the subdominant forbs and cool-season grasses favored by summer burns.

In shortgrass prairies, biomass production following growing-season (July) burning was shown to be substantially less than following dormant-season (April) burning. Grass cover was also significantly reduced after growing-season burns, owing primarily to a drop in cover of buffalo grass (*Buchloe dactyloides*), a late warm-season species. Another study in a similar grassland type showed that spring burns enhanced forage production more than fall burns. In a marsh plant community, summer (August) burning decreased the biomass of common reed (*Phragmites australis*), whereas spring (May) burns increased biomass, and fall (October) burns resulted in no change in biomass.

**Nonnative Vegetation**

Prescribed fire is sometimes used to control nonnative species in grasslands. Shifting the plant community by timing burns to coincide with the most vulnerable stage of the target nonnative species while favoring native species, is seen as key to success. One study found summer (July) burning at the time of flowering reduced population growth rates of spotted knapweed (*Centaurea maculosa* L. ssp. *micranthos*), whereas spring (April) and fall (October) burns had no significant effect. Summer burns killed the flowering stalk, but not the adult plant. Spring burns allowed surviving plants to flower, whereas fall burns occurred after seeds had dropped. Summer burning is, however, not the best time for native late-season grasses that can keep spotted knapweed at bay through competition. In another study, mid-spring burning (late April to late May), timed to kill newly germinating seedlings, increased the dominance of native warm-season grasses and reduced spotted knapweed abundance. Because many of the nonnative species in grasslands dominated by native warm-season grasses germinate early, numbers can often be suppressed more effectively with spring burning, which also tends to be beneficial for the native grasses. Unfortunately, because many nonnative species thrive with disturbance, populations are also often enhanced by fire. Hotter fall burns (September) were found to increase numbers of the nonnative sulphur cinquefoil (*Potentilla recta*) more than spring (April) burns.

**Trees and Other Woody Vegetation**

The presence of trees and shrubs in grasslands is often limited to areas that have experienced a break in the fire regime. This is evident in oak savannas that occur along the transition zone between the tallgrass prairie and the deciduous eastern forests. It is thought that fire may have once kept grasslands free of fire-sensitive tree species. For example, absence of fire in Texas grasslands has contributed to an influx of mesquite and scrub oak. Although growing-season burns in mesquite savannas are sometimes higher intensity than dormant-season burns with greater flame length and faster rates of spread, One study reported that either dormant- or growing-season burns reduced the cover of mesquite and other shrubs. However, these shrubs also resprout, and neither growing-season nor dormant-season burns were intense enough to kill them. Intensity differences among burning seasons (higher intensity with summer burns) were
associated with mortality of prickly pear cactus (*Opuntia* spp.), a grassland invader. One study manipulated fire intensity by adding fuels around the base of some mesquite shrubs prior to growing- and dormant-season burns, and noted that although resprouting was on average less vigorous after growing-season burns, resprouting was reduced in higher intensity patches within burns in both seasons. Both intensity and fire season apparently play a role, influencing the outcome by different mechanisms; intensity by damage to growing parts, and season through changes in rate of recovery as a result of seasonal differences in carbohydrate storage.

**Soils**

Grass fires move rapidly, and because the amount of fuel consumed and heat produced when grasslands are burned is relatively low, heating below the immediate soil surface is generally minimal. However, burning is thought to influence soil heating in other ways. Growth in the spring, especially in areas with cooler winters, is limited by soil temperature. Clearing the ground of litter and thatch, whether through spring burning or other means, allows sunlight to reach and heat the soil surface, thereby promoting earlier growth of the warm-season grasses. Earlier initiation of growth and a longer growing season may be one reason why spring prescribed fire has frequently been found to increase vegetative production; however, researchers found that plants in burned areas also senesced earlier without significantly greater production.

Burning in the early spring can lower soil moisture compared to burning in late spring, because the ground is exposed for a longer period of time, allowing more evaporation to occur. Excess evaporation may be detrimental to herbage production, especially in low rainfall years when moisture is already limited. The presence of litter and thatch is also thought to increase snow accumulation, time required for snow to melt, and rate of moisture infiltration into the soil. Therefore, any burning regime that leaves the soil uncovered during the winter and spring could potentially reduce soil moisture.

Burning during the growing season minimized the impact on biological soil crusts compared to burning during the dormant season, presumably because of lower fire severity. However, recovery of soil crusts was rapid, regardless of the burn season.

**Wildlife**

Wildlife is impacted by fire in two main ways: direct mortality and indirect changes through alteration of their habitat. However, few data on the effect of prescribed fire season on wildlife in grasslands have been published. Most studies have looked at either the difference between growing-season fire and no fire or the difference between dormant-season fire and no fire, without comparing among burning seasons.

**Birds and Small Mammals**

Some mortality of birds and small mammals is expected with fire, especially those that nest above the ground. Burns, stress, and asphyxiation are possible mechanisms. However, prairie vegetation is composed of fine fuels that burn rapidly in a narrow band of flame; this makes heating relatively transient and allows animals to more easily escape.

Because of their mobility, adult grassland birds rarely experience direct mortality with fire. Young birds still in the nest are more vulnerable, and as a result, spring burning during the nesting season may cause greater mortality than burning in the summer or fall. Two studies observed that nests of ducks and other bird species were destroyed by spring prescribed burns. However, if the nest is lost, many prairie species will renest. In the Nebraska grassland, harvest
mouse mortality was noted with a dormant-season burn occurring during the nesting season. Even so, the high reproductive capability of rodents generally compensates for any impact of different seasons of fire.

As in other vegetation types, longer-term changes in animal numbers owing to fire are thought to be caused mainly by effects on habitat. Burning-season-mediated shifts in grassland species composition can affect animal populations, but lack of cover likely plays a stronger role. In grasslands, fire removes all or nearly all of the aboveground biomass, and it is thought that amount of time without cover can affect wildlife (either positively or negatively, depending on the species). Because vegetative growth typically starts with warm weather and precipitation in the spring, cover is generally reduced for a longer period after a fall burn than a spring burn. In a study comparing duck nesting in plots burned in the spring (June) during the May 1 through July 31 nesting season, and plots burned in the late summer (August-September), after the nesting season, researchers noted that far fewer ducks initiated nests the following spring in the sparse cover after late-summer burns. In the following year, number of nests was the same between treatments, but nest success was greater in the late-summer burning treatment compared to the spring burning treatment. This difference equalized over time, and by year 4, no difference between burning seasons was found. One study found that nest densities of the greater prairie chicken (*Tympanuchus cupido*) increased after burns in either the late summer (August) or spring (March).

Losses or gains in food sources may lead animals to migrate, and loss of cover could increase predation rates during migration. When managing for key animal species, burning has sometimes been done to manipulate the abundance of plant food sources, but the optimal time of the year differs, with no time best for all species. For example, growing-season prescribed fire, which favors grasses over forbs, may benefit species that feed on grass seeds but not be ideal for species that eat seeds of legumes and other forbs. If the goal is to increase the abundance of forb food sources, dormant-season burns may be preferred.

A variable fire regime with burns in multiple seasons may be necessary to maximize grassland biodiversity. Two studies argued for less uniform burn management and greater patchiness to promote multiple grassland habitats and greater diversity of birds.

**Amphibians and Reptiles**

In a mesquite savanna grassland in Texas, dormant-season burns had no effect on the diversity and abundance of amphibians and reptiles, whereas diversity and abundance tended to be slightly greater in plots managed with growing-season burns. One species of lizard was 10 times more abundant in plots burned in the growing season than in the unburned control; however, burning season overall had few short-term effects on the community. These authors recommended a varied fire regime to maximize diversity of this group of species.

**Arthropods**

Burning in different seasons has been used in attempts to control arthropod pests, such as ticks, but results from studies to date have been mixed because of differences in fire intensity and timing in relation to periods of aboveground activity. For winged arthropods that can escape the main heat pulse, a fire will tend to favor those species that are mature at the time of the burn. In a Kansas prairie, grasshoppers (Acrididae), which overwinter as eggs in the soil, were reduced by burns timed to occur after the nonflying nymphs emerged. In another study, researchers found that the response to burning season differed among grasshopper species, with two unaffected by prescribed fire in any season, one reduced by both spring and fall burns, and one reduced more
by fall than spring burns. The latter species lays eggs near the soil surface, where they are presumably killed by fall burns. Developing burning prescriptions to target vulnerabilities of each species was suggested.

Mortality of other arthropods, such as centipedes and millipedes that live in crevices in the soil, is likely minor with flaming combustion, varying more with habitat modifications. That may differ among burning seasons. Conditions as vegetation recovers following a fire are beneficial to many arthropods. Total weight of insects in a Texas grassland was greater in burned than unburned areas one season after fire, with more insect biomass following spring burns than winter or fall burns, presumably owing to attributes of the post-fire vegetation. In another study of a Texas grassland burned three times in either the winter (dormant season) or summer (growing season), and sampled 3 years after the final burn, researchers found 170 percent more individual insects in the summer burn plots. Although species richness was also 60 percent higher in the summer burn plots, the difference between burn-season treatments was only marginally significant.

Spring prescribed burning was shown to suppress arthropod diversity in an Illinois tallgrass prairie. Because of low survival in place, recovery of burned landscapes may depend upon recolonization from adjacent unburned areas. These authors suggested that to avoid negative impacts to arthropods, managing for burn patchiness and leaving unburned refuges would be beneficial. Burn seasons were not compared experimentally; therefore the magnitude of potential burn season effects is unknown.

**Implications for Managers**
Reviews of the literature on burning season in prairies of North America highlight the wide range of outcomes that are possible, making broad generalizations a challenge. How fire interacts with the ecosystem depends on the frequency of fire, time since previous fire or successional stage of the grassland, grassland type (shortgrass, mixed-grass, or tallgrass), the evenness of cool-season and warm-season species within grassland type, herbivory, and climatic conditions, most of which differ among the many studies that have been done. Timing of fire in relation to seasonal growth is key to understanding response in grassland species. For example, a greater increase in production with spring than summer burns might be expected in areas where warm-season grasses currently predominate (i.e., the more mesic grasslands in the eastern portion of the Central region), than in areas where cool-season grasses predominate, such as the more xeric western grasslands.

In many studies, the descriptions of when the fires were conducted is vague (i.e., spring burn, early-season burn, fall burn, late-season burn, etc.) and slight variation in timing of fire in relation to plant phenology can produce different results. Significant variation in outcomes has been reported for burns conducted as little as 4 days to 3 weeks apart. Effect of prescribed burning also depends on year-to-year variation in rainfall, with greater expected plant mortality from burning in drought years. Year-to-year variation in precipitation or temperature can also alter the onset of seasonal activity and growth. Thus lack of detail on the exact phenological stage of organisms at the time of burning, inadequate description of burn timing, and climatic variability limit syntheses and generalization of results. Each year and each burn is potentially unique.

Although prairies are generally fairly resilient to burning in any season, it is clear from the literature that prescribed burns in different seasons can sometimes lead to substantial ecological change. Population sizes of certain species can shift from a single burn, but such changes are
usually ephemeral. The role of vegetation phenology on response is perhaps stronger in grasslands than in any other ecosystem. As with other ecosystems, response is tied to both the phenology of organisms and intensity of the fire. Because grassland fires consume much, if not all, of the aboveground vegetation regardless of fire season, differences in intensity among seasons are likely of lesser magnitude than in many other vegetation types. (Note, however, that intensity does differ depending on whether heading fires or backing fires are used, and this too can affect the vegetation response. Without strong differences in intensity, the role of phenology becomes increasingly important.

Rather than managing fire intensity through prescribed burning under different conditions or time of year, or using different firing strategies, the issue for the fire manager is mainly one of timing burning to achieve different goals. The optimal burn season depends on the objective: Is the goal to improve forage biomass, or to enhance native biodiversity? If the latter, is the goal to restore conditions/processes to the time immediately prior to Euro-American settlement, taking into account the impact that Native American burning likely had, or is the goal to mimic processes in place prior to anthropogenic manipulation of vegetation?

Fine-tuning the timing of burns will depend on many other factors including a complete understanding of the phenology or periods of greatest vulnerability of key species, the role of climatic variation, and the interaction between phenology and climate. It is also important to recognize that repeated burning in any one time of year over large land areas may have the effect of simplifying the system. With grassland species differing in response to timing of fire, heterogeneity in the prescribed burning regime, including a mix of fire seasons, may be necessary to maintain prairie diversity.

**Table 5. Key Points - Central Region**

<table>
<thead>
<tr>
<th>Key Points-Central Region</th>
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<tr>
<td>Grasslands exhibit resiliency to fire in any season, but substantial changes in community composition can result from altering the burn season.</td>
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<tr>
<td>Shifts in the plant community are caused by variation in phenology and susceptibility to fire among species. Prairies with a mix of cool-season and warm-season species having different periods of growth appear to be most susceptible to community shifts, whereas prairies dominated by one or the other appear to be more resistant to change.</td>
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<tr>
<td>Phenology of the vegetation at the time of burning appears to play a more important role in grasslands than most other vegetation types, presumably because fuel consumption and fire intensity do not differ substantially among burn seasons (assuming the same firing strategy: backing or heading). When intensity is similar, the influence of phenology is more likely to be seen.</td>
</tr>
<tr>
<td>Low fuel loading and rapid fire passage allows most mobile animal species to escape the flames in any season. Although fire during periods of vulnerability, such as the nesting season, can cause short-term losses, the effect on populations in the longer term is unclear.</td>
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<tr>
<td>A burn program that promotes heterogeneity, including burning in multiple seasons within the historical range of variability will likely benefit the greatest number of grassland species.</td>
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Southeastern Region

The Subtropical region averages approximately 50 in of precipitation a year. Much of the rainfall occurs with the passing of maritime tropical air masses that arise from the Gulf of Mexico, as well as continental polar air masses. These same air masses bring warm temperatures and high humidity in the summer months and cold temperatures in the winter. In south Florida, rainfall peaks in the summer, with drier weather in the fall, winter, and spring. Along the gulf coast, two distinct wet periods occur: one during the summer lightning storms (June-August) and a second during the winter (January-March) with the arrival of cold fronts when transpiration rates of the vegetation are low. The Ouachita Mountains of western Arkansas and eastern Oklahoma also have two distinct wet periods, with rainfall peaking around May and November. Farther east, rainfall generally becomes more evenly distributed throughout the year.

Forests of the subtropical region are dominated by overstory pines and scrub oaks closer to the coast, bottomland hardwoods along waterways, and a mixture of pines and upland hardwoods farther inland from the coast. The longleaf pine (Pinus palustris) forest once covered the majority of the Coastal Plain, but has been reduced owing to a variety of past land management activities. Shortleaf pine (Pinus echinata) was at one time the most widespread pine species across the East, occupying a variety of soil types and environmental conditions, but has been reduced because of fire exclusion logging replanting with other species. Slash pine (Pinus elliottii) and loblolly pine (Pinus taeda) were historically restricted to wetter areas but are now found throughout the pine zone. Forest composition in the pine-oak forests has shifted to a greater percentage of mesophytic hardwoods and planted species such as loblolly pine.

Historical Fire Regime

Based on fire scars in the tree ring record, it is believed that prior to Euro-American settlement, many forests in the south had an average fire-return interval of less than 15 years. The mean fire-return interval increased along a moisture gradient with more mesic sites having less frequent fire. The southernmost longleaf pine forests grow in areas with longer dry periods, and these forests burned with the highest frequency. Oak- pine forests in the highlands of eastern Oklahoma burned every 2 to 12 years. Fires ranged from low-severity surface fires in longleaf pine forests to mixed-severity fires in oak-pine forests. Drought conditions sometimes led to higher fire intensity and greater damage to trees, even in areas that typically experienced low-severity fire.

The Coastal Plain pine zone is characterized by flammable understory fuels (both live and dead) that respond quickly to fluctuations in moisture, and will burn nearly year round. Moisture content of live vegetation is often lowest from April through June, prior to the onset of the summer rains and as temperatures are warming. Understory shrubs such as saw palmetto (Serenoa repens), gallberry (Ilex glabra), and wax myrtle (Morelia cerifera) that contain volatile oils are common. These oils allow combustion at high moisture levels, and fire is therefore not dependent upon longer periods of drying. Burns can be conducted just days after rainfall.

Location of fire scars within annual tree rings suggest that slash and longleaf pine communities adjacent to the Gulf of Mexico were most likely to burn in the middle of the growing season (April-August). In contrast, fire scars from other parts of the longleaf pine range showed evidence of a higher proportion of dormant season fire (September-March).

The Southeast has the highest lightning strike frequency in the United States. Ten to 21 strikes per square mile per year are common, with a peak of 22 to over 41 strikes per square mile.
per year found throughout much of Florida. Most convective activity occurs between May and September, with the number of lightning-ignited fires peaking in July. Lighting-ignited fires burn more acres in May and June, at the transition between the dry season and the onset of the summer rains. Thus, the peak fire season occurs prior to the peak convective season. Precipitation increases with the summer convective storms, and although fires do occur during the summer, they are typically less intense and smaller as a result of higher moisture levels. During drought years, fire season tends to expand into the warm summer months, and fires are often larger and more intense. In the Ouachita highlands of eastern Oklahoma, the majority of lightning fires occur in August and September, with drying following an early summer peak in thunderstorm activity and rainfall.

There is some question as to the temporal and spatial extent of burning by Native Americans and its effects on native species in the East, leading to controversy as to what constitutes the historical fire regime. Native Americans used fire for a number of reasons, including propagating native plants, hunting, clearing of land, defense, and communication. It is thought that Native Americans would not have restricted their burning to a particular season, but rather used fire in a variety of seasons to meet their needs. Ignitions in the fall or late winter to early spring would have coincided with hunting season and preparation of agricultural fields, respectively. The prevalence of dormant season scars, despite the relative lack of lightning during this time suggests a contribution of Native American ignitions to the fire regime.

**Prescribed Fire Regime**

Active prescribed fire management was preceded by a period of fire exclusion that began in the 1920s. However, the practice of fire suppression was not widely embraced in the East. Passage of the Weeks and Clarke-McNary Act, which established significant fire control organizations, sparked a debate concerning the importance of fire to the Eastern ecosystems. Managers quickly realized the importance of fire to this region and continued to use prescribed burning to maintain forested ecosystems. A substantial proportion of the prescribed burning in the southeastern coastal plain is conducted during the fall, winter, and spring (October-April). Burning at this time of year is/was based on the belief that such burns would be less likely to impact nesting birds or harm growing trees. Operational issues also favor burning at this time of year, with lower temperatures and more predictable winds making prescribed burns easier to conduct. Gusty and unpredictable winds associated with thunderstorms are common during the late spring and summer.

The main prescribed burning season occurs during the dormant phase of many plant species and at a time of reduced biological activity, whereas the historical fire regime consisted of a higher proportion of spring and summer fire, when vegetation was actively growing and birds were nesting. Because these dormant-season burns are outside of the typical historical period of lightning-ignited fire, there is some concern that repeated burning at this time of year might result in undesirable ecological changes.

On lands where the objective of prescribed burning is to restore historical processes, such as Everglades National Park, considerable burning is also often done during the growing season (May-August), the peak of the lightning season. In Everglades National Park, South Florida slash pine (*Pinus elliottii* var. *densa*) has burned every 2 to 3 years during the months of May and June since 1989. However, such burns are considered risky because of the chance for escape. Specific resource conflicts, such as game bird management and concern about nest destruction, can also make managers reluctant to use growing-season prescribed fire.
Ecological Effects of Burning Season

Pines
Fire is a vital tool in the management of pine forests in the Southeastern United States. Early research guided managers who were focused on timber production to avoid burning during the growing season (May-August) because of concern that damage to the tree crop would reduce profits.

Tree mortality can result from excessive root loss, damage to bole cambium, or crown scorch/photosynthetic material loss, some or all of which can differ among seasons. Duff consumption, which is considerably greater when moisture levels are low, has been linked to increased long-leaf pine mortality in long unburned forests where substantial duff had accumulated. Lowest duff moisture levels are often found from late in the dormant season to early in the growing season (March-April). Mechanisms of tree mortality were not determined, but could be the result of root death or cambium damage. However, fine roots are less likely to grow into the duff layer when it is dry. Thus greater duff consumption may not necessarily translate into greater fine root mortality. There is some evidence that root growth may be reduced more following summer (July) burns than dormant- (March) and early-growing-season burns (May). However, this later study occurred during a drought year and results may be most applicable to these drought conditions.

Early research showed that pine crowns were more severely scorched by spring or summer (May-August) burns than by fall and winter (October-March) burns, owing to higher ambient temperature, which reduced the time to reach lethal heating and cause foliage mortality. It was assumed that greater crown loss would mean higher mortality or slower growth. To test the effect of crown loss in different seasons, loblolly and slash pines were defoliated to varying levels in January, April, July, and October, and found substantial mortality only after October defoliation. Southern pines form new buds and flush multiple times during the growing season and can therefore recover better from defoliation if it occurs prior to the last flush of the season. In the fall, when no additional growth is expected until the following spring, the time between tissue loss and regrowth of photosynthetic structures is greater, which apparently causes more stress on the tree.

In one of the most robust long-term studies of burning season mortality of mature longleaf pines with burns conducted at eight different times of the year did not vary in any predictable way. Much of the other literature on post-fire mortality or growth rates of pines has also reported no effect or mixed results of burning season. Magnitude of any burning-season effect may be a function of tree age, with the seedling stage of some species being more sensitive. Greater mortality was noted in longleaf pine saplings following summer (August) than following winter (January) or spring (May) burn. Seedlings appear to benefit more from growing season (May) burns, presumably at least in part because fire at this time of year reduces the incidence of fungal infections such as brown spot needle blight (Scirrhia acicula).

Fire intensity and season are confounded in many burning studies. In south Florida, slash pine was found to experience higher mortality with fall burns (September- November) compared to burns in other seasons. However, bark char heights were also greatest for the fall burns. Measures associated with fire intensity (i.e., percentage of green canopy and bark char) were most strongly associated with tree mortality within burns in the same season as well. One study reported fall (October) burns to be the most intense in one treatment cycle, and found that pine mortality in the 2 to 3.5 in diameter at breast height (dbh) size class appeared to be correlated
with amount of fuel consumed (and total heat released), whereas mortality of pines greater than 3.5 in dbh was correlated with fireline intensity. A second study noted that mortality was less when low-intensity backing fires were used, rather than heading fires.

A review of the literature indicates that burning season appears to have little effect on the growth rate of mature pines, but mortality is often somewhat more following fires late in the growing season, which corroborates the previously mentioned defoliation study. However, considerable variation in results have been reported, which probably has to do with differences in fuel consumption and resulting fire intensity among seasons, as well as the time of year burns were conducted relative to tree phenology. One study suggested that fire intensity may explain much more of the variation in effects to longleaf pine than either the ambient temperature at the time of burning or the phenology/burning season.

**Understory Vegetation**

**Shrubs and Hardwoods**
Maintaining adequate regeneration of overstory trees is a common goal in the management of pine forests. To reduce competition for light, fire is used to selectively top-kill the hardwood midstory and shrub understory, while minimizing the impact to overstory pines. Numerous research results have suggested that burning during the peak of the historical fire season (May) reduces stem density of understory hardwoods more than burns at other times of the. This is particularly true if burns are repeated at annual or biennial intervals. A single burn in any season will not kill enough plants to control hardwood resprouting. However, following 43 years of burning on the Santee Experimental Forest in South Carolina, fewer hardwood sprouts survived with a fire regime of annual late spring/early summer (June) burns than annual winter (December) burns. With late spring/early summer burns, the woody vegetation was gradually replaced by an understory dominated by forbs and grasses. In contrast, more oaks and other hardwoods were maintained with repeated burns during the fall/winter dormant season (October-January). In another study in shortleaf pine-grassland ecosystems of Arkansas, late-growing-season (September-October) burns were found to be less effective for reducing understory hardwoods than late dormant season (March-April) burns.

It is important to note that the regime of annual growing-season burning that most successfully reduced competing hardwoods and shrubs in two of the most widely cited studies (Santee Experimental Forest study, and St. Mark’s National Wildlife Refuge study was considerably more frequent and invariant than was likely the case historically and therefore may not be the most beneficial for other components of the ecosystem. Although fires as frequent as 1 to 2 years apart have been recorded in the tree ring record of eastern pine forests, the overall historical fire-return interval averaged 3 to 7 years. Annual prescribed burning may not even be possible in some stands, if fuel accumulation rates are slower. For pines to regenerate naturally, longer fire-free periods may be necessary so that seedlings can establish and grow above the zone of lethal heat. Depending on the management objective, a prescribed burning regime of variable frequency and seasonality (within the historical ranges) may be preferred.

There are several explanations relating both to the physiological status of the plant and to fire intensity for the difference in midstory hardwood and shrub mortality following burns in different seasons. Physiological status appears to play a role in the greater shrub and hardwood reductions noted with growing-season burns in many studies. During the dormant season, shrubs store more of their carbohydrates underground, and these carbohydrates enable resprouting when the aboveground portion is killed by fire. During the growing season, more of the carbohydrates
are allocated aboveground, and are lost with topkill, leaving fewer reserves for resprouting. One study evaluated shrub response to fires of different temperatures in different seasons and found changes were not associated with fire intensity, suggesting that the physiological status of the shrub at the time of burning may be playing a greater role. Studies of defoliation of evergreen shrub species in different seasons also point to a physiological influence, with one study reporting complete kill following leaf removal in October, but a much reduced effect in April. Other studies suggest an effect of fire intensity differences among burn seasons.

Shorter statured vegetation, such as midstory hardwoods and shrubs, is more likely to be affected by seasonal differences in scorch height. In another study, the dormant-season burns (March-April) were both more intense and more effective at thinning the midstory hardwoods than the late-growing-season burns (September-October), suggesting that differential intensity may have overwhelmed effects of phenology. Indeed, some burning-season studies have reported fire intensity to be just as important as phenology in shaping the outcome.

**Herbaceous Understory**

Burning during the historical fire season has been hypothesized as important because organisms are presumably best adapted to disturbance at this time of year. Studies show that this may indeed be the case for some understory plant species of southern pine forests. At the St. Marks National Wildlife Refuge in Florida, greater increases in shoot number and flowering of narrowleaf goldenaster (*Pityopsis graminifolia*) were observed following burns in May than burns in January or August. The increases in shoot numbers did not lead to long-term increases in stem densities, however, suggesting that there may be some cost to using resources for reproduction. The flowering response indicates an adaptation to and dependence on growing-season fire. Brewer (2006) hypothesized that this species would likely benefit from “modest variability in fire frequency and fire season.” Numerous grass species, including the commonly studied wiregrass (*Aristida beyrichiana*), also flower more vigorously after growing-season burns. Saw palmetto produced more flowers and fruits with periodic growing-season (April-July) burns than with dormant-season (November-February) burns. Growing-season burns have also been shown to increase flowering synchrony of forbs and shrubs by decreasing the flowering duration. Flowering synchrony may lead to a higher probability of cross-pollination. In another study, no difference in the density of reproductive American chaffseed (*Schwalbea americana*) plants was noted between burning-season treatments. Numbers increased following burning in either the growing or dormant season. However, burning season did influence the timing of flowering, with plants flowering earlier after dormant-season burns than after growing-season burns.

The positive response of some species to growing-season burning provides evidence for fire at this time of year being an important part of the natural disturbance regime. However, what is best for one species may not be for all, with some species also responding more strongly to dormant-season burns. Many species do not appear to be influenced by burning season at all. For example, of the more than 150 plant species evaluated for response to late growing-season (September-October) and late dormant-season (March-April) burns in a shortleaf pine-grassland community in Arkansas, fewer than 10 percent were differentially affected by burning season. The variable response of understory species to fire season suggests that a heterogeneous fire regime (including variation in the seasonal timing of fire) may help conserve biodiversity.

For species with growth or flowering influenced by burning season, response has sometimes been shown to differ at fine temporal scales, i.e., for fires within the same growing season, or among plant growth stages. One study reported that early wet-season (May-June) fires were
beneficial and late wet season (July-September) fires detrimental to the cycad species *Zamia pumila* L. The variation in response of herbs and woody plants observed among burns within the growing season by researchers was attributed the response mainly to climatic differences. Several researchers noted that slight differences in burn timing within the wet (growing) season had substantial effects on survival and growth of big pine partridge pea (*Chamaecrista lineata* var. *keyensis*), and concluded that comparing fires by seasons may be too broad and not useful to managers.

In a study of response of multiple growth stages, small plants of the forest herb pineland *Jacquemontia* (*Jacquemontia curlisii*) suffered greater mortality with growing-season (June) prescribed burns than dormant-season (January) burns, even though the latter burns were hotter. However, the plants surviving the growing-season burns produced more flowers. Therefore, different parts of the plant life-cycle were variably affected by burning season. Similar findings have been reported for wiregrass, where growing-season burns promote flowering, but also cause higher mortality of established seedlings than dormant-season burns, and big pine partridge pea, where stem growth was greater but plant survival lower following growing-season (summer) burns. These results all highlight the importance of variability in the fire regime.

At the plant community level, repeated growing-season burning generally increases the cover of grasses and diversity of herbaceous species. This shift is likely because of release from shrub competition (shrubs are selected against by growing-season burns) and removal of the litter layer. The robustness of the understory herbaceous layer is not only important for biodiversity conservation, but also for grazing animals. Studies focused on livestock management have reported grass productivity gains with early growing-season burns, which is likely also tied to reduced shrub competition. However, overall productivity (herbs and shrubs) was found to be greater following fall burns than spring burns. Other studies that have followed productivity over several years have been unable to document any increase in biomass and cover of grasses and forbs with burns in different seasons.

One study suggested that understory composition was, in part, influenced by fire intensity through its effect on litter consumption and woody shrub removal. However, fire intensity did not appear to play much of a role in another study. A second study burned plots containing between 2.6 and 7.1 tons/ac of surface fuel with and without 54.0 tons/ac of additional fuel, and found little effect on understory shrub species richness or density although the fuel addition treatment significantly increased fire temperatures and soil heating. The authors suggested that species are well adapted to variation in fire intensity. In another study, plant mortality did not differ with fuel consumption differences, suggesting that seasonal timing may be more important than fire intensity. However, a big picture view suggests that the effect of season of burning is less critical to maintaining understory biodiversity in the longleaf pine system, than frequency of burning.

Despite the many benefits of growing-season burning that have been reported in the literature, a recent publication from the St. Marks study in Florida indicates that growing-season burns, if applied annually, may over time actually reduce the cover of plants such as wiregrass that are stimulated to flower by fire. These results warrant closer scrutiny to exotic species. However, May burns also caused different and longer lasting effects to the native herbaceous understory than March burns, with composition in the March (dormant season) burn plots appearing more similar to the unburned control.
Soils

Consumption of surface and live fuels releases nutrients, some of which may be leached from the system unless they are taken back up by micro-organisms or growing vegetation. It is therefore believed that prescribed fire close to the onset of growth or during the active season when growing tissue is accumulating nutrients might lead to less leaching from the system. Another possibility is that more nutrients could be volatilized when actively growing tissues are burned than when tissues are burned during the dormant season. By the time of the dormant season, at least some of the nutrients from aboveground structures have already been translocated to underground storage structures and therefore escape being volatilized. However, very little data are available to back up either the leaching or volatilization theories. In longleaf pine forests, one study documented greater nitrogen loss with growing-season (June) burns than dormant-season (March-April) burns, presumably as a result of live fuels being volatilized. However, nitrogen fixation and atmospheric deposition were believed sufficient to compensate for this loss if the fire regime is not exclusively growing season, i.e., including a mix of seasons. There was no difference in phosphorous with burning-season treatments.

Wildlife

Birds

Timing of early prescribed burning in the Southeastern United States was strongly influenced by concerns about game birds and other ground-nesting species. Late winter to early spring burning became popular because this period occurred after the end of hunting season but prior to nesting season for quail and other species. To reduce the feared catastrophic effect on clutch success of ground-nesting species, burning at this time of year became “ingrained in the culture of the Southeast”. However, the majority of studies have since shown few strong effects of burn season on direct mortality, breeding success, or survival of birds. In fact, overwinter survival of Henslow’s sparrow (Ammodramus henslowii) was found to be greater in areas previously burned in the growing season than in areas previously burned in the dormant season. In another study, abundance of wintering bird communities did not differ one year after burns conducted in the growing season (April-August) or the dormant season (January-March).

Many bird species prefer to nest in stands that have been burned within 1 or 2 years. For example, the majority of Bachman’s sparrow (Aimophila aestivalis) nests (>85 percent) were found in areas that were recently burned during the growing season, and the majority of wild turkey nests (62 percent) were found in forest that had experienced a growing-season burn within the past 2 years. Management using a regime of growing-season burns 3 or more years apart, but within a patchy landscape with units varying in time since last fire, would therefore likely impact relatively few ground nests.

Changes in vegetation brought about by burning in different seasons can indirectly influence bird populations. Dormant-season burning in longleaf pine forests can impact the structure and composition preferred by different bird species by promoting hardwoods over grasses and forbs. Red-cockaded woodpecker (Picoides borealis) and other bird species are generally less abundant in forests where understory hardwoods have encroached. Although lengthening of fire intervals is believed to be the main cause of red-cockaded woodpecker decline, growing-season burns have been shown to more effectively suppress midstory hardwoods and promote a ground cover composition favorable for arthropod food sources for these birds. In a study of bird community response to fire, it was found that neither January nor June prescribed burns in a dry prairie in south Florida altered bird species richness, compared with the unburned control. Both
of the burning season treatments reduced shrub cover.

Ground cover is beneficial to some overwintering migratory birds such as Henslow’s sparrow. Burns in the winter (February-March) eliminate this ground cover, and research shows that growing-season burns improve survival over dormant-season winter burns. Spatial patchiness is another characteristic of fires potentially important for birds and other wildlife, and spatial patchiness can differ among burning seasons because of variation in fuel moisture.

Overall, reviews of the limited literature show few if any effects of burning season on bird populations. Although growing-season burns may cause some direct mortality by destroying nests and killing young birds, many bird species renest, and the indirect benefits of habitat alteration are usually far more important and likely compensate or more than compensate for losses.

**Arthropods**

One study hypothesized that burning during the growing season may have fewer detrimental effects on arthropods than burning during the dormant season because a greater number of individuals have wings and are mobile at this time of year. Arthropod abundance was found to be equal or greater following growing-season burns than following dormant-season burns. However, a fall survey in Florida oak scrub found that garden orbweaver spider (*Argiope* sp.) numbers were not affected by burns in February, but were substantially reduced by burns in July and August. Spiderlings disperse in April and May through ballooning, so the low numbers immediately following summer fires may simply be due to lack of dispersal opportunities between the time of the fire and the time of sampling. In a hardwood stand in Kentucky, a single March prescribed fire reduced the invertebrate mass by 36 percent, with the majority of this loss occurring among species associated with the forest floor.

Neither burns in July nor November altered the population size of the Karner Blue butterfly (*Lycaeides melissa samuelis*) 1 to 3 years later, compared with unburned controls. The July burns were during the period of the second flight of the summer, whereas the November burns occurred after activity had ceased for the year. Burns in both seasons were described as “cool” (i.e., not at times of the year when flame lengths are greatest), which may have allowed some of the eggs on vegetation in this oak savanna system to survive. Overall, it is apparent that how fire affects arthropods will differ greatly by species and functional group, with burning potentially most detrimental if the timing coincides with a particularly vulnerable life history stage. Several authors have recommended that prescribed burning be done in such a way as to maximize patchiness so that invertebrates are able to survive in refugia and recolonize the burned areas.

**Implications for Managers**

The majority of studies on burning-season effects in eastern forest ecosystems have been conducted in pine- and pine-oak-dominated forests of the Southeast. In this forest type, the literature provides compelling evidence that growing-season fire can lead to shifts in the plant community, relative to a regime of dormant-season fire. Repeated burns during the growing season (especially in May, early in the growing season) curtail resprouting and eventually suppress the less fire-resistant midstory hardwood vegetation more so than burns at other times of the year. On the other hand, the pine overstory appears to be minimally affected by burns in any season. This is particularly true for longleaf pine, a strongly fire-adapted species. The end result is that repeated growing-season burning leads to greater grass and herbaceous species abundance and diversity under the pine canopy, whereas more shrubs may be maintained with a regime of dormant-season burning. Early prescribed burning was often done during the dormant
season to avoid conflicts with wildlife reproduction, including bird nesting. However, recent research generally does not show that burns in the growing season affect bird populations more than burns at other times of the year. In the few cases where differences in animal communities with varying burning seasons have been reported, the mechanism is usually indirect, involving some alteration of understory structure. Understory vegetation of the Southern United States grows so rapidly in the absence of fire that the effect of burning or not (fire frequency) is generally much greater than the effect of burning season.

Data from the many long-term burning studies conducted in the Southeastern United States indicate that substantial changes likely require many burn cycles to achieve. A single burn in any season generally does little to alter plant or animal communities. Therefore one burn or a few burns outside of normal season is/are unlikely to have a major impact. In addition, the importance of burning generally outweighs any effect of season of burning. Because prescribed burns are usually easier to conduct during the dormant season than during the growing season/lightning season, more acres may ultimately be treated by employing a regime of both dormant- and growing-season burns.

**Table 6. Key Points - Southeastern Region**

<table>
<thead>
<tr>
<th>Key Points-Southeastern Region</th>
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<tbody>
<tr>
<td>• There is little evidence that mortality or growth of southern pines differs after growing- or dormant-season prescribed burns.</td>
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<tr>
<td>• Phenology does influence the response of midstory hardwoods in pine forests, with early-growing-season (May) burns (coupled with short fire-return intervals) more likely to control or kill these species than dormant-season burns. The result of early-growing-season burns is often an understory with greater cover of grasses and forbs.</td>
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<tr>
<td>• Burning season has little effect on growth and mortality of overstory oak species, but higher intensity fire (in whatever season fuels are sufficiently dry to burn at higher intensity) likely favors oaks over the long term, by killing competing mesophytic species such as yellow poplar or maple.</td>
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<tr>
<td>• Although some understory plant species respond positively to fire in the growing season and others respond positively to fire in the dormant season, the majority do not appear to be significantly affected by burning season.</td>
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<tr>
<td>• Few strong direct impacts to wildlife from prescribed fire in any season have been documented; effects, both positive and negative, appear to be mostly indirect, and primarily the result of fire-season-specific habitat changes.</td>
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<tr>
<td>• Whether the ecosystem is burned or not (fire frequency) appears to play a stronger role in the response of most species than the relatively minor effect caused by different burning seasons.</td>
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<tr>
<td>• Differences in fire effects among species suggest that a variable fire regime, including a mix of growing- and dormant-season burns and different burn intensities may maximize biodiversity.</td>
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**North East and North Central**

The fire climate in the Hot/Warm Continental regions of the Central, Great Lakes, and North Atlantic States is generally driven by air masses bringing moist humid tropical air in the spring and summer and polar continental air in the late fall and winter. The annual precipitation averages between 20 to 45 inches in the Central States and about 30 inches in the Great Lakes States. Although precipitation is fairly well distributed throughout the year, somewhat more rainfall occurs during the summer, coinciding with the highest temperatures of the year.

Forests of the warmer areas from the middle-Atlantic States through the Appalachian Mountains and into the Northeast are mostly dominated by oaks and hickories. The main carrier of fire is leaf litter, which differs in flammability with site and time of year. Recurring fire has maintained oak dominance in these forests at the expense of mesophytic tree species. On xeric sites, lack of fire has increased the presence of ericaceous shrubs such as rhododendron (*Rhododendron*) and mountain laurel (*Kalmia latifolia*). When fire does occur, these shrubs can burn at high intensity, potentially leading to stand replacement.

Farther north, in the Great Lakes region, spruce (*Picea*), fir (*Abies*), eastern white pine (*Pinus strobus*), red pine (*Pinus resinosa*), jack pine (*Pinus banksiana*), and aspen (*Populus*) dominate as a fire-maintained stage or as a climax forest. Fires in pure aspen stands are typically of low intensity, but fire can still cause significant mortality of aboveground stems. Areas with higher fuel loads in mature aspen stands may sometimes experience high-intensity stand-replacing fires. Red and eastern white pines occupied pure stands or were found in association with aspen, jack pine, and a variety of hardwoods, and experienced similar mixed-severity fire regimes as aspen stands.

**Historical Fire Regime**

The fire regime of the mixed-oak forests consisted of primarily low-severity events occurring approximately every 3 to 13 years. Farther north, in the Great Lakes and Atlantic regions, typical fire-return intervals ranged from 35 to over 200 years. Location of fire scars within growth rings suggests that most fires occurred during the dormant season. The dormant season lasts from approximately late September to April. When hardwoods are not in leaf, litter is exposed to sunlight, making it susceptible to fast drying. Aboveground portions of understory herbaceous vegetation are also mostly dead at these times of the year, increasing the likelihood of fire spread. When leaves are on the trees, the microclimate on the forest floor is often shady and moist, which generally results in poor conditions for burning. The exception occurs during periods of drought. Convective activity is still high during this time, and drought overrides the typically moist understory microclimate.

Lightning is fairly common and mostly associated with summer convective storms that also typically include precipitation. However, because of the lack of dry fuels, the peak fire season is frequently driven more by the surface fuel conditions than the times of peak lightning frequency. The relative lack of lightning during times of the year when leaves are on the ground and most flammable, and tree ring data indicating predominantly dormant-season burns, suggests the role of another ignition source in many areas. Paleoecological evidence that fire-resistant tree species were more abundant during periods of Native American settlement also hints at a link between
forest composition, fire, and human activity.

**Prescribed Fire Regime**
Most prescribed burning in eastern hardwood forests is conducted during the dormant season, prior to leaf emergence in the spring or after leaf drop in the fall. The period of time that the litter fuel bed is receptive to fire depends on the latitude and year-to-year weather variation. In southern hardwood forests, prescribed burning may be conducted any time the litter layer is dry, whereas farther north, persistent snow cover limits application of fire to a narrower period in the spring and fall.

The prescribed fire season appears not to differ greatly from the historical fire season, at least for the period of Native American settlement. However, in areas where late summer burning was historically part of the fire regime, a higher proportion of the landscape is now possibly being treated in the dormant season. Because vegetation is dormant and wildlife species are less likely to be active during the dormant season, concerns about direct fire effects are minimized. The extent to which prescribed fire effects differ from historical fire effects may be due primarily to differences in fire intensity, if any. One concern may be the lack of heterogeneity in the fire regime when a strictly dormant-season prescribed burning program is employed.

**Ecological Effects of Burning Season**

**Overstory Hardwoods**
A frequent goal in restoring fire to eastern hardwood forests is to improve growing conditions for a variety of oak (*Quercus*) species. In the absence of fire, hardwoods such as maples (*Acer*) and yellow poplar (*Liriodendron tulipifera*) that would normally be restricted to wetter sites have gradually moved into the uplands, outcompeting and eventually replacing the oaks. Because the majority of prescribed burning in this forest type is done in the dormant season when litter is the most flammable (similar to the main historical fire season), season of burning is less of an issue. As a result, few burning-season studies have been done in hardwood stands.

Of fires conducted in February, April, and August, the April fires were, on average, the most intense and did the most to favor oaks over yellow poplar. Variation within burns was exploited to investigate regeneration differences with burn intensity and burn season. High-intensity fire was the most effective at reducing yellow poplar and favoring oak in each burn season. Although summer burns were predominantly low intensity owing to shading and higher relative humidity, moderate- and high-intensity patches within the fires at this time of year produced the strongest differences in regeneration success between species. It therefore appears that both fire intensity and phenology play a role.

**Understory Shrubs**
Less is known about effects of burning season on understory shrubs in areas north of the southeastern pine zone. In one of the few studies on the topic, researcher noted that 95 percent of small saplings and shrubs in an Illinois forest were top-killed by either a single dormant-season (March) burn or a single growing-season (May) burn. In another study of understory response in mixed-hardwood and pine forests of Minnesota, both spring dormant-season and summer growing-season burns completely top killed hazel (*Corylus*), but resprouting was enhanced by repeated spring burning and reduced by repeated summer burning. Because humus was combustible during dry summer conditions, fires at this time of year were more likely to kill the
roots. Carbohydrate reserves were also more likely to be exhausted following repeated summer burning.

**Soils**
A recent study reported very little effect of burning season on soil variables in an oak-pine forest in Massachusetts. The organic horizon (duff layer) was reduced more by summer burns than by spring burns, and replacement with mineral soil caused the bulk density to also be higher. All other variables including pH, acidity, base saturation, total exchangeable cations, carbon, and nitrogen did not differ between burn seasons.

Some other potential impacts of fire in different seasons on soils are likely associated with variation in fire intensity or extent of soil exposure. Soil is exposed for a longer period after burns in fall and winter (dormant season), and this could alter the rate of erosion. A literature review found only a single study addressing erosion and season of burning. A study reported greater sediment yields after winter burns than spring and summer burns, attributing this to direct exposure of the soil to raindrops for a longer period with winter burns. Summer burning produced the least erosion, possibly because these burns were patchier. The lack of studies on erosion with prescribed fire in the Eastern region may be due, in part, to the relative lack of topography in many areas with active prescribed burning programs.

**Wildlife**
Early forest managers generally avoided burning southeastern pine forests during the late spring and early summer, because of concerns about harming wildlife species. However, with this time of year being the peak historical fire season, others concluded that wildlife must have evolved means to survive. Direct effects to wildlife are perhaps less of a concern in the eastern hardwood forest ecosystems because especially in the north, fire historically occurred primarily during the dormant season when many species are less active.

**Small Mammals**
The effect of different prescribed burning seasons on small mammal populations remains poorly studied. Both historical fires and prescribed burns in eastern forests may be of sufficiently low intensity and patchy enough that the variable needs of small mammal populations are met, regardless of burn season. A study in oak stands in Virginia that compared effects of winter, spring, and summer prescribed burns reported no detectable short-term losses of ground-dwelling species such as shrews (*Sorex* and *Blarina*) and white-footed mice (*Peromyscus leucopus*). Longer term habitat changes, such as differences in hardwood midstory cover or ground exposure owing to variation in the burning season, could potentially affect small mammal populations. Fires conducted in March or August annually for 3 years in Florida longleaf pine sandhill forests resulted in no difference in pocket gopher (*Geomys pinetis*) mounding or body size. Although a minor increase in herbaceous biomass was noted following March burns, this apparently did not influence gopher behavior. Overall, consistent trends in small mammal response to habitat changes with burning season have not.

**Implication for Managers**
Both phenology and fire intensity appear to play a role in determining fire effects in forests of the Eastern region, with the outcome depending on the species and the differences in intensity
between burn seasons. As with fire in the Western and Central regions, phenology and intensity are often confounded, making their relative contributions a challenge to determine. Several of the more robust studies of burning season concluded that for many species, fire intensity plays a significant role in determining the outcome. Differences in intensity, if any, are often due to higher ambient temperatures and greater use of heading fires during the growing season. However, lower fuel moisture levels can also sometimes result in dormant-season burns being more intense, particularly in hardwood forests that lack the pyrogenic vegetation of the southeastern pine zone.

The importance of phenology relative to fire intensity in the Eastern region appears to be intermediate between the Western region and the Central grasslands; this goes along with apparent differences in the amount of fuel consumed between seasons, which are in most cases less than differences among burning seasons in the Western region, but greater than differences among burning seasons in the Central grasslands. For some species, fire intensity may override the effects of phenology at the time of the burn, especially if the difference in fire intensity among seasons is substantial.

One key point mentioned repeatedly in the literature is that a frequent yet heterogeneous fire regime, including a range of fire seasons, may be necessary to sustain species diversity, or even to maximally benefit individual species where different parts of the life cycle are variably affected by burning season. To mimic the variability inherent in the historical fire regime, one study created a table random fire frequencies and seasons (within specified ranges) for xeric to mesic longleaf pine habitats, with a weighting so that two growing-season (May-June) burns are conducted for each dormant-season burn. The objective of such a table is to ensure that rigid burning schedules, which would tend to favor some species over others, are avoided. Also, occasional longer (8 to 10 years) rest periods are incorporated that would allow seedlings of certain species to become established.

Table 7. Key Points - Northeastern Region

<table>
<thead>
<tr>
<th>Key Points-Northeastern Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Burning season has little effect on growth and mortality of overstory oak species, but higher intensity fire (in whatever season fuels are sufficiently dry to burn at higher intensity) likely favors oaks over the long term, by killing competing mesophytic species such as yellow poplar or maple.</td>
</tr>
<tr>
<td>• Although some understory plant species respond positively to fire in the growing season and others respond positively to fire in the dormant season, the majority do not appear to be significantly affected by burning season.</td>
</tr>
<tr>
<td>• Few strong direct impacts to wildlife from prescribed fire in any season have been documented; effects, both positive and negative, appear to be mostly indirect, and primarily the result of fire-season-specific habitat changes.</td>
</tr>
<tr>
<td>• Whether the ecosystem is burned or not (fire frequency) appears to play a stronger role in the response of most species than the relatively minor effect caused by different burning seasons.</td>
</tr>
<tr>
<td>• Differences in fire effects among species suggest that a variable fire regime, including a mix of growing- and dormant-season burns and different burn intensities may maximize biodiversity.</td>
</tr>
</tbody>
</table>
Alaska

It is clear from recent research that lightning ignitions have been the principal source for burned area in the boreal forest region of Alaska since the 1950s; however, during the 1950s and 1960s, human-ignited fires contributed significantly to annual burned area (30% of the total). Because of their proximity to suppression resources, human-caused fires are more easily controlled than lightning-ignited fires. With the increase in the availability of fire suppression resources, as well as the change in fire management policy in the mid-1980s that gave higher priority to suppressing fires in areas near human settlements, the number of large human-caused fires has been drastically reduced, and the portion of annual area burned from humans is now low (<5% of the total). An unintended consequence of fire suppression around settlements, however, is the increase in hazardous fuel types, which may require fuels mitigation in the future if the potential for rapid fire spread continues to be high in a warming climate.

Recent changes in climate have resulted in increases in the frequency of large fire years and have resulted in a dramatic increase in extreme fire events. Four of the 11 largest fire years on record since 1940 have occurred between 2002 and 2009, and the increase in frequency of large fire years has been accompanied by an fourfold increase in late-season burning that occurs because large and increasing numbers of extreme fire events in remote areas are too large to control. The evidence now points toward the fire regime being vulnerable to climate warming over the near term with the potential for a continuation of large fire years and events and more late-season burning being high. Given the fact that management options are limited by both economic considerations and difficulties in suppressing fires in remote regions (especially during droughts), opportunities for reducing burned area through suppression are limited. Because permafrost is warming, the likelihood of increases in the frequency of deep-burning fires that change forest ecosystems is also high. At some point, however, increases in early-successional vegetation combined with changes to post-fire succession in black spruce forests will reduce the vulnerability of the landscape to fire spread.

Historical Fire Regimes

Combining burned area derived from climate reconstructions (1860-1939) with estimates from fire management records (1940-2009) has provided for an assessment of longer-term trends in Alaskan wildfire activity. Average area burned at a decadal scale was regulated by the frequency of large fire years (>1.1 million acres burned). There was a change in Alaska’s fire regime beginning early in the 20th century. Since the 1920s, there has been at least one large fire year each decade, an average of 2.3 large fire years per decade, and an average area burned of 987,680 acres/year. The highest average annual burned area (1,895,298 acres/year) occurred in the 2000s. Between 1860 and 1919, there were three decades without a large fire year, an average of 0.8 large fire years per decade, and an average burned area of 1,038,831 acres/year. The highest average burned area of 2,654,582 acres/year occurred during the 1870s. The fire return interval was 159 years for 1860-1919 and 105 years for 1920-2009.

Data from the 1940s to 2000s show that the number of large fire years during the 1940s and 1950s was the same as during the 1990s and 2000s (seven), with less frequent large fire years during the intervening 30 years. The number of extreme fire events (>123,552 acres) was high during the 1950s, low in the 1960s through 1980s, and then rose during the 1990s and 2000s. As a result of changes in the frequency of large fire years and extreme fire events, there was a
decrease in decadal average area burned from the 1940s and 1950s through the 1980s and a rise in the 1990s and 2000s. The 2000s experienced the highest burned area and number of extreme fire events during the modern record period.

The relationship between burned area and the number of large fire years has been observed across all Canadian boreal forest ecoregions. The burned area trend in Alaska over the past 70 years differs from that observed Canada, where average burned area increased continuously from the 1940s (2,017,615 acres/year) through the 1990s (7,834,970 acres/year) before sharply decreasing in the 2000s (4,087,864 acres/year).

**Prescribed Fire Regimes**

During the 2000s, 13.5% of the land surface below treeline (<26,250 feet asl) in the nine ecoregions that comprise the boreal forest of interior Alaska was impacted by fire, affecting 26.6% of the area in the North Ogilvie Mountains and 25.3% of the area in the Yukon-Tanana Uplands. The increases in burned area during the 2000s lowered the fire return interval in all ecoregions compared with previous estimates. The decrease was particularly dramatic in the Yukon-Tanana Uplands and the North Ogilvie Mountains. Overall, the estimated fire return interval based on assuming that all area within a fire perimeter burned decreased from 196 to 144 years.

Although not a widely used practice in Alaska, prescribed burning has been utilized as a hazard reduction and resource management tool by the BLM, NPS, USFWS, USFS, and State of Alaska. The National Wildlife Refuge system in Alaska encompasses 16 refuges and 77 million acres. The Tetlin National Wildlife Refuge, at 724,000 acres, and the Kenai National Wildlife Refuge, at 1.7 million acres, are the only two road-accessible refuges in Alaska. A refuge management purpose common to both refuges is "to conserve fish and wildlife populations and habitats in their natural diversity." In Alaska, fire often plays an important role in supporting this purpose. Both Tetlin and Ken& refuges have stand replacement prescribed burn plans in place.

**Ecological Effects of Burning Season**

Black spruce (*Picea mariana*) is the dominant tree species found in the boreal forest region of Alaska, occurring primarily in monospecific stands containing deep (10 to >40 cm) surface organic layers. Tree mortality is not used as a measure of severity in these forests because black spruce has low resistance to high temperatures and exposure to even moderately intense surface fires results in death. Rather, the reduction in depth of the surface organic layer is felt to be the most relevant measure of severity in this forest type.

Recent studies using data collected in Canadian black spruce forests have shown that weather-driven variations in the moisture of the surface organic layer (as indicated by the drought code of the Canadian Forest Fire Danger Rating System) are a good predictor of the level of surface fuel consumption in all forest types. In contrast, studies have shown that the drought code is not a good predictor of surface fuel consumption in Alaskan black spruce forests, most likely because the moisture content of deeper organic layers in interior Alaska is strongly influenced by seasonal thawing of soils in areas underlain by permafrost (a characteristic that is not reflected in the drought code). Studies showed that within a single fire event, black spruce sites without permafrost have shallower residual surface organic layers following the fires than sites with permafrost. The depth of the pre-fire organic layer in black spruce forests is related to site drainage, which in turn controls depth of burning and residual depth. Sites located on poorly drained north aspect backslopes and foot and toe slopes were more resistant to deep burning.
Sites with permafrost that burned late in the growing season experienced deeper burning than sites that burned in the middle of the growing season as a result of seasonal increases in the thaw depth.

Finally, the hydrologic conditions of the forest floors of Alaskan black spruce forests control moss species composition, which has a strong influence on the consumption of ground layer fuels. Wetter sites with higher proportions of Sphagnum mosses tended to have high spatial variability in fuel consumption due to the efficient moisture retention traits of many Sphagnum species that inhibit combustion. As a result, Sphagnum hummocks often were the only fuels left remaining following severe fire activity.

Stands of black spruce are common on poorly drained sites and stands of white spruce (P. glauca) are common on better drained sites. Birch (Betula) and aspen (Populus tremuloides) are abundant in early to mid-successional stages of forest development. Alder (Alnus), willow (Salix) and ericaceous shrubs (heath) are common in the understory with a moss layer and lichens on the forest floor.

In boreal forests, tree establishment generally occurs in the first few years after fire. Therefore, factors affecting tree regeneration could have a long-term effect on forest succession. Post-fire forest succession in boreal forests as generally returning to the predisturbance forest cover type, thus, white spruce forests, after fire, generally return to white spruce in the absence of additional disturbance, but the rate of change and species composition can differ. Post-fire vegetation succession depends on a number of factors including initial vegetation state, fire severity, and post-fire conditions such as (1) presence of seeds and resprouting buds, (2) seedbed quality, and (3) climate and weather conditions.

A generalized post-fire successional path to mature forest for spruce stands in interior Alaska would likely pass through the following stages: (1) the moss-herb stage with seedlings of woody species (if seeds are available and seedbed conditions are favorable for establishment) immediately following disturbance; (2) the tall shrub-sapling stage, assuming either sprouts or seeds are available and seedbed conditions are favorable; (3) the dense tree stage (either hardwoods or conifers); if hardwoods are present the stand passes into; (4) the hardwood stage; if no hardwoods are present the stand progresses to; (5) the spruce stage. In forests of interior Alaska, the age of mature spruce trees is generally less than 300 years. A divergent or delayed successional pathway may be caused by several conditions: catastrophic fire events, fire events that are not sufficiently severe to create a mineral seedbed, or recurrent fire events that change the rate or pathway of forest development (Payette 1992). For example, if seedlings and shrubs are not established owing to lack of seeds or suitable seedbed, the herbaceous phase may dominate for an extended period.

Herbivory is an additional factor that impacts the successional sequence and rate of vegetation composition change by selectively reducing or eliminating certain species. Although fire is considered an important disturbance force in boreal forests, few fire history studies have been completed in Alaska. Reconstructing fire history is impeded by lack of long-term historical records and lack of fire scarring on boreal tree species. The goal of many fire history studies is to produce an estimate of the fire interval (the average number of years between two successive fire events in a given area) and fire cycle (the average time required to burn an area equal to the size of the study area). In the Porcupine River drainage in interior Alaska, one study described a fire cycle and fire-return interval of 105 and 113 years, respectively, for white spruce; and 36 and 43 years, respectively, for black spruce. A fire cycle was described for lowland black spruce on the Kenai National Wildlife Refuge, which borders the Chugach National Forest to the west.
between 42 and 56 years; an increase in fires after 1828 was coincident with European settlement of the Kenai.

**Implications for Manager**
Changes in ecosystem structure associated with the response of the fire regime to a changing climate also have implications for the use of subsistence resources because the species composition as well as the stand age structure of Alaska’s boreal forests influence the suitability of these forests as wildlife habitat. This is particularly true for the two large-mammal species (caribou and moose) that represent major subsistence food sources for many Native Peoples. While older mature black spruce woodlands with arboreal lichens are the preferred winter forage for caribou, early-post-fire-successional forests with willow and aspen regrowth are preferred by moose. Thus, future increases in fire frequency and fire severity are likely to result in a vegetation cover mosaic that favors moose over caribou, making Alaska’s interior caribou herds vulnerable to forest cover changes that are being driven by changes in the fire regime.

Major shifts in vegetation type and distribution as a result of changes in the fire regime could substantially impact land management policies. At present, fire suppression policies are based on the perception that black spruce forests represent the fuel type that is required for sustaining large fire growth and thus provides for increased fire risk in the wildland-urban interface. Yet, recent modeling of the impacts of fires shows that the landscape will be transformed in such a way that future fire suppression activities will occur during the smaller fire events caused by the increased presence of multiaged stands. This represents a paradigm shift from the picture of black spruce forests underlain by feathermoss as being the most prevalent problem-fuel type and will eventually force a reexamination of current forest fuels management and hazard fuel reduction practices.

For wildland fire management programs within land management agencies (primarily the US Fish and Wildlife Service and the US National Park Service), managing the landscape to maintain the values in the natural ecosystems present in the landscape has become increasingly complex. As changes in the interlinked relationships among climate, fire frequency, fire severity, vegetation patterns, and permafrost that result from changes to the fire regime become more clearly understood, new strategies will have to be considered for managing for biodiversity and other important natural resource values. With the recent development of remotely sensed data and modeling tools following the large fire years of 2004 and 2005, land and fire managers are now discussing and developing different options to manage fire to meet various agency mandates. Ideas being considered range from increasing the desired suppression level for older-aged black spruce stands in a rotational pattern to maintain a portion of an area in older classes to using prescribed fire or mechanical treatments to change fuel composition in large contiguous stands to decrease the potential for a single fire to burn over a large area.

The increase in the frequency of large fire years has resulted in an increase in late-season burning, thus lengthening the fire season. In addition, warming summer temperatures clearly trigger more convective storm activity and increase the number of lightning strikes. A larger, warmer expanse of Arctic Ocean in September may contribute to more fires in tundra areas in the northern part of Alaska. All of the factors above seem to point toward more wildland fire across a broader area in Alaska if the climate continues to warm.
Table 8. Key Points - Alaska

<table>
<thead>
<tr>
<th>Key Points-Alaska</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Early-successional grasses and forbs and browse species increase in abundance following prescribed burning where they were present in the initial vegetation composition. Late-successional and forest associated species tend to decrease following prescribed fire.</td>
</tr>
<tr>
<td>• Deeper burning of surface organic layers in black spruce forests occurred during late-growing-season fires and on more well-drained sites. These trends all point to black spruce forests becoming increasingly vulnerable to the combined changes of key characteristics of Alaska’s fire regime, except on poorly drained sites, which are resistant to deep burning.</td>
</tr>
<tr>
<td>• Over the past 60 years, there was a decrease in the number of lightning-ignited fires, an increase in extreme lightning-ignited fire events, an increase in human-ignited fires, and a decrease in the number of extreme human-ignited fire events.</td>
</tr>
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<td>• Changes in ecosystem structure associated with the response of the fire regime to a changing climate also have implications for the use of subsistence resources because the species composition as well as the stand age structure of Alaska’s boreal forests influence the suitability of these forests as wildlife habitat. This is particularly true for the two large-mammal species (caribou and moose) that represent major subsistence food sources for many Native Peoples. Future increases in fire frequency and fire severity are likely to result in a vegetation cover mosaic that favors moose over caribou.</td>
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Hawaii

Historical Fire Regimes

The natural fire regime in Hawaii is difficult to reconstruct in detail. Accounts of natural fires are rare and contain little ecological information. Lack of annual tree growth rings precludes developing a precise fire history based on fire scar chronologies. Radiocarbon dating of charcoal found in soil and bogs has the potential to indicate broad patterns of fire occurrence, but most carbon-dating studies have been conducted by geologists interested in dating lava flows or by anthropologists interested in cultural sites. Moreover, carbon in volcanic sites may indicate fires along the immediate edge of flows or phreatic eruptions, rather than free-burning fires. The published literature on carbon-dating of charcoal deposits in Hawaiian bogs is meager and not useful for detailed fire history studies.

Studies have confirmed the probable occurrence of fire prior to human colonization. Carbon has been found in a core from an 0’ahu bog revealing a 26,000-year record of fire occurrence. One study reported undated carbon burned at a depth of 0.5 m in Laupahoehoe Forest Reserve on Hawaii Island, a location that suggests the occurrence of wildfire rather than volcanic activity. Evidence has been found of natural fire in a widely distributed pattern of carbon dates on the northern, eastern, and southeastern slopes of Mauna Loa, all approximately 400 years old and not
consistent with local flows. This pattern suggests the possibility of a large fire, possibly ignited by Keamoku lava flows of that age.

The paucity of carbon in subsurface soils formed before human colonization and away from volcanically active areas implies a low fire frequency. Carbon dating in Hawaii Volcanoes National Park, which should have the highest occurrence of soil carbon because of volcanic activity, confirms this pattern. Soil profiles from three Park sites, Klpuka Ka, Klpuka Puaulu, and ‘01a’a, indicate the absence of fires over the last 2,000 years, although charcoal is associated in these sites with phreatic eruptions. However, these are mesic and wet sites, and soil pits in dry sites might indicate a different pattern.

A low natural frequency of fire is also implied by the infrequency of natural ignition sources, low flammability of native vegetation, and discontinuous distribution of natural fuels. Lightning was a more frequent source of fire than commonly believed. However, lightning-initiated fire is uncommon, although strikes without fire spread are responsible for tree mortality in rain forest, and lightning strikes are known to have started a few recent grassland fires. Fires started by lava flows are common during volcanic eruptions, at least in alien grass fuels. However, volcanism is highly localized in Hawaii, being confined mostly to one island at any one point in time.

Flammable, fire-dependent, or fire-maintained vegetation did not characterize most original, undisturbed Hawaiian vegetation types. The low flammability of native fuels implies poor adaptation to fire. Few native species have oils or resins frequently associated with fire-adapted plants, although Dubautia and Dodonaea may have. Moreover, most vegetation types were dominated by open stands of trees and shrubs. Alpine and subalpine plant communities were characterized by a sparse to open cover of low shrubs with localized patches of grass. Before disturbance, the submontane seasonal vegetation zone was dominated by woodlands with an understory of open shrubs, sedges, lichens, and bryophytes. The rain forest vegetation zone is almost invariably wet, and litter usually recycles rapidly, although uluhe (Dicranopteris linearis)-dominated rain forest can carry fire after extended dry periods. Pre-Polynesian coastal vegetation is not well understood. Pili grass (Heteropogon contortus), possibly indigenous to Hawai‘i, may have been abundant in some areas. Dryland forest, which may have been much more widespread, does not support fine fuels to carry fire.

The apparent fire tolerance of some native plants is less clearly indicative of past natural fire regimes than fire history, ignition sources, flammability, and fuel distribution. Some native species do not recover well from fire, but these species may eventually recover from seed and be important late in plant succession. The fact that other native plants can resprout after fire does not imply that they are specifically adapted to fire. One study suggested that adaptations to various natural stress factors provides a good explanation for fire tolerance of some native species. In addition, ancestral populations of certain species may have been adapted to fire prior to their establishment in Hawai‘i. The ability to resprout after fire is found in species characteristic of plant communities unlikely to carry fire. For example, many rain forest woody plants (e.g., kawa‘u, Ilex anomala) and tree ferns (e.g., Cibotium glaucum) resprout vigorously after fire. Yet, many lowland trees in Hawai‘i, e.g., lama (Diospyros sandwicensis) and wiliwili (Erythrina sandwicensis), which grow in relatively dry environments, do not resprout. Recovery of native plants from fire is also difficult to evaluate in Hawaiian ecosystems because it is strongly influenced by competition from alien vegetation. Native vegetation may recover adequately from fire, but it is often masked by the prolific spread of alien plants.
In conclusion, the natural fire regime in many areas of Hawaii is best characterized as fire-independent. Pre-settlement fires were probably irregular, infrequent, short-term ecological perturbations from which vegetation eventually recovered; fires were thus insignificant as long-term evolutionary factors.

**Prescribed Fire Regimes**

The fire regime in Hawaii has changed dramatically in recent decades, with a considerable increase in fire frequency and probably fire size. An altered fire regime is reflected in the fire history of Hawaii Volcanoes National Park, the only natural area with continuously recorded fire history over the last 60 years. Most of the fires (73%) in the Park have been caused by humans. Twenty-five percent were ignited by lava flows in an area with the highest incidence of volcanism in the State, and 2% were caused by lightning (National Park Service 1990).

Fire frequency and size increased greatly in Hawaii Volcanoes after 1968. Twenty-seven fires, averaging 10 acres, were recorded between 1920 and 1967. Since then, 58 fires have burned an average of 507 acres each. The increase in fire frequency and size can be attributed to an accumulation of fine fuels, primarily alien grasses, which spread and intensified in the 1960s and 1970s. Photo points and exclosure studies indicate that increase of grasses in the coastal lowlands coincided to the removal of feral goats (*Capra hircus*) in the early 1970s. During this period, the proliferation of perennial grasses such as thatching grass (*Hyparrhentia rufta*), Natal redtop (*Rhynchelytrum repens*), pili grass, and molasses grass (*Melinis minutiflora*) produced a many-fold increase in biomass and a fuel bed capable of supporting fire. Broomsedge (*Andropogon virginicus*) and bush beardgrass (*Schizachyrium condensatum*) invaded and spread throughout the submontane seasonal zone during the 1960s and 1970s, in spite of the presence of feral goats. The first fire carried by these grasses was reported in 1968. Increased volcanic activity and greater numbers of visitors may have also contributed to the increased number and average size of fires in Hawaii Volcanoes National Park.

The use of natural fire is not appropriate to the management of native ecosystems in Hawaii. Studies and observations to date indicate that fires of all intensities, timing, and causes are harmful to most native ecosystems in Hawaii. Alien species, particularly grasses, recover rapidly and fill in the spaces left by native plants, which recover more slowly, if at all. The intensification of fire-prone alien grasses following fire assures the increased incidence of fire, thereby establishing a self-perpetuating alien grass/fire cycle. The effects of fire argue strongly that all agencies responsible for the management of fire in natural areas in Hawaii should aggressively suppress all fires, whether caused by lava flows, lightning, or humans. Fire size should be minimized, even though limited suppression resources may necessitate confinement or containment strategies, with control lines established at a distance from the fire, rather than direct attack.

Prescribed burning is not, on the whole, an effective management tool in Hawaii, although it may have potential limited management and research value. On the U.S. Mainland, prescribed burning is useful in restoring natural ecological processes, rectifying anthropogenically altered vegetation patterns, reducing hazardous fuel loadings, enhancing wildlife habitat, and in a few cases controlling alien plants. However, fire is not useful in controlling alien plant species in native Hawaiian ecosystems, although it may be useful in controlling selected alien plants in managed systems dominated by alien plants. Kiawe and melastomes, for example, are relatively sensitive to fire and may be controlled by burning.

Prescribed fire in Hawaii may be useful in accelerating the recovery of ‘a‘ali‘i shrublands
and koa forest or woodlands, because these two species are stimulated by fire. However, before fire is used for this purpose, the effects of fire on stimulating alien species, damaging sensitive native plants in these communities, and natural recovery should be considered. Fire may have been a natural ecological factor in montane seasonal shrublands, grasslands, and koa forest.

Prescribed fire may also be useful in managing habitat for the Hawaiian goose or nene (Nesochen sandwichensis). Wildfire at Hawaii Volcanoes National Park provided an attractive, albeit short-term, food source in the form of resprouting bush beardgrass, broomsedge, and other alien grasses. Wildfire also created an open habitat favorable for nesting. There were twelve nesting attempts in 1987-1988 in the Uila Bum, an area with less than 17 attempts in the six years previous to the bum. Fledgling success was apparently limited by mongoose (Herpestes auropunctatus) predation, which is controllable by diphacinone bait stations.

Prescribed fire is essential in developing customized fuel models, which enable fire suppression personnel to predict fire behavior (rate of spread, fire intensity, tire size). This information is invaluable in developing fire suppression strategies. Prescribed fire is also important in understanding fire effects because pre-fire conditions can be characterized.

**Ecological Effects of Burning Season**

**Subalpine Ecosystems**
In subalpine ecosystems, fires are rare natural events, but a few fires of human origin have occurred. The mamane/naio forest tolerates fire to a certain extent, but recovery of the native species is slow, and alien bunchgrasses rapidly invade the opened environment. ‘Ohelo-pukiawe scrub does not tolerate fire. Pukiawe is killed and is slow to become reestablished. When fire intensity is low, ‘ohelo shoots resprout, but recovery after high-intensity fire is only from root suckers. The native tussock grass Deschampsia nubigena recovers slowly but may achieve higher cover after fire. ‘Ama’u fronds are killed, but new ones are produced rapidly. A few other species, e.g., kukaenene (Coprosma ernodioides) and strawberry (Fragaria chiloensis), recover within a year or so after fire. However, all native species subsequently have lower cover values following fire, as compared with alien species, particularly velvet grass (Holcus lanatus) and sweet vernalgrass (Anthoxanthum odoratum). The fire potential of subalpine ecosystems is increasing because alien grasses, particularly sweet vernalgrass and velvety grass, are invading the naturally discontinuous fuel bed.

**Montane Seasonal Ecosystems**
The montane parkland ecosystem, a mosaic of koa stands, shrublands, and grasslands, demonstrates considerable adaptation to fire, with rapid recovery of native plant species. Koa is sensitive to fire but regenerates very rapidly and, with ‘emoloa’ and bracken, produces abundant regrowth within a month. The rapid regeneration of koa from suckers often reaches beyond the original aerial boundary of parent trees. The native Deschampsia nubigena and mountain pil (Panicum tenuifolium) recover vegetatively. ‘A‘ali‘i is one of the first native shrubs to reinvade burned areas, whereas pukiawe recovers much more slowly. In montane seasonal communities elsewhere, fire has contributed to the spread of alien grasses, as demonstrated by the invasion of fountain grass in the Pohakuloa area of Hawai‘i Island. Fire potential is relatively high in the montane seasonal zone because of the continuous arrangement of grasses and abundance of shrubs. The invasion of alien grasses such as fountain grass, Andropogon, Schizachyrium, and Paspalum spp. is increasing the fire potential in this ecological zone.
Montane Rain Forest Ecosystems
Documented fires in montane rain forest ecosystems are rare, and fire-effects studies in this zone have been limited to uluhe-dominated rain forest. After fire, ‘ohi‘a, kawa‘u, and other native trees typically resprout from the root crown. Hapu‘u and ‘ama‘u also recover vegetatively. However, the other common rain forest fern, uluhe, is eliminated from early successional stages, and alien species such as broomsedge and yellow Himalayan raspberry invade burned sites and become dominant. Fire potential is relatively low in rain forest because fuels rarely dry out and organic matter is rapidly recycled.

Submontane Seasonal Ecosystems
Many of the ecosystems in this zone have been disturbed significantly by fire. The lower elevations of this zone were occupied by the indigenous Hawaiians, who probably burned the area inadvertently or deliberately to clear land for agriculture, thereby selecting for fire-tolerant species. In the 1800s, many lowland areas were abandoned as the native Hawaiian copulations were decimated by disease and the survivors moved. Fuel loadings were low in these principally native sclerophyllous woodlands because of the paucity of grasses. However, invasions of alien bunchgrasses have greatly increased fire frequency and size. Fire suppresses most native shrubs, particularly pukiawe, ‘ulei (Osteomeles anthyllidifolia), and ‘akia, and increases alien grass cover, particularly bush beardgrass and molasses grass. ‘A‘ali‘i is an early colonizer and may reach higher densities than in pre-fire communities. The fire potential of the submontane seasonal zone is now very high because of alien grasses.

Dry Lowland Ecosystems
This zone was the most heavily impacted by aboriginal Hawaiians, and alien plant species now dominate many coastal lowland areas. Many native species, for example, wiliwili and lama, remaining in this environment are not adapted to fire. For this reason, relictual native woodlands are now threatened by fine fuel loading from alien grasses. Fire in the coastal lowlands of 0‘ahu maintained and extended alien grass communities. Broomsedge, bush beardgrass, fountain grass, and thatching grass, as well as the native pili grass, have replaced shrub communities in Hawaii Volcanoes National Park after fire.

There are extensive remnants of a forest dominated by hala (Pandanus odoratissimus), ‘ohi‘a, and uluhe inland of Kolo Point, Hawaii. These forest remnants have been burned on several occasions recently. Hala and the alien shrub Malabar melastome (Melastoma candidum) disappeared from the community very rapidly, and the aerial portions of ‘ohi‘a have been killed. Alien broomsedge, bamboo orchid (Arundina graminifolia), melochia (Melochia umbellata), and native hi‘aloa (Waltheria americana) commonly invade after each fire, whereas the native uluhe only reinvades as long as the forbs and shrubs are not too dense.

Koa haole and kiawe (Prosopis pallida) communities are frequently burned. The recovery rate of kiawe is approximately 20%. Fountain grass and buffel grass (Cenchrus ciliaris) rapidly invade or take over the area. Fire intensifies the cover of koa haole, which resprouts from the base and becomes established from seed. The fire potential of the coastal lowlands is very high because of low rainfall and continuously arranged fine fuels.

Coastal Strand Ecosystems
Coastal strand environments are rarely subjected to fire because most of the communities have insufficient fuel to carry it. The heavy salt loading from ocean spray may also retard fires. However, when these communities are burned the majority of the species are killed. The
succulent species, such as naupaka kahakai (*Scaevola sericea*), are particularly sensitive. Other species, such as *Chamaesyce degeneri*, *Myoporum*, and *Wikstroemia*, resprout. Coastal strand ecosystems are not readily invaded by alien grasses.

**Implications for Managers**
The average annual rainfall on the islands of Hawaii has resulted in terrestrial ecosystems that range from dry forests to montane tropical forests. Rainfall for Hawaii ranges from over 235 inches on the windward side to less than 10 inches on the leeward side. There is little agreement on the current ecological role of wildfire in these areas, but in general the ecosystems and weather patterns lack the ingredients for frequent wildfires or the application of prescribed burning. Weather patterns on the Hawaiian islands do not produce lightning that can be a source of wildfire ignitions. Lacking a history of fire, the vegetation has not evolved to be fire tolerant or fire dependent. Wildfire ignitions have historically been mostly confined to volcanic eruptions.

In 1917, the owners of the Pu’u Waawaa Ranch on the Big Island imported fountain grass (*Pennisetum setaceum*), an ornamental landscaping plant native to Mediterranean and North African coasts. Since its introduction the species has become an invasive pest that sequesters groundwater and outcompetes native woody vegetation. It is now common on windward valley walls, sea cliffs, lava flows and roadsides. It has spread into the rangelands of Hawaii’s cattle country where it is displacing more nutritious, introduced pasture grasses that already carry low intensity fire quite well. Fountain grass has compounded that flammability and established a strong foothold on the landscape. Fountain grass is now recognized as an invasive species in California, Oregon, Nevada, Colorado, Arizona, New Mexico, Louisiana, Florida, and Tennessee. The Division of Forestry and Wildlife of the Hawaii Department of Land and Natural Resources has designated fountain grass as one of Hawaii’s most invasive horticultural plants.

Prescribed burning alone is most effective for immediately reducing fountain grass fuel loads but effects are short-lived. Repeated burns may not be feasible for private landowners and ranchers because of cost and complexity. The most dramatic and sustained reduction in fuel loads occurred on sites that received a combination of prescribed burning, cattle grazing and aerially applied herbicide. The most effective, immediate fuel load reduction treatment was prescribed fire alone. Repeated burning however may not be feasible for private landowners and ranchers due to the cost and complexity of conducting fires. Low-intensity grazing alone was not effective at reducing fountain grass. Herbicide (commercial Glyphosate 41 percent active ingredient) killed fountain grass and caused a gradual reduction in fountain grass fuel load. The fountain grass seed bank is somewhat depleted by burning and can be maintained at low levels with herbicide. Well-managed rotational cattle grazing holds promise as a long-term sustainable fine fuels management technique where compatible with land management objectives.
Table 9. Key Points - Hawaii

<table>
<thead>
<tr>
<th>Key Points-Hawaii</th>
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<tbody>
<tr>
<td>• Alien grasses usually recover to pre-burn levels and often intensify after fire. Fire facilitates the spread of broomsedge, bush beardgrass, molasses grass, and fountain grass. These are fire-adapted alien grasses from the tropics, subtropics, and warm-temperate areas and are the most important widespread alien fuels in Hawai‘i.</td>
</tr>
<tr>
<td>• Woody alien plants usually invade burned areas only to a limited degree and are typically early successional species. Alien shrubs such as partridge pea (<em>Chamaecrista nictitans</em>), indigo (<em>Indigofera suffrutescens</em>), sourbush (<em>Pluchea symphytifolia</em>), and yellow Himalayan raspberry (<em>Rubus ellipticus</em>) invade burned sites immediately after fire but appear to be early successional species. Other common trees and shrubs, such as common guava (<em>Psidium guajava</em>), lantana (<em>Lantana camara</em>), koa haole (<em>Leucaena leucocephala</em>), faya tree (<em>Myrica faya</em>), and Java plum (<em>Syzygium cumini</em>), resprout vigorously.</td>
</tr>
<tr>
<td>• A number of native plant species are fire-tolerant, although no native plant is fire-resistant. Aerial portions of all native plant species are readily killed by fire, but some resprout or recover from seed.</td>
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<tr>
<td>• A number of widespread native plants are sensitive to fire and do not recover well from seeds or sprouts. Pukiawe (<em>Styphelia tameiameiae</em>) is readily killed by fire, Uluhe fem is very fire-sensitive and recovers slowly, and ‘Akia (<em>Wikstroemia sandwicensis</em>) and lama in the coastal lowlands are also easily killed by fire.</td>
</tr>
<tr>
<td>• The fire tolerance of ‘ohi’a (<em>Metrosideros polymorpha</em>) varies with fire intensity. ‘Ohi’a recovers by epicormic resprouting from the root crown.</td>
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Adapted from the following References:


Chapter 5 Prescribed Fire Planning

Introduction
Fire is an essential ecological process in many fire-dependent ecosystems and prescribed fire is one of the tools available to natural resource managers on DoD installation to reduce wildfire risk, reduce fuel loads, and ensure uninterrupted training and testing missions. In large areas of the country, fire exclusion from forest, shrubland, and rangeland ecosystems has led to unhealthy and unsustainable conditions. These areas are at risk of intense, severe wildfires that threaten terrestrial and aquatic ecosystems, installation staff and infrastructure, and the surrounding communities and the public. As one component of fire management, prescribed fire is used to alter, maintain, or restore vegetative communities; achieve desired resource conditions; and to protect life, installation and private property, and values that would be degraded or destroyed by wildfire.

The success of fire management planning is in part dependent on the foundations of clear, concise, and documented planning, review, and approval process encompassed in the INRMP, Wildland Fire Management Plan (WFMP), and Prescribed Fire Plans (PFP). These documents result in specific natural and cultural resource management goals and objectives, priorities, and measures of success for the application of prescribed fire and wildfire suppression.

Two categories of problems can arise on the use of prescribed fires and wildfire suppression:

- Problems as a result of poor planning of wildfire suppression and prescribed fire, and
- Problems that occur during implementation of the wildfire suppression actions and prescribed fire use.

The effect of all errors is cumulative. Together, these errors can diminish the probability of successful natural and cultural resource management, installation sustainability, and short- and long-term installation mission capabilities.

Fire use planning on DoD installations begins with the INRMP as a component of the overall land and natural and cultural resource management planning. The planned uses of prescribed fire and mechanical fuel mastication to reduce wildfire risk should be one of the component of stated resource management goals. The use of prescribed fire should include an analysis of potential alternative treatments and the risks of no action. Installation Operations Managers have a vision of how natural resources will meet mission training and testing objectives. This vision should be included in the planning of natural and cultural resource management. The INRMP should identify the barriers to implementing best management practices to achieve long-term sustainability. These barriers may include federal and state regulations, available funding over the five-year planning effort, and insufficient staff resources. The likely terrestrial and aquatic ecological impacts should be documented within the INRMP. On installations where prescribed fire is selected as the most effective and cost efficient management practice, the next step is the development, review, and approval of the WFMP.

The WFMP described the uses of prescribed fire to achieve installation natural and cultural resources goals, ensure uninterrupted testing and training missions, and prevent wildfire encroachment on the installation. Items commonly addressed in the WFMP are:

- Background information on the area, such as topography, soils, climate and fuels.
- Applicable fire laws and regulations, including any legal constraints.
- Fire history of the area, including the natural fire regime, and recent fire occurrence or use.
- Justification for fire management to achieve natural and cultural resource goals.
Fire management goals for the area, including a description of sustainability targets.
Fire management scheduling, qualitatively describing how fire will be applied on the installation over time to achieve stated resource objectives.
Listed species, species of special concern, wildlife habitat issues, invasive species issues.
Definition and descriptions of prescribed fire treatment blocks.
Air quality and smoke management considerations for the installation and surrounding communities.
Outside the fence populations, communities, and infrastructure, such as roads, power lines, water, and sewer.
Maps illustrating fuels distribution, prescribed fire treatment units, and smoke sensitive areas.

The WFMP should enable the Natural Resource Manager to gain the support of the installation Operations Manager and staffs. Federal, state, local, NGO, and community partner involvement is critical to the successful implementation of the WFMP. Adjacent federal land managers, state forestry and wildlife agencies, and local community fire departments should be involved early in the WFMP planning process to reach agreement and address concerns. The public in surrounding communities is key to the long-term success of the fire management program. All entities are likely to have some impacts from ground level smoke emissions form the installation’s prescribed fire program and their support and understanding will ameliorate negative perceptions. Once the WFMP is approved by the installation staffs, the next step is the development of site specific PFPs.

PFPs are a critical component of any prescribed burn. The installation Natural Resource Manager used the PFP to identify specific objectives for an individual burn unit. These objectives are likely to vary over time and may vary with the time of year. Objectives during the dormant season are likely to focus on fuels reduction and objectives during the growing season are likely to include wildlife and vegetation structure changes. The purpose of a burn plan is to provide a description of the burn area, target weather conditions, hazards that may be encountered, personnel needs and safety, and contacts to make prior to burning. The PFP typically consists of the following topics:

- An assessment and description of the burn unit,
- A map of the burn unit and surrounding area,
- A description of the burn objectives with specific and quantifiable targets,
- Weather and fuel prescription that define the burn parameters,
- Burn season and time window to conduct the burn,
- Smoke management plan to assess impacts to sensitive areas and smoke transport,
- Notification list and phone contacts for local authorities and the public,
- Environmental and legal constraints,
- Operational burn planning for safety, communications, equipment, and personnel,
- Contingency plan for escaped fire and halting the burn,
- Pre-burn checklist for pre-burn briefing, and
- Post-burn monitoring and burn effects evaluation.

Fire Use Planning for Federal Land Managers
The Wildland and Prescribed Fire Management Policy: Implementation Procedures Reference
Guide (USDI and USDA Forest Service 1998) represents an effort by Federal wildland fire management agencies to establish standardized procedures to guide implementation of the policy described in the 1995 Federal Wildland Fire Management Policy and Program Review. It uses new terminology and definitions to provide consistency and interpretation to facilitate policy implementation, and describes relationships between planning tiers to fire management objectives, products, and applications.

Integrated Natural Resource Planning Plans
The DoD’s INRMP Implementation Manual policy was updated on November 25, 2013 in DoD manual Number 4715.03 (http://www.dtic.mil/whs/directives/corres/pdf/471503m.pdf). The goal of each installation’s INRMP is to: implement and maintain natural resources conservation programs to ensure access to land, air, and water resources for realistic military training and testing while support and be consistent with the military mission. The DoD installations that are subject to wildfire hazards, utilize prescribed burns as a land management tool, and develop and implement an integrated Wildland Fire Management Plan.

The INRMP has minimal requirements for coordination with USFWS and the State fish and wildlife agencies in INRMP scoping, design, preparation, and periodic review. Stakeholders (e.g., operations and training, public works, planners) must be engaged in the review and approval process of installation INRMPs to ensure goals, objectives, and actions are in line with mission requirements, and to identify potential project conflicts or opportunities for cooperative program implementation. In addition, installations must communicate annually with USFWS and State fish and wildlife agency personnel regarding INRMP implementation progress, potential areas of improvement, and expected projects for the coming year.

Updates to installation INRMPs must include climate change considerations which should include projections in the frequency and severity of wildfires in a changing climate for the region. The INRMP must include a vulnerability assessment of the DoD mission of training and testing related to climate change.

Wildland fire risk needs to be assessed within the historical regional trends and projections of future climate to determine climate change impact vulnerability assessments and adaptation strategies. The DoD Components that are subject to wildfire hazards and utilize prescribed burns as a land management tool, develop and implement an integrated Wildland Fire Management Plan and incorporate it into the INRMP. DoD wildland fire fighters should register their certifications in the DoD Fire and Emergency Services Certification Program website, found at http://www.dodffcert.com.

General INRMP contents address how natural resources management goals support no net loss in military mission capability for military installation lands while enhancing training and testing capabilities to the maximum extent practicable. Natural resources personnel coordinate INRMPs with other installation plans and include this information. The general guidelines for INRMPs include the following:

1. Summary of general information about the installation’s mission and history, including the ecological history of the landscape.
2. Summary of how the installation’s natural resources support the military mission.
3. Identification of all legal requirements pertinent to natural resources management.
4. Identification of the installation’s natural resources, including but not limited to vegetation communities, topography, soils, climate patterns, water resources, wildlife,
federal and State listed species, other sensitive species, and context within the regional ecosystem.

5. Description of any sensitive areas that federal regulation or installation requirement restricts, such as critical habitats, essential fish habitats, wildland fire, or special management areas.

6. Description of natural resources programs specific to the installation, such as forestry, agricultural outlease, and hunting and fishing.

7. Description of land management partnerships affecting military training and natural resources management on the installation, such as the DoD Readiness and Environmental Protection Integration Program, agreements with other federal or State agencies, or nongovernmental organizations.

8. Procedural recommendations for managing the installation’s natural resources in ways that are compatible with the installation mission, satisfy legal requirements, and that ensure long-term stewardship is not compromised by agricultural out-lease, timber sales, or energy development.

9. Natural resources management priorities that ensure compliance with legal requirements and ongoing stewardship responsibilities, as well as goals and objectives that are clear and practical and that the DoD Components can assess for adaptive management.

10. Management procedures for the ongoing identification, maintenance, and enhancement of natural resources.

11. Recommendations for managing the installation’s Bird/Wildlife Aircraft Strike Hazards, if applicable.

12. Establishment of requirements, goals, and objectives reflected in budget documents and decision-making processes, and addressed in conservation self-assessments.

13. Analysis of natural resources, ecosystems, and areas of critical or special concern from both technical and policy perspectives.

14. Consideration of access for the public (e.g., disabled Americans, disabled sportsmen, American Indians, Alaska Natives, Native Hawaiians) and comprehensive outdoor recreation and planning.

15. Assessment of regional context, challenges and opportunities with respect to managing natural resources on the installation (e.g., effects of climate change, landscape scale partnerships, ecosystem services, opportunities for conservation or mitigation banking, compatible use buffer programs, in lieu of fee banking).

16. Identification of the critical management requirements necessary for maintaining ecosystem health and integrity to ensure the sustainability of the land for current and future military missions and to ensure effective stewardship of public land.

17. Identification of critical natural resources related encroachment areas and prioritization of adaptive management objectives relative to natural resources related impacts on the installation mission.

**Wildland Fire Management Plans**
The purpose of a DoD installation’s Wildland Fire Management Plan (WFMP) is to reduce wildfire potential, protect and enhance valuable natural resources, and implement ecosystem management goals and objectives on AF installations. The WFMP will be incorporated into or be consistent with the INRMP as a component plan. The WFMP directly support the DoD mission and must be consistent with installation emergency operations plans (AFB32-7064). DoD’s

The goal of the WFMP is to: (1) document the policies, objectives, and history of the fire management program, (2) provide managers with the information and guidelines needed to conduct a safe and effective fire management program, (3) comply with the 1995 Federal Wildland Fire Management Policy and Program Review that “every area with burnable vegetation must have an approved Fire Management Plan” and “must be complete as promptly as possible” (NIFC 2001, p. iv), and (4) comply with the Endangered Species Act (ESA) requiring that “all federal departments and agencies shall seek to conserve endangered species and threatened species” (Section 2, c1) and “shall utilize their authorities in furtherance of the purposes of this Act” (Section 7, a1) (ESA 1973; as amended in 1988).

Federal agencies follow the policies and guidance found in the Interagency Standards for Fire and Fire Aviation Operations (Redbook NFES #2724). The Interagency Standards for Fire and Fire Aviation Operations provides fire and fire aviation program management direction for managers. Employees engaged in fire management activities comply with all agency-specific health and safety policy. Other references, such as the National Wildfire Coordinating Group (NWCG) Incident Response Pocket Guide (PMS 461, NFES 1077) and the NWCG Fireline Handbook (PMS 410-1, NFES 0065), provide operational guidance. Federal Wildland Fire Management Policy and Guidance documents can be found at the NWCG Policy Website including:

- Prescribed Fire Smoke Management Guide (NWCG, NFES 1279, PMS 420-1).

The Federal Wildland Fire Management Policy provides guidance for the implementation of federal wildland fire management and includes guidelines that should be used to provide consistent implementation of federal wildland fire policy. These guidelines include:

1. Wildland fire management agencies will use common standards for all aspects of their fire management programs to facilitate effective collaboration among cooperating agencies.
2. Agencies and bureaus will review, update, and develop agreements that clarify the jurisdictional inter-relationships and define the roles and responsibilities among local, state, tribal, and federal fire protection entities.
3. Responses to wildland fire will be coordinated across levels of government regardless of the jurisdiction at the ignition source.
4. Fire Management Plans will be intergovernmental in scope and developed on a landscape scale.
5. Wildland fire is a general term describing any non-structure fire that occurs in the wildland. Wildland fires are categorized into two distinct types: a) Wildfires - Unplanned ignitions or prescribed fires that are declared wildfires, and b.) Prescribed Fires - Planned ignition.
6. A wildland fire may be concurrently managed for one or more objectives and objectives can change as the fire spreads across the landscape. Objectives are affected by changes in fuels, weather, topography; varying social understanding and tolerance; and involvement of other governmental jurisdictions having different missions and objectives.
7. Management response to a wildland fire on federal land is based on objectives established in the applicable Land/Resource Management Plan, and/or the Fire Management Plan.
8. Initial action on human-caused wildfire will be to suppress the fire at the lowest cost with the fewest negative consequences with respect to firefighter and public safety.
9. Managers will use a decision support process to guide and document wildfire management decisions. The process will provide situational assessment, analyze hazards and risk, define implementation actions, and document decisions and rationale for those decisions.

The Interagency Prescribed Fire Planning and Implementation Procedures Guide (PMS 484) provides standardized procedures specifically associated with planning and implementation of prescribed fire. These procedures meet all policy requirements described in the 2009 Guidance for Implementation of Federal Wildland Fire Management Policy. The PMS 484 provides unified direction and guidance for prescribed fire planning and implementation for the U.S. Department of the Interior BIA, BLM, NPS, USFWS, and the USFS. The purpose of the PMS 484 is to provide consistent interagency guidance, promote common terms and definitions, and provide standardized procedures, for the planning and implementation of prescribed fire. The PMS 484 describes what is minimally acceptable for prescribed fire planning and implementation. Agencies may choose to provide more restrictive standards and policy direction, but must adhere to these minimums. The prescribe fire plan may vary in the degrees of complexity but the following elements must addressed in the PMS 484 template:

1. Goals and Objectives. The WFMP establishes goals and objectives for the wildland fire management program on the installation.
2. Organizational Structure. The WFMP describes the wildland fire management organizational structure, and will indicate its position within the installation command structure. The organizational structure for wildland fire activities will be consistent with NWCG Incident Command System standards.
3. Interagency Cooperation and Mutual Aid Agreements. Installations are encouraged to develop regional partnerships for wildland fire management support by means of reciprocal agreements with other federal, state, local and private entities to share human, logistical, and operational resources. Emergency assistance and mutual aid agreements will conform to the guidelines stated in DODI 6055.6 – DoD Fire and Emergency Services Program, and AFI 32-2001.


6. Risk Assessment/Decision Analysis Processes. Sound operational risk management are the foundation of the Wildland Fire Management Plan. The plan identifies the indices and/or fire danger rating system that will be used to assess wildfire risk and potential fire behavior. The indices and/or fire danger rating system must adequately describe fire hazard, severity, intensity, and other significant factors affecting the protection of life and property, and the environmental factors that will be measured prior to ignition of a prescribed fire treatment. Identify normal and unique weather patterns that affect fire behavior on the installation.

7. Wildland Fire History. Includes in the WFMP an analysis of both recent and long- term wildland fire history on the installation and in the region.

8. Natural and Cultural Resources Considerations Checklist. Provides a checklist in the WFMP that can be used to identify sensitive natural and cultural resources that should be given consideration before conducting any wildland fire management activity.

9. Mission Impact Considerations. Identifies the potential impacts to the installation mission (positive and negative) that may occur as a result of implementation of the WFMP.

10. Wildland Fuel Factors. Identifies the effects of installation fuel types and fuel loads on fire behavior. Display data on fuel types and fuel loading by maps or other means. Conduct fuel surveys to collect wildland fire fuels data if necessary.

11. Monitoring Requirements. Identifies the environmental factors that will be monitored and the frequency of monitoring required for both a wildfire and prescribed fire. Identify post-fire assessment protocols for both wildfire and prescribed fires.
12. Public Relations. Identifies a protocol for notifying the media and affected persons for wildfire incidents and prescribed burning activities.

13. Funding Requirements. Identifies the funding requirements to train and equip wildland fire management personnel to ensure safe, effective, and cost-efficient operations in support of the Wildland Fire Management Plan. Identify the appropriate sources of funding for wildland fire activities.

14. Personnel Training and Certification Standards and Records. The WFMP identifies the staffing requirements, according to specific certification and training requirements, for the tasks associated with wildland fire management activities on the installation. Current training and qualification records will be maintained for all personnel involved in wildland fire management activities.

15. Environmental Impact Analysis Process for WFMP Implementation. Actions proposed in a WFMP may constitute a major federal action as defined in 40 CFR Part 1508.18 (b) (2). Major federal actions must be evaluated for potential environmental effects in accordance with 32 CFR Part 989.

**Prescribed Fire Plans**

NWCG guidelines for the minimum requirements for Prescribed Fire Plans are found in PMS 484, Interagency Prescribed Fire Planning and Implementation Procedures Guide (http://www.dtic.mil/whs/directives/corres/pdf/471503m.pdf). The PMS 484 provides unified direction and guidance for prescribed fire planning and implementation for the BIA, BLM, NPS, USFWS, and the USFS. The National Wildfire Coordinating Group (NWCG) member agencies agree with the principles identified in the PMS 484.

At a minimum, burn plans will include the following:

1. Signature Page. The signature page identifies the project name, signatures of the preparer, reviewer, and agency administrator, complexity rating, and burn boss qualifications.

2. Agency Administrator Ignition Authorization and Prescribed Fire Go/No Go Checklist. The agency administrator ignition authorization must be completed prior to ignition. The prescribed fire burn boss completes and signs the Go/No Go checklist, PMS 486.


4. Description of Prescribed Fire Area. The prescribed fire area describes the physical location, vegetation and fuels, unique features and values, and maps.

5. Objectives. Objectives are well-defined statements describing how a treatment accomplishes project goals as described through the NEPA process and documented in the decision document.
6. Funding. Identifies the funding source(s) and estimated cost(s) of the prescribed fire.

7. Prescription. The prescription will describe a range of low-to-high limits for the environmental or fire behavior parameters (or both) required to meet prescribed fire objectives.

8. Scheduling. Identifies the implementation schedule including time of day, duration of ignition, and constraints.


10. Briefing. Specifies the minimum required implementation organization or capabilities, equipment and supplies needed for each phase of the prescribed fire out.

11. Organization and Equipment. Specifies the minimum required implementation organization or capabilities, equipment and supplies needed for each phase of the prescribed fire until declared out.

12. Communication. A communication plan must be specific to the project’s implementation to address safety and tactical resource management needs.


14. Test Fire. The purpose of the test fire is to describe the test fire ignition process and to verify that the prescribed fire behavior characteristics will meet management objectives and to verify predicted smoke dispersion.

15. Ignition Plan. A description of the active ignition, actual firing patterns, techniques, sequences, patterns and staffing will be determined and adjusted to meet objectives as dictated by topographic, fuels and weather factors.

16. Holding Plan. General procedures for operations to maintain the fire within the project area and meet project objectives until the fire is declared out must be described.

17. Contingency Plan. The contingency plan is the portion of the prescribed fire plan that considers low probability but high consequence events and the actions needed to mitigate them.

18. Wildfire Declaration. A prescribed fire, or a portion or segment of a prescribed fire, must be declared a wildfire by those identified in the plan with the authority to do so, when either or both of the following criteria are met: prescription parameters are exceeded and holding and contingency actions cannot secure the fire by the end of the next burning
period, or, the fire has spread outside the project area or is likely to do so, and the associated contingency actions have failed or are likely to fail and the fire cannot be contained by the end of the next burning period.

19. Smoke Management and Air Quality. Description of how the project will comply with local, county, state, tribal, and federal air quality regulations. Identify what permits, if any, are needed. Identify smoke sensitive receptors, including population centers, recreation areas, hospitals, airports, transportation corridors, schools, non-attainment areas, Class I areas, and restricted areas that may be impacted. Include modeling outputs and mitigation strategies and techniques to reduce the impacts of smoke production, if required by State Implementation Plans (SIPs), Tribal Implementation Plans (TIPs), and/or state or local regulations.

20. Monitoring. Describe at a minimum the weather (forecast and observed), fire behavior and fuels information, and smoke dispersal monitoring required during all phases of the project and the procedures for acquiring it, including who and when.

21. Post-Burn Activities. This may include preparing a post-burn report, finalizing the project file, safety mitigation measures, close out of applicable pre-burn considerations, close out of NEPA mitigations and rehabilitation needs.
Chapter 6 Fire Behavior Fuel and Effects Toolkit

Introduction

Fuels
There are 3 main types of fuels: ground fuels, surface fuels, and aerial fuels. Ground fuels are combustibles that lie just under the surface, i.e. organic soils, buried logs, and tree and shrub roots, and burn slowly because of the higher moisture and lower oxygen levels. Surface fuels lie on top of or just right above the soil surface and can include litter, grass and shrubs to about six feet in height. Surface fuels are what generally carry a prescribed fire and are therefore considered the most important fuel type. Aerial or crown fuels refer to the tops of tall shrubs and trees, are the most dangerous fuel type and dominates wildfires in the western U.S. Crown fires typically have extreme fire behavior due to the large fuel loads present in the needles, leaves, and branches of the crown and the increased availability of oxygen from fire driven winds.

The major determining factor of the severity of wildfires and prescribed burns is fuel biomass and its physical and chemical properties. The available biomass for combustion on installations will vary by vegetation type, past forest and grassland management practices, mechanical and prescribed burn fuel reduction treatments, and exotic and invasive species. Fuel biomass is a determining factor in wildfire risk modeling analyses and in the development of Prescribed Fire Plan for biomass reduction burning. The major 7 component of fuels are listed below.

Fuel Loading
Fuel loading is the oven-dry weight of fuels in a given area usually expressed in tons/acre or pounds/acre. Fuel loadings vary greatly by fuel groups. For example grass fuel types can vary from <1 to 5 tons/acre, shrub fuel types from 2-80 tons/acre. Logging slash from 10 to 200 tons/acre and timber litter from 4 to 12 tons/acre. When interpreting and predicting fire behavior, predictive tolls are more concerned with the surface fuel loading; in particular those dead fuels that are less than 3 inches in diameter and live fuels of less than 1.4 inch diameter. Much of the vegetation on a site may not be available to carry fire due to its height above the ground or high moisture levels.

Fuel loadings are generally separated by different sizes of live and dead fuel particles. Dead fuels are broken into 4 size classes according to their diameter. They are:

1. 1-hour fuels - Grasses, litter and duff; < 1/4 inch in diameter.
2. 10-hour fuels - Twigs and small stems; 1/4 to 1 inch in diameter.
3. 100-hr fuels - Branches; 1 to 3 inches in diameter.
4. 1000-hr fuels - Large stems and branches; > 3 inches in diameter.

Fuel loading is usually measured and expressed in tons/acre (T/A) or pounds/acre (lbs/A) for lighter fuels such as grass.

Size and Shape
Surface-area-to volume ratio is the ratio of the surface area of a fuel to its volume using the same unit of measurement. The higher the ratio (1:3,000) the finer is the fuel (grass). The lower the ratio (1:6) the larger the fuel (logs). The size and shape of firebrands affect the amount and
distance of spotting. Small embers ordinarily produce short-range spotting only, because they cannot sustain combustion for the period of time required for long-distant transport. Live cedar often produces short-range spotting due to the smallness of the firebrands. Oak leaves are larger and more aerodynamic. Cones, cedar fronds, bark plates, and pine needles are examples of some firebrands which have been lifted into convection columns and then deposited 10 miles or more down wind from the fire. In these cases, their flatness and greater surface-area-to-volume ratios have increased the aerodynamic qualities of the particles, thus making it easier for convection columns to lift them to greater altitudes. The shape of fuels is also important to spotting down slope by rolling firebrands.

**Compactness**
Compactness can be simply defined as the spacing between fuel particles. The closeness and physical arrangement of fuel particles affects both ignition and combustion. Rates of spread in closely compacted fuels (forest litter) are usually slower than rates of spread in loosely compacted fuels (grasses). Fuel bed depth is the average height of surface fuel that is contained in the combustion zone of a spreading fire front. Orientation of the fuel refers to the horizontal or vertical orientation of the fuel arrangement that carries the fire. Vertically oriented fuels are found in the grass and shrub groups, which rapidly increase in depth with an increase in fuel load. Horizontally oriented fuels are found in the timber litter and logging slash fuel groups and slowly increases in depth as the load is increased.

**Horizontal Continuity**
Horizontal continuity is the horizontal distribution of fuels at various levels or planes. Horizontal continuity applies to all levels of the fuel complex but the continuity of fine fuels is especially important to the spread of surface fires, since prescribed fires burn most often in this fuel level. These characteristic influences where a fire will spread, how fast it will spread and whether the fire travels through surface fuels, aerial fuels or both. Discontinuous or patchy fuels are difficult for a fire to travel through and usually require strong winds with spotting for good fire coverage. Continuous fuels provide available fuels at one or more levels giving allowing the fire to spread uniformly for great distances.

Horizontal continuity in aerial fuels or the effects of a closed versus open timber canopy plays a major role in fire behavior. A forest canopy not only shades surface fuels and prolongs moisture retention but also greatly reduces wind speeds from levels above the canopy to levels near the surface. Generally, the greater the crown closure, the greater the wind speed reduction.

**Vertical Arrangement**
Vertical arrangement is the relative height of fuels above the ground as well as their vertical continuity, both of which influence fire reaching various fuel strata. When fuels are mostly vertically continuous, they are referred to as a fuel ladder. Fuel ladders transport fire into the forest canopy. The intensity of the surface fire and the live fuel moisture usually determine whether a fire will travel up through the green ladder fuels.

**Chemical Content**
All fuels, living and dead, contain fiber that is known as cellulose. Fuels also contain chemicals and minerals than can enhance or retard combustion. Chemical contents include the presence of volatile substances such as oils, resins, wax and pitch. There are certain fuels having rather high
amounts of these volatile substances that can contribute to rapid rate of spreads and high fire
intensities. On the other hand, certain fuels may be high mineral content, which can reduce fire
spread and intensity. A burn boss is primarily concerned with volatile substances that increase
severe fire behavior and put firefighter at risk. Vegetation with volatile compounds is commonly
found in pocossins in the southeastern U.S. and juniper and sagebrush in the western U.S.

**Fuel Moisture**

Fuel moisture content is the amount of water in a fuel expressed as a percent of the oven-dry
weight of that fuel. Fuel moisture can exceed 100% and ranges from 0-30% for dead fuels and
30-300% for live fuels depending on species and their growth stage. The formula for obtaining
fuel moisture is:

\[
\text{Fuel Moisture} = \left( \frac{\text{Wet Weight} - \text{Dry weight}}{\text{Dry Weight}} \right) \times 100
\]

Fine dead fuels less than 1/4 inch, such as grass and needle/leaf litter, are most responsible for
the spread of fire. The fine fuels are considered the primary carrier of a surface fire. The live-to-
dead ratio becomes critically important when evaluating the potential for a fuel to burn. The
greater the amount of dead fuel compared to live fuel, the more flammable the fuel.

The dead component of the fuel is extremely important since it is the dead material that
carries the fire and heats the live component to ignition temperatures. With insufficient dead
fuels present, a live stand may not burn even under good burning conditions. Normally, at least
one-third of the fine fuel complex must be dead or cured in order to have an adequate ratio of
live-to-dead to carry a fire.

**Standard Fire Behavior Fuel Models**

Fuel classification during the last 75 years has evolved from a fire control planning focus to the
beginning of predictive fire behavior modeling in the 1970s. Current fuel classification models
have focused on the rate of spread, resistance to control, and the flame length of fires in surface
fuels. Fire behavior is predicted by land managers with thirteen stylized Rothermel surface
spread models. Decision support systems such as FARSITE and the National Fire Danger Rating
system are based on the Rothermel’s fire spread model and are the basis of predicting fire
behavior today. Land managers recognize that these models are limited in their ability to predict
extreme fire behavior, persistent fires, and fuel consumption. Some of these limitations are
currently being addressed by a fuel characteristic classification (FCC) research.

The availability of fire-spread models has increased the need for quantitative fuel field data.
A line-intersect method developed by Brown, usually referred to as “Brown’s Transects”, has
been widely adopted to quantify fuel-loading inputs. The USFS Forest Inventory and Analysis
(FIA) program recognized the need for extensive information on fuels across the landscape. Fuel
field protocols were piloted by the former Forest Health Monitoring Program between 1998 and
2000, and implemented in 2001 on a 1/16th subset of the standard base FIA grid plots. These
FIA methods generally partition the forest ecosystem into pools for live trees, down deadwood,
standing dead trees, understory vegetation, forest floor materials, and soil. Estimating site-
specific fuels from this database has been particularly problematic. The data is not consistently
available from the largest inventory data source, FIA, and there is little data on fuel pools in the
scientific literature. Additionally the biomass algorithms are based nationally on data collected.
primarily on western US tree, shrub, and herbaceous species and associated wood density for
decay classes. The original 13 fire behavior fuel models are for the severe period of the fire
season when wildfires pose greater control problems. Those fuel models have worked well for
predicting spread rate and intensity of active fires at peak of fire season in part because the
associated dry conditions lead to a more uniform fuel complex, an important assumption of
Rothermel’s underlying fire spread model.

The National Fire Danger Rating System (NFDRS) uses Rothermel’s spread model as its
core. However, there are differences in the calculations that require the use of different fuel
models than those for fire behavior prediction. Therefore, there is a separate set of fuel models
for use within NFDRS. The NFDR is a system that allows fire managers to estimate today’s or
tomorrow’s fire danger for a given area. It combines the effects of existing and expected states of
selected fire danger factors into one or more qualitative or numeric indices that reflect an area’s
fire protection needs. It links an organization’s readiness level or pre-planned suppression
actions to the potential problems of the day.

Reference: NWCG Fire Danger Working Team. 2002. Gaining an Understanding of the National
Fire Danger Rating System. National Interagency Fire Center, Boise, Idaho. Pub. NFES #2665,
72 p.


Anderson 13 Standard Fire Behavior Fuel Models
A quantitative basis for rating fire danger and predicting fire behavior became possible with the
development of mathematical fire behavior models developed by Rothermel. The mathematical
models require descriptions of fuel properties as inputs to calculations of fire danger indices of
fire behavior potential. The collections of fuel properties become known as fuel models and were
organized into four groups: grass, shrub, timber, and slash. Fuel models for fire danger rating
have increased to 20 while fire behavior predictions and applications have utilized the 13 fuel
models tabulated by Rothermel and Albini. The Anderson 13 Standard Fire Behavior Fuel
Models are intended to aid the user in selecting a fuel model for a specific area through the use
of photographic illustrations (Table 6-1). A similarity chart for each fuel model allows the user to
relate the fire behavior fuel models to the fire danger rating system fuel models. The chart also
provides a means to associate the fire danger rating system fuel models with a photographic
representation of those fuel types. The four general fuel types are as follows:

- Grass and Grass-Dominated
- Chaparral and Shrub Fields
- Timber Liter
- Slash

Forest and Range Experiment Station. 28 p.

Table 10. Anderson 13 Standard Fire Behavior Fuel Models

<table>
<thead>
<tr>
<th>Fuel model</th>
<th>Typical fuel complex</th>
<th>1 hour</th>
<th>10 hour</th>
<th>100 hour</th>
<th>Live</th>
<th>Fuelbed depth</th>
<th>Moisture of extinction</th>
<th>dead fuels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grass and grass-dominated</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Short grass (1 foot)</td>
<td>0.74</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>1.0</td>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Timber (grass and understory)</td>
<td>2.00</td>
<td>1.00</td>
<td>.50</td>
<td>.50</td>
<td>1.0</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tall grass (2.5 feet)</td>
<td>3.01</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
<td>2.5</td>
<td>25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chaparral and shrub fields</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chaparral (6 feet)</td>
<td>5.01</td>
<td>4.01</td>
<td>2.00</td>
<td>5.01</td>
<td>60</td>
<td>20</td>
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<td></td>
</tr>
<tr>
<td>Brush (2 feet)</td>
<td>1.00</td>
<td>.50</td>
<td>.00</td>
<td>2.00</td>
<td>2.0</td>
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<tr>
<td>Dormant brush, hardwood slash</td>
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<td>2.50</td>
<td>.00</td>
<td></td>
<td>2.5</td>
<td>25</td>
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<tr>
<td>Southern rough</td>
<td>1.13</td>
<td>1.87</td>
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<td>.37</td>
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<td>40</td>
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<tr>
<td>Timber litter</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Closed timber litter</td>
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</tr>
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<td>Hardwood litter</td>
<td>2.92</td>
<td>41</td>
<td>.15</td>
<td>.00</td>
<td>.2</td>
<td>25</td>
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<tr>
<td>Timber (litter and understory)</td>
<td>3.01</td>
<td>2.00</td>
<td>5.01</td>
<td>2.00</td>
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<tr>
<td>Slash</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light logging slash</td>
<td>1.50</td>
<td>4.51</td>
<td>5.51</td>
<td>0.00</td>
<td>1.0</td>
<td>15</td>
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<td></td>
</tr>
<tr>
<td>Medium logging slash</td>
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<td>14.03</td>
<td>16.53</td>
<td>.00</td>
<td>2.3</td>
<td>20</td>
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<td></td>
</tr>
<tr>
<td>Heavy logging slash</td>
<td>7.01</td>
<td>23.04</td>
<td>28.05</td>
<td>.00</td>
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<td>25</td>
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</tbody>
</table>

Scott and Burgan 40 Standard Fire Behavior Fuel Models

The Rothermel model has been used as the basis for the development new fire behavior fuel models. Fuel complex information was assembled from several volumes of the USFS’s Natural Fuels Photo Series and other sources. The range of fuel complex characteristics suggested the range of fuel conditions for which fuel models were needed. A fire-carrying fuel type and dead fuel extinction moisture content was assigned to each fuel complex, then grouped the complexes by fine fuel load, fuel type, and extinction moisture. One fuel model was created for each of the approximately 60 groups. Surface-area-to-volume ratio for 1-hr time lag, live herbaceous and live woody classes were assigned subjectively for each draft fuel model. Fuelbed depth was assigned after subjective interpretation of fuel complex data and visual inspection of photographs. Heat content of live and dead fuels is 8000 BTU/lb for all fuel models except GR6 (High Load, Humid Climate Grass), which is 9000 BTU/lb for both live and dead fuels. Fire behavior was simulated over a range of midflame wind speeds and several fuel moisture scenarios. After comparing fire behavior outputs from the draft fuel model set with outputs from the original 13 fuel models, stylized fuel models were added to simulate specific fire behavior characteristics not simulated by any of the draft models.

Fuel models in the Scott and Burgan 40 Standard Fire Behavior Fuel Models are grouped by fire-carrying fuel type. The number of fuel models within each fuel type varies. Non-burn fuel models were included in the set to facilitate consistent mapping of these areas on a fuel model.
Table 11. Scott and Burgan 40 Standard Fire Behavior Fuel Models

<table>
<thead>
<tr>
<th>Fuel Model Code</th>
<th>Fuel load (t/ac)</th>
<th>Live Herb</th>
<th>Live Woody</th>
<th>SAV ratio (1/ft)(^b)</th>
<th>Fuel depth (ft)</th>
<th>Dead Fuel moisture (percent)</th>
<th>Heat (BTU/lb)</th>
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<tbody>
<tr>
<td>GR1</td>
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<td>0.00</td>
<td>0.00</td>
<td>0.30</td>
<td>2200</td>
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<td>GR2</td>
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<td>2000</td>
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<td>15</td>
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<td>3.40</td>
<td>2200</td>
<td>1.5</td>
<td>40</td>
</tr>
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<td>GR7</td>
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<td>7.30</td>
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<td>1800</td>
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<td>2000</td>
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<td>750</td>
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<tr>
<td>SH6</td>
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<td>0.00</td>
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<td>750</td>
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<td>4.35</td>
<td>750</td>
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<tr>
<td>SH9</td>
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<td>750</td>
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<td>0.25</td>
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<td>0.00</td>
<td>2.00</td>
<td>2300</td>
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<td>2000</td>
<td>2.7</td>
<td>25</td>
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</tbody>
</table>

\(^a\) Fuel model type does not apply to fuel models without live herbaceous load. \(^b\) The value 9999 was assigned in cases where there is no load in a particular fuel class or category. \(^c\) The same heat content value was applied to both live and dead fuel categories.

Fuel types are as follows:
- (NB) Nonburnable
- (GR) Grass
- (GS) Grass-Shrub
- (SH) Shrub
- (TU) Timber-Understory
- (TL) Timber Litter
- (SB) Slash-Blowdown

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map. Fuel types were ordered in a way similar to the original 13, with hybrid fuel types (such as Timber- Understory) generally between the two types that compose the hybrid.

Parameters of the Scott and Burgan 40 Standard Fire Behavior Fuel Models include load by class and component, surface-area- to-volume (SAV) ratio by class and component, fuel model type (static or dynamic), fuelbed depth, extinction moisture content, and fuel particle heat content. Fuel inputs not listed are constant for the entire set: 10-hr dead fuel SAV ratio is 109 1/ft, and 100-hr SAV ratio is 30 1/ft. Total fuel particle mineral content is 5.55 percent; effective (silica-free) mineral content is 1.00 percent. Oven dry fuel particle density is 32 lb/ft³.


**Custom Fire Behavior Fuel and Effect Tools**

**FuelCalc**

FuelCalc is a desktop software application for determining changes in surface and crown fuel loading after thinning, pruning, piling, and prescribed fire. Ground, surface, and canopy fuel characteristics serve as essential inputs to computer models of fire behavior and fire effects. FuelCalc is a fuel characteristics simulation software application that calculates initial canopy fuel characteristics and quickly simulates the effects of thinning, pruning, piling and broadcast burning on ground, surface and canopy fuel characteristics. FuelCalc is useful for planning fuel treatments, as well as for estimating the effects of wildfire on surface and canopy fuel characteristics. FuelCalc works by simulating changes in ground, surface, piled, and canopy fuel loads by size class as fuel treatments add to, or subtract from, the load in each class. The FOFEM, Burnup, and Nexus simulation models are used for predicting stand structure and fuel loading changes post fire. FuelCalc input files can be created in the FFI ecological monitoring software (http://www.frames.gov/ffi) or by manually creating an input file in FuelCalc’s standard format.


**FARSITE**

FARSITE computes wildfire growth and behavior for long time periods under heterogeneous conditions of terrain, fuels, and weather. FARSITE is a fire growth simulation modeling system. It uses spatial information on topography and fuels along with weather and wind files. It incorporates existing models for surface fire, crown fire, spotting, post-frontal combustion, and fire acceleration into a 2-dimensional fire growth model. FARSITE is widely used by the U.S. Forest Service, National Park Service, and other federal and state land management agencies to simulate the spread of wildfires and fire use for resource benefit across the landscape. It is designed for users familiar with fuels, weather, topography, wildfire situations and the associated terminology. Because of its complexity, only users with the proper fire behavior training and experience should use FARSITE where the outputs are to be used for making fire and land
management decisions. It uses the following spatial and tabular data similar to FlamMap and it incorporates the following fire behavior models: Rothermel's surface fire spread model, Van Wagner's crown fire initiation model, Rothermel's crown fire spread model, Albini's spotting model, and Nelson's dead fuel moisture model.

FARSITE computes wildfire growth and behavior for long time periods under heterogeneous conditions of terrain, fuels, and weather. It uses existing fire behavior models for surface fire spread, crown fire initiation, and crown fire spread, post-frontal combustion, and dead fuel moisture. FARSITE is a deterministic modeling system, meaning that simulation results can be directly compared to inputs. This system can be used to simulate air and ground suppression actions as well as for fire "gaming," asking multiple "what-if" questions and comparing the results. FARSITE is a spatial fire modeling system that produces outputs that are compatible with PC and Workstation graphics and GIS software for later analysis and display. It accepts both GRASS and ARC/INFO GIS raster data themes. Required spatial data for FARSITE can be accessed from the Web Link: http://www.landfire.gov/

Web Link:  http://www.firelab.org/document/farsite-software

FlamMap
FlamMap version 5.0 is a fire behavior mapping and analysis program that computes potential fire behavior characteristics (spread rate, flame length, fireline intensity, etc. The FlamMap fire mapping and analysis system is a PC-based program that describes potential fire behavior for constant environmental conditions (weather and fuel moisture). Fire behavior is calculated for each pixel within the landscape file independently, so FlamMap does not calculate fire spread across a landscape. Potential fire behavior calculations include surface fire spread, crown fire initiation, and crown fire spread. Dead fuel moisture is calculated using the Nelson model and FlamMap permits conditioning of dead fuels in each pixel based on slope, shading, elevation, aspect, and weather.

Because environmental conditions remain constant, FlamMap will not simulate temporal variations in fire behavior caused by weather and diurnal fluctuations as FARSITE does. It will no display spatial variations caused by backing or flanking fire behavior. These limitations need to be considered when viewing FlamMap output in an absolute rather than relative sense. Outputs are well-suited for landscape level comparisons of fuel treatment effectiveness because fuel is the only variable that changes. Outputs and comparisons can be used to identify combinations of hazardous fuel and topography, aiding in prioritizing fuel treatments.

The FlamMap software creates raster maps of potential fire behavior characteristics (for example, spread rate, flame length, crown fire activity) and environmental conditions (dead fuel moistures, mid-flame wind speeds, and solar irradiance) over an entire FARSITE landscape. These raster maps can be viewed in FlamMap or exported for use in a GIS, image, or word processor. FlamMap is not a replacement for FARSITE or a complete fire growth simulation model. There is no temporal component in FlamMap. It uses spatial information on topography and fuels to calculate fire behavior characteristics for a single set of environmental conditions. FlamMap is widely used by the U.S. Forest Service, National Park Service, and other federal and state land management agencies in support of fire management activities. It is designed for use by users familiar with fuels, weather, topography, wildfire situations and the associated terminology. Because of its complexity, only users with the proper fire behavior training and experience should use FlamMap where the outputs are to be used for making fire and land
management decisions. It uses the same spatial and tabular data and incorporates the same fire behavior models as FARSITE.

Web Link: http://www.firelab.org/document/flammap-software

**FireFamily Plus**

FireFamily Plus version 4.1 is a Windows application used as a primary tool in the fire behavior/danger suite of programs which share data and models that are used in a variety of environments to address a range of business needs. FlamMap is part of a suite of fire behavior systems that includes BehavePlus, FARSITE, and FSPro. These are complementary systems that are based on the same fire models. BehavePlus is a point system with input supplied interactively by the user. FlamMap, FARSITE, and FSPro are spatial systems that use the same base GIS data. FireFamilyPlus supports the spectrum of fire weather/fire danger/fire climate/fire occurrence analysis tools required by fire managers to successfully use the National Fire Danger Rating System (NFDRS). NFDRS is mandated for use in fire preparedness by all Federal and most State agencies and is operationally run with the Weather Information Management System (WIMS).

FireFamily Plus is the computational and analysis cornerstone for Advanced Fire Danger Rating (at NAFRI) and S-491 (Regional/Local Fire Danger Rating) and provides climate summaries for techniques taught at S-492 (Long Term Fire Behavior). It generates the Fire Danger Rating Pocket Cards required by the 30-Mile Abatement Plan and supports the Predictive Services functions at all the Geographic Coordination Centers. Updates have been supported by the USFS Fire and Aviation Management (sponsor) and the Rocky Mountain Research Station (developer). FireFamilyPlus 4.1 is the most recent certified version was approved for installation on USFS and BLM computers in June 2013. Uses of FireFamilyPlus include:

- FireFamilyPlus can be used to compute indices and components of the National Fire Danger Rating System (NFDRS), and the Canadian Forest Fire Danger Rating System from weather climatology data.
- FFP can summarize weather climatology to produce climatological breakpoints for fire management decision making.
- Combining the fire occurrence record in the analysis displays the historical relationships between weather conditions and increasing fire occurrence which can be used to set fire business thresholds and track seasonal progression of Fire Danger.

Analysis of specific weather information helps in estimating fire potential for an ongoing fire’s continued growth. For example, analyzing the precipitation record can assess the likelihood of an adequate amount of rain occurring by specific points in time to slow or stop fire growth. Examining the wind record can help with determining the most likely direction for long-term fire growth.

Web Link: http://www.firelab.org/document/firefamilyplus-software

**FIREMON**

The Fire Effects Monitoring and inventory system (FIREMON) version 2.1.2 is an agency independent plot level sampling system designed to characterize changes in ecosystem attributes over time. The system consists of a sampling strategy manual, standardized sampling methods,
field forms, Access database, and a data analysis program. FIREMON is a desktop application created for computers running Windows 98, ME, 2000, XP, 7, and 8 operating systems. FIREMON contains the following sampling procedures for monitoring ecosystem characteristics: plot description, tree data, fuel load, species composition, cover/frequency, point intercept, density, line intercept, and rare species. Below are sampling forms/data sheets, monitoring protocols/methods, and field equipment checklists for monitoring these characteristics. Additionally, there are forms to record metadata information and fire behavior, as well as a general FIREMON 'How to Guide', appendices, and glossary.

The Integrated Sampling Design (ISD) component in FIREMON is critical to fire monitoring for several reasons. First, many fire managers do not have the background in ecosystem inventorying and sampling to design a statistically credible and efficient sampling strategy. Second, fire managers rarely have the time to learn sampling theory and concepts. And last, integrated sampling requires extensive experience in statistical sampling design and field implementation. So, FIREMON contains this detailed section on sampling strategy to guide the fire manager to plan and implement an appropriate fire monitoring project.

Web Link: [https://www.frames.gov/partner-sites/firemon/firemon-home/](https://www.frames.gov/partner-sites/firemon/firemon-home/)

**FFE-FVS**
The Forest Vegetation Simulator (FVS) is an individual-tree, distance-independent, growth and yield model. It has been calibrated for specific geographic areas (variants) of the United States (Figure 1). FVS can simulate a wide range of silvicultural treatments for most major forest tree species, forest types, and stand conditions. The model is used by silviculturists, researchers, wildlife biologists, and ecologists to plantation owners, timber foresters, and most recently carbon traders, and fire and fuels specialists. FFE-FVS links the dynamics of forest vegetation (primarily trees) with models of snag, fuels, and fire behavior. In tracking fuel dynamics, processes such as litterfall, snag fall down, the accumulation of activity fuels, and decomposition are modeled. Fuel loading, forest type, and other stand characteristics, are used to classify stands into one of the standard fuel models used to model fire behavior. Fire behavior is then represented using pre-existing methods—the algorithms in systems such as Behave and Nexus are used internally to estimate surface and crown fire behavior. Fire effects equations were also taken mostly from published work. FFE has been developed for almost all of the FVS geographic variants.

FFE-FVS is widely used by natural resource specialists throughout the US. The majority of use is by the US Forest Service, but other federal agencies, state agencies and others have used the model as well. The goal of FFE-FVS is to provide managers a tool that simulates fuel dynamics and potential fire behavior over time (years and multiple decades), in the context of stand development and management. A climate-sensitive version known as Climate-FVS is currently available for western states, and an eastern version is in development. Climate-FVS changes core growth, mortality, and regeneration estimates to respond to climate change, according a user-selected general circulation model (GCM), thereby allowing users to model the effects of management under changing climate conditions.

The FVS Staff of the U.S. Forest Service’s Forest Management Service Center in Fort Collins, Colorado, maintains, supports, develops, and provides training for FVS. The FMSC performs a technology transfer role, working with researchers and National Forest staff from various geographical areas to incorporate their findings into the FVS framework.
FOFEM
The First Order Fire Effects Model (FOFEM) version 5.0 is a computer program for predicting tree mortality, fuel consumption, smoke production, and soil heating caused by prescribed fire or wildfire. First order fire effects are those that concern the direct or indirect or immediate consequences of fire. First order fire effects form an important basis for prediction secondary effects such as tree regeneration plant succession, and changes in site productivity, but these long-term effects generally involve interaction with many variables (for example, weather, animal use, insects, and disease) and are not predicted by this program. Currently, FOFEM provides quantitative fire effects information for tree mortality, fuel consumption mineral soil exposure, smoke and soil heating.

First order fire effects are the immediate consequences of a fire. The FOFEM tool is designed to calculate these consequences for prescribed fire or wildfire using four separate metrics: tree mortality, fuel consumption, emissions or smoke production, and soil heating. This tool is intended for direct use in assessing fire impacts and severity, planning prescribed fires that accomplish resource needs, and other applications. The model can be run in either 'prediction' or 'planning' mode; the first computes expected fire effects, the second generates a range of conditions that may lead to a specified set of desired effects. The tool is national in scope, dividing the U.S. into four separate regions.

Web Link: http://www.firelab.org/document/fofem-software

BehavePlus
The BehavePlus fire modeling system is a PC-based program that is a collection of models that describe fire and the fire environment. It is a flexible system that produces tables and graphs and can be used for a multitude of fire management applications. BehavePlus is the successor to the BEHAVE fire behavior prediction and fuel modeling system.

The BehavePlus fire modeling system is a Windows®-based computer program that can be used for any fire management application that involves modeling fire behavior and fire effects. The system is composed of a collection of mathematical models that describe fire behavior, fire effects, and the fire environment based on specified fuel and moisture conditions. The program simulates rate of fire spread, spotting distance, scorch height, tree mortality, fuel moisture, wind adjustment factor, and many other fire behaviors and effects; it is commonly used to predict fire behavior in multiple situations. Some applications include:

- Predicting the behavior of an ongoing fire. Historically, this was the original use for Behave as described in "How to Predict the Spread and Intensity of Forest and Range Fires". Today, the modern version of Behave, BehavePlus Version 5.0, is even more powerful for predicting fire behavior during wildfires and prescribed fires in the United States and other countries because of its expanded features and capabilities.
- Planning fire treatments. Contingency planning depends on complex fire variables, such as spotting distance, probability of ignition, spot fire growth, and probability of containment. All of these are modeled in BehavePlus to facilitate planning of prescribed
fires for ecological restoration or fuel reduction programs.

- Assessing fuel hazard. Fuel moisture and wind conditions are easily manipulated in BehavePlus. Variations in these factors affect fire behavior in surface and crown fuels, so understanding the sensitivity of fuels to moisture and wind is essential to assess whether fuel accumulations have potentials to burn or whether planned treatments may be dangerous to fire fighters or the public.

- Understanding fire behavior. Modeling systems are excellent sources for educating and training personnel on the subtleties of fire behavior. The complex interactions among fire, fuel, moisture, and wind can be easily explored in BehavePlus by changing input variables and fuel conditions for each model run. This makes BehavePlus well suited to learning about fire behavior in safe surroundings.

Successful application of BehavePlus depends upon knowledgeable user decisions. To effectively use BehavePlus in fire modeling, users must have enough fire and fuel experience and fire behavior training to recognize whether their input values are reasonable and make appropriate adjustments. BehavePlus is designed to balance ease of use with options and features that users want and need. Training modules are available to increase user knowledge of both fire behavior and BehavePlus use.


**NEXUX**

NEXUX 2.1 is crown fire hazard analysis software that links separate models of surface and crown fire behavior to compute indices of relative crown fire potential. Use NEXUX to compare crown fire potential for different stands, and to compare the effects of alternative fuel treatments on crown fire potential. NEXUX includes several visual tools useful in understanding how surface and crown fire models interact. NEXUX uses the FARSITE file format for importing custom fuel models. It is an ASCII text file format, so creating or editing one is very easy. The file consists of two or more lines of ASCII text. The first line indicates whether the values are in English or metric units. Each of the following lines consists of 16 data fields (fuel model number, fuel model code, 1-hr dead fuel load, 10-hr dead fuel load, 100-hr dead fuel load, live herbaceous fuel load, live woody fuel load, fuel model type, 1-hr SAV ratio, live herbaceous SAV ratio, live woody SAV ratio, fuelbed depth, dead fuel extinction moisture, dead fuel heat content, live fuel heat content, and description), separated by one or more spaces. Each data line in the file represents a custom fuel model.

NEXUX links existing models of surface and crown fire behavior to produce a system to assess the potential for crown fires at the stand level. NEXUX is a stand-alone computer program. There are other modeling systems whose functions partially overlap with those of NEXUX. BehavePlus is the industry standard tool for modeling surface fire behavior. The present version simulates only surface fire spread, but later versions may include crown fire simulation capability.

NEXUX users should already very familiar with BEHAVE or BehavePlus for simulating surface fire behavior. Users should take all of the NWCG fire behavior courses through S-490, or have thoroughly studied the supporting papers. In addition, familiarity with crown fire modeling techniques is also necessary to fully utilize and understand the crown fire simulations in NEXUX.
Landscape Fire and Resource Management Planning Tools (LANDFIRE)

LANDFIRE fuel data describe the composition and characteristics of surface and canopy fuel. LANDFIRE fuel products provide consistent fuel data to support fire planning, analysis, and budgeting to evaluate fire management alternatives. They complement strategic and tactical planning for fire operations. LANDFIRE is an interagency vegetation, fire, and fuel characteristics mapping program. LANDFIRE has produced a comprehensive and consistent suite of data and geospatial data layers for the entire 50 United States and Territories. The program has produced three updates to capture changes from a variety of disturbances and vegetation modifications and is in the process of planning a base map update or remap for the landscape products.

LANDFIRE deliverables are serving as core data sets in the Wildland Fire Program with the National Cohesive Strategy, Wildland Fire Decision Support (WFDSS), and Fire and Fuels Planning. Data products are being used by federal, state, tribal, local, and private entities including research and educational institutions as well as for fire and resource management applications (Bighorn Sheep habitat analysis, Grizzly Bear assessment, landscape and wildland fire assessments). LANDFIRE products are not a substitute for finer scale, local mapping efforts, but do provide a comprehensive, standardized, nation-wide data set. The quality of the data products vary by geography, product, and scale of use.

LANDFIRE Anderson Fire Behavior Fuel Models

These original 13 standard fire behavior fuel models serve as input to Rothermel's mathematical surface fire behavior and spread model. The 13 Anderson Fire Behavior Fuel Model (FBFM13) layer represents distinct distributions of fuel loading found among surface fuel components (live and dead), size classes, and fuel types. The fuel models are described by the most common fire-carrying fuel type (grass, brush, timber litter, or slash), loading and surface area-to-volume ratio by size class and component, fuelbed depth, and moisture of extinction.

LANDFIRE 40 Scott and Burgan Fire Behavior Fuel Models

The 40 Scott and Burgan Fire Behavior Fuel Model (FBFM40) layer represents distinct distributions of fuel loading found among surface fuel components (live and dead), size classes, and fuel types. This set contains more fuel models in every fuel type (grass, shrub, timber, slash) than Anderson's set of 13. The number of fuel models representing relatively high dead fuel moisture content increased, and fuel models with an herbaceous component are now dynamic, meaning that loads shift between live and dead (to simulate curing of the herbaceous component) rather than remaining constant.

LANDFIRE Canadian Forest Fire Danger Rating System

The Canadian Forest Fire Danger Rating System (CFFDRS) layer fuel types are defined "as an identifiable association of fuel elements of distinctive species, form, size, arrangement, and continuity that will exhibit characteristic fire behavior under defined burning conditions". The CFFDRS arranges fuel types into five major groups with 16 discrete fuel types that are qualitatively distinguished by variations in their forest floor and organic layer, surface and ladder fuels, and stand structure and composition. The CFFDRS assignments for Alaska were made by
fire behavior and fuels experts based on existing vegetation type descriptions and representative photos. The CFFDRS layer was created for Alaska only.

**LANDFIRE Fuel Characteristic Classification System Fuelbeds**
The Fuel Characteristic Classification System Fuelbeds (FCCS) layer describes the physical characteristics of a relatively uniform unit on a landscape that represents a distinct fire environment. FCCS provides standardized descriptions of fuelbeds and fire hazard. The system is designed to provide land managers, regulators, and scientists with a nationally consistent and durable procedure to characterize and classify fuel. The FCCS layer was created with default fuelbeds provided by the FCCS software. FCCS facilitates the mapping of fuel characteristics and fire hazard assessments, and landscape level spatial fire effects simulations. The FCCS layer can serve as input to wildland fire effects models.

**LANDFIRE Fuel Loading Model**
The Fuel Loading Model (FLM) surface fuel classification system characterizes wildland surface fuel. FLMs provide a simple and consistent way for managers to describe onsite fuel for input into fire behavior and effects software. FLMs contain representative loading for each fuel component (e.g., woody and non-woody) for typical vegetation classification systems. They characterize fuel loading across all vegetation and ecological types. To develop FLM classes, maximum soil surface heating and total PM2.5 emissions were simulated for a large set of surface fuelbeds sampled across the contiguous United States. The simulated effects were then grouped into ten Effects Groups using a statistical clustering routine. Finally, classification tree analysis was used to predict duff, litter, fine woody debris (FWD) and log load that resulted in the soil heating and emissions seen in each of the Effects Groups. The FLM layer may be used to prioritize fuel treatment areas, evaluate fire hazard and potential status, and examine fuel loading characterizations. It may be used as input into wildland fire simulation software.

**Fuel Characteristic Classification System (FCCS)**
There are several techniques available for determining fuel loading. Collecting and weighing the fuel is the most accurate method but is impractical for many fuel types except grasses and small shrubs. Brown’s transects methods measure some biomass parameter and estimating the biomass using a pre-derived equation is less accurate but also less time consuming. The Fuel Characteristic Classification System (FCCS) is a tool that enables land managers to create and catalogue fuelbeds and to classify those fuelbeds for the capacity to support fire and consume fuels. The FCCS will provide managers tools to better estimate fuel loadings and reduce the uncertainty that currently exist with assigning fuel characteristics across a landscape. The photo series is a sequence of single and stereo photographs with accompanying fuel characteristics. The system enables modification and enhancement of fuelbeds to represent a particular scale of interest. The FCCS then reports assigned and calculated fuel characteristics for each existing fuelbed stratum including canopy, shrubs, nonwoody, woody, litter-lichen-moss, and duff. The system classifies each fuelbed by calculating fire potentials that provide an index of the intrinsic capacity of each fuelbed to support surface fire behavior, crown fire, fuels for flaming, smoldering, and residual consumption. Seventeen volumes are available for logging and thinning slash and natural fuels in forested, shrubland, and grassland fuelbed types throughout the United States. The FFCS is a national system being designed for classifying wildland fuelbeds according to a set of inherent properties to provide the best possible fuels estimates and probable fire parameters based on available site-specific information.
The Digital Photo Series (DPS) application consists of a user-friendly web interface that can be accessed using a web browser (such as Internet Explorer or Mozilla Firefox), either through the internet or from an individual computer's hard drive. In the absence of a web connection, a stand-alone version of the DPS can be used to run the site from a local computer hard drive. At present, an approximately 300 MB self-executing zip file can be sent to users upon request, and soon the file will be downloadable from the FERA website.


References:


Browns Transects

The Browns transect method is a procedure for inventorying downed woody material. The protocols instruct users on how to estimate weights and volumes of downed woody material, fuel depth, and duff depth using the planar intersect technique. Downed material is inventoried by 0-
to 0.25-inch, 0.25- to 1-inch, and 1- to 3-inch diameter classes; and by 1-inch classes for sound and rotten pieces over 3 inches. The field protocols are time consuming, but relatively easy to use and can be applied to naturally fallen debris and to slash. The method involves counting downed woody pieces that intersect vertical sampling planes and also measuring the diameters of pieces larger than 3 inches in diameter. The piece counts and diameters permit calculation of tons per acre. The inventory of volumes and weights is based on the planar intersect technique, which has the same theoretical basis as the line intersect technique. The planar intersect technique involves counting intersections of woody pieces with vertical sampling planes that resemble guillotines dropped through the downed debris. Volume is estimated; then weight is calculated from volume by applying estimates of specific gravity of woody material. The planar intersect technique is nondestructive and avoids the time-consuming, costly, and often impractical task of collecting and weighing large quantities of forest debris.

Woody pieces less than 3 inches in diameter are tallied by size classes. Pieces 3 inches and larger are recorded by their diameters. Size classes of 0 to 0.25, 0.25 to 1, and 1 to 3 inches were chosen for tallying intersections because:

- The class intervals provide the most resolution for fine fuels and are small enough to permit precise estimates of volume.
- They correspond, in increasing size, to 1-, 10-, and 100-hour average moisture timelag classes for many woody material. [These are standard moisture timelags used in the National Fire-Danger Rating System.

Chapter 7 Predicting Smoke Dispersion

Introduction
Smoke dispersion modeling is an increasing valued tool for prescribed fire planning and implementation, and for compliance of federal and state air quality regulations. The applications for smoke dispersion predicting tools include the visualization of fuel and weather on fire behavior and the likely smoke emission, concentrations, and their trajectory. Smoke prediction tools allow natural resource managers to communicate potential impacts of prescribed burns and wildfire suppression actions to installation operational staffs and their sea, ground, and air missions. The tools also allow burn bosses to submit outputs from smoke dispersion models for state burn permit approval and as supporting evidence that the prescribed fire will not violate clean air thresholds or impact smoke sensitive areas.

Predicting the smoke effects of wildland fires consists of four basic components. The first component is a description of the emissions source, which should include both pollutants and heat release. The second component involves determination of plume rise as calculated from the atmospheric stability, the wind profile, and the rate of heat release to determine the vertical extent of the smoke plume. The third component is the movement of the smoke transport and dispersion by the wind. A fourth component that may be included in smoke models is the chemical transformations that occur as smoke constituents react with each other and the atmosphere.

The effect on air quality of smoke from agricultural, grassland, and forest burning on human health has resulted in the development of methods to simulate and predict the transport and dispersion of smoke. The following review of smoke dispersion tools that have been used to simulate smoke transport and dispersion emphasizes operational tools for DoD installations. The review describes numerical models: Box, Plume, Puff, Particle, and Grid Models, and multiple models imbedded within modeling frameworks.

Ventilation Index
The ventilation index has become a useful smoke management tool throughout the U.S. as a simple method for determining whether the atmosphere can effectively disperse smoke by using indexes of ventilation or dispersion. Fire and smoke managers in the Southeastern U.S. have been using the ventilation index or clearing index to help regulate prescribed burn permitting. The ventilation index is the product of the average wind speed within the mixing layer of the atmosphere times the mixing height. Ventilation indexes tools cannot be used at night when there is no mixing height. If the atmosphere is very stable within the mixed layer, the ventilation index may be too optimistic in estimating smoke dispersion potential.

Spatial patterns of the monthly mean ventilation index can be viewed on the Ventilation Climate Information System (VCIS) Web site at: http://www.fs.fed.us/pnw/fera/vent/data.html. In addition to maps of ventilation index classifications, the temporal variability of ventilation indexes can be viewed from the VCIS Web site for any point on the landscape through frequency plots of all twice-daily values. The frequencies are shown as box plots, making it possible for users to determine the chance of experiencing a desired ventilation index value on any day of the month. Alaska, Hawaii, and the contiguous 48 states are separate sites because their maps are projected differently.
The ventilation index derived for VCIS is most useful for addressing concerns about smoke that stays relatively close to the ground smoke that stays relatively close to the ground.

The ventilation index is somewhat conservative but provides a reasonably accurate view of ventilation climate during the last 40 years.

The VCIS provides the first national coverage of ventilation climate.

Risks to air quality occur when ventilation index values are low and harmful pollutants are held close to the ground. Risks to visibility also occur when ventilation index values are low. Light-scattering and absorbing elements of smoke near the ground cause significant degradation of visual range, especially when combined with high atmospheric humidity.

In general, ventilation index data show the greatest risks to air quality and visibility in the Southeastern United States where marginal to fair ventilation conditions prevail most of the year. This region also has a high concentration of roads, hospitals, and schools. Additionally, the northern plains and deep valleys of the Western United States show risk potential with consistently poor to marginal ventilation during winter and marginal to fair conditions during spring and autumn. Sensitive receptors in the northern plains and western valleys, however, are much more sparse than in the Southeastern United States.

Most locations in the U.S. have significant potential of reaching good ventilation conditions during the afternoon at any time of the year. Exceptions include the Upper and Lower Mississippi regions, which, while exhibiting some good ventilation occurrences at all times of the year, seldom reach fair conditions in winter. Good conditions occur within a standard deviation only in April and May. Thus, it may be more difficult to find good ventilation conditions in the Mississippi regions than elsewhere. The large range of ventilation conditions in California shows that the frequency of good conditions is nearly the same as the frequency of very poor conditions regardless of the time of year. Although other regions may confidently expect good ventilation conditions in July, for example, the chances of finding good conditions in the California region are equal to finding poor conditions. This makes seasonal planning in the California region more difficult than for other regions. Key elements of risks to air quality and visibility from wildland fire include:

- Risks to air quality and visibility from wildland fire can be estimated by assessing spatial and temporal patterns of ventilation index.
- The greatest risks to air quality and visibility from wildland fire occur in the Southeastern United States.
- Risks to air quality and visibility from wildland prescribed fire can be minimized by planning times when good ventilation conditions are most frequent.
- The best ventilation conditions during morning hours occur during winter along the northern coasts of the contiguous 48 states, in southern Alaska, and in the north-central plains.
- The best ventilation conditions during afternoon hours occur in spring and early summer in the Rio Grande airshed.
- The VCIS point statistics allow identification of times of highest or lowest risk at any point on the landscape.
- The VCIS monthly maps show the spatial patterns of potential risk.
Atmospheric Dispersion Index
Ventilation indexes have no value when there is no mixing height at night and when the atmosphere is very stable within the mixed layer. Therefore, to help determine the atmosphere’s capacity to disperse smoke during all atmospheric conditions, the Atmospheric Dispersion Index (ADI) was developed to combine stability classes and ventilation indexes with a simple dispersion model. National Weather Service (NWS) fire weather offices include the ADI as a regular part of their smoke management forecast. Commonly the ADI must be greater than 30 before burning is recommended.

The Atmospheric Dispersion Index (ADI) is a numeric rating of the atmosphere's capability of transporting pollutants away from their sources. The ADI is based on the Gaussian distribution statistical models in which a normal distribution of pollutant concentration is expected within the plume. The ADI ranges from 1 to over 100. Low values indicate poor dispersion, where smoke will be trapped near the ground, and high values indicate good dispersion, where smoke will be quickly carried away from the source and high into the atmosphere. Normal daytime values in good prescribed burning conditions vary from 60 to 100. Values much larger than 100 indicate blow-up conditions, under which crown fires are likely. Overnight values of 10 or less are common, although forcing events such as frontal passages may produce high values. Surface and weather balloon observations provide information about atmospheric stability, the mixing height, and the mean wind within the mixing layer (transport wind vector). Upper air conditions are normally observed every 12 hours at stations much farther apart than surface stations.

Simple Smoke Screening

Atmospheric Dispersion Index (ADI)
In states that have not issued smoke management guidelines, the Southern Forest Smoke Management Guidebook (Web Link: [http://www.srs.fs.usda.gov/pubs/viewpub.php?index-683](http://www.srs.fs.usda.gov/pubs/viewpub.php?index-683)) provides protocols for predicting smoke concentrations at any distance downwind from the fire point of origin. Additional protocols can be found in A Guide for Prescribed Fire in Southern Forests (Web Link: [http://ncprescribedfirecouncil.org/pdfs/guide_for_prescribed_fire.pdf](http://ncprescribedfirecouncil.org/pdfs/guide_for_prescribed_fire.pdf)). The protocols consists of five steps:

1. Determine the screening distance based on the expected fuel consumption.
2. Using a map on which smoke sensitive areas can be identified, locate the burn unit and mark its center.
3. Draw a line through the center point along the preferred wind direction for the burn that extended out the distance calculated in Step 1.
4. Draw a line through the center point perpendicular to the line drawn in Step 3 that extends the width of the burn unit. At each end of the line, draw lines parallel to the line drawn in step 3. This is the anticipated smoke path.
5. Draw two lines at 30 degree angles from the anticipated smoke path. Repeat if wind direction changes. Locate all smoke sensitive targets within or adjacent to the area of smoke impacts.
Numerical Smoke Dispersion Models
Most smoke dispersion predictive models are three types of deterministic numerical models (dispersion, box, and three-dimensional grid) that predict the timing, trajectory, and concentration of smoke emissions from fires. Dispersion models are the most common tool used by prescribed fire managers to predict smoke plumes and gaseous emissions along a straightline trajectory from the fire origin. Box models are useful for estimating the smoke concentrations in confined basins and valleys. Smoke concentrations are estimated within a confined area over time as smoke enters and transports out of a confined (box) area. Grid models calculate smoke concentrations across a series of gridded boxes in which each box within the geographical grid computes smoke concentrations. Both dispersion and box models are used for wildfire and prescribed fire smoke predictions. Grid models are being used within multiple model framework for smoke concentration and projections but computer resources usually require that these fire scenarios be run within web based applications at regional computing facilities. Gridded models have the advantage of estimating smoke and chemical interaction of emissions across large airsheds and regions.

Figure 1. Conceptual Diagram of (A) Gaussian Plume, (B) Gaussian Puff, and (C) Box Model (Adapted from Hardy, C.C. et. al., 2001)
Box Models
A single box model is the simplest approach to estimating pollutant concentrations within a confined geographic area, typically basins and valleys. Box models are characterized by low wind speeds and strong temperature inversions that keep the mixing height of the smoke plume within the basin or valley. The coordinates of the box are used to predict smoke dispersion at a fixed time within Eulerian coordinates. Box model assumptions include that an airshed can be represented by a simple box whose height is defined by the top of the mixed layer, and whose horizontal dimensions are defined by the spatial extent of the airshed. A key assumption in the box model is that emissions are instantaneously well-mixed throughout the entire volume of the box, bypassing the processes of plume rise and dispersion and treating the entire lower boundary of the box as the emission source.

One example of a box model used for smoke management is the Ventilated Valley Box Model or VALBOX. VALBOX is a screening model designed to predict ground level concentrations of particulate matter and gaseous pollutants under stagnation conditions in mountain valleys. In this case the box is defined by the valley floor and sides, and an atmospheric inversion that restricts vertical mixing of smoke. Although VALBOX is not ideal for predicting surface concentrations from single fires, it is useful when assessing total smoke loading within a valley for an air quality episode that lasts several days.

The simplicity of the box model is evident in an index commonly used to estimate the atmosphere’s ability to disperse pollutants. The ventilation index (VI) is defined as the product of the mixing height and the mean wind speed through the mixing layer, also called transport wind speed. The transport wind speed and direction, mixing height and VI are routinely transmitted by the National Weather Service in its fire weather forecasts.

Another smoke management index with roots in the box model concept is the Atmospheric Dispersion Index (ADI). As with the VI, the primary inputs of the ADI are mixing height and transport wind, but the ADI also requires information on atmospheric stability. The ADI provides an open-ended scale for evaluating smoke dispersion conditions for both daytime and nighttime conditions. Although higher values of either the VI or ADI reflect improved dispersion capacity in the atmosphere, this improved dispersion comes with an increased potential for erratic fire behavior as a result of stronger winds, an unstable atmosphere or a combination of these factors.

Box models represent an extreme simplification of the smoke dispersion process as they instantly disperse emissions uniformly throughout the box volume, eliminating the need for a description of plume rise or diffusion. Required meteorological data are reduced to know mixing height and transport wind speed, and these variables are assumed to be constant for a given box volume. Near a fire the assumption of instantaneous mixing cannot be met as the initial buoyancy of smoke tends to concentrate smoke closer to the top of the mixing layer. For this reason, concentration estimates from box models tend to be too high downwind of the fire. Box models can be instructive when trying to assess total pollutant load within an airshed.

Gaussian Plume Models
Plume models are a step towards a more realistic description of a smoke plume. The plume method assumes that smoke travels in a straight line under steady-state conditions of constant speed and direction that do not change during the modeling time period. Rather than treating a fire as a diffuse area source spread across an entire airshed, plume models define the source as a point or specific area encompassing the fire. Atmospheric processes of transport and dispersion
are treated with greater detail than the instantaneous dispersion of a box model. Smoke is transported in the direction defined by a wind that is constant in both space and time. Crosswind dispersion is represented by a Gaussian distribution. Original applications for such models are rooted in industrial pollutant emission studies, but two wildland fire specific Gaussian plume models have been developed, namely VSMOKE, VSMOKE-GIS, and SASEM.

Plume rise is not incorporated in VSMOKE. The user specifies a fraction of smoke that is released at the ground vs. the amount released near the top of the mixing layer. Based on observations of prescribed fires in the southeastern United States, emissions are portioned with a ratio of 60% subject to plume rise and 40%, no-plume-rise. Although the assumption of all smoke being confined to the mixing layer is workable for small prescribed fires, plumes from large prescribed fires and wildfires do rise above the mixing height. That means much fine particulate matter can be transported above the boundary layer and away from ground-level sensitive targets. VSMOKE’s assumption that all smoke stays within the mixed layer limits its applicability in such cases and would strongly overestimate surface smoke concentrations. SASEM (Simple Approach Smoke Estimation Model) is another example of a plume model designed for use with wildland fires in flat to gently rolling terrain in the western United States. SASEM predicts ground-level particulate matter and visibility impairment from single fires and utilizes internally calculated plume rise, and emission rates based on specified fuel types. Like VSMOKE, SASEM is a screening model, in that it uses simplified assumptions (steady-state, homogenous weather and all smoke confined to mixed layer) and tends to over predict effects, yielding conservative results.

Gaussian plume models assume smoke travels in a straight line under steady-state, homogenous conditions. Areas of changing weather conditions such as approach and passage of frontal systems, or areas prone to local phenomena such as sea breezes or slope and valley winds in complex terrain, are likely to violate these assumptions and reduce the reliability of the results. One advantage of plume models is that they do not require detailed weather inputs and are very useful when meteorological information is scarce.

**Puff Models**
Puff models simulate a continuous plume using a series of puffs that can be used to predict smoke with changing wind directions and topography that determines smoke trajectory patterns. Smoke plumes are represented as a collection of independent ‘puffs’ released throughout the duration of the burn with each ‘puff representing a volume that contains a specific amount of pollutant. Puffs are transported by winds that vary in both space and time (and can include the influence of complex terrain). In addition, the puffs expand with time due to diffusion and entrainment. As the puff volume increases, the pollutant concentration decreases within the puff. Examples of puff models used for wildland fire applications include CALPUFF and HYSPLIT. CALPUFF is a modeling system that consists of a diagnostic meteorological model (CALMET) and an advanced Lagrangian-Gaussian non-steady-state air quality model (CALPUFF). CALMET produces hourly fields of such meteorological parameters as winds, temperature, mixing height and plume dispersion on a three-dimensional gridded modeling domain by either interpolating routine surface and upper air meteorological data or downscaling output from a numerical weather prediction model or by merging both together. CALPUFF is one of the US Environmental Protection Agency’s (EPA) preferred models for assessing transport of pollutants and their effects, on a case-by-case basis, or for certain near-field applications involving complex meteorological conditions.
The HYSPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectory) model is a complete system for computing simple air parcel trajectories and complex dispersion and deposition simulations. A joint effort between the United States National Oceanic and Atmospheric Administration (NOAA) and Australia’s Bureau of Meteorology, the model has recently been upgraded to include modules for chemical transformations. As the name suggests, HYSPLIT uses a hybrid modeling approach, using either puffs, particles or a combination of these. In the puff model, puffs expand until they exceed the size of the meteorological grid cell (either horizontally or vertically) and then split into several new puffs, each with its share of the pollutant mass. In the particle model, a fixed number of initial particles are advected about the model domain by the combined mean and turbulent wind fields. The model’s default configuration assumes a puff distribution in the horizontal and particle dispersion in the vertical direction. In this way, the greater accuracy of the vertical dispersion parameterization of the particle model is combined with the computational efficiency of having an array of puffs represent the horizontal pollutant distribution.

A Smoke Forecasting System (SFS) intended to provide air quality forecasters and the public with guidance on expected fine particulate matter (PM$_{2.5}$) concentration emitted from large wildfires and agricultural burning is currently operated by NOAA. The SFS integrates satellite-based fire detection products from the National Environmental Satellite, Data and Information Service (NESDIS) Hazard Mapping System (HMS), particulate matter emission rates from the USDA Forest Service’s BlueSky Framework, and dispersion calculations using HYSPLIT.

**Particle Models**

Particle models differ from other model types in that there is no numerical diffusion of the pollutants. Each particle represents an infinitesimal air parcel containing a fixed mass of pollutant. Individual particles respond to the mean and turbulent components of the wind field, making diffusion a direct result of the movement of particles rather than a parameterized process. Three models are being used for wildland fire applications: FLEXPART, DaySmoke and PB-Piedmont. FLEXPART follows traditional Lagrangian particle modeling theory, DaySmoke is an empirical model that employs particle modeling in a hybrid model formulation, and PB-Piedmont is a particle model adapted specifically to modeling the movement of residual smoke in a stable, nocturnal environment.

FLEXPART is a Lagrangian particle dispersion model designed to simulate the long-range and mesoscale transport, diffusion, and wet deposition. DaySmoke is an extension of ASHFALL, a model developed to simulate deposition of ash from sugarcane fires. As adapted for prescribed fire, DaySmoke consists of four sub-models: an entraining turret model, a detraining particle model, a large eddy parameterization for the mixed boundary layer, and a relative emissions model that describes the emission history of the prescribed burn. A burn in DaySmoke may have multiple, simultaneous updrafts cores. In comparison with single-core updrafts, multiple-core updrafts have smaller updraft velocities, are smaller in diameter, are more affected by entrainment, and are therefore less efficient in the vertical transport of smoke.

Planned Burn-Piedmont (PB-P) is a very high resolution meteorological and smoke model that can be used predictively or diagnostically to simulate near-ground smoke transport at night over complex interlocking ridge-valley systems typical of landforms over much of the eastern United States.
Eulerian Grid Models
In contrast to the moving coordinate frame used by puff and particle models, grid models use a reference frame that is fixed in both space and time (Eulerian coordinates). Grid models are a collection of interconnected box models arranged as a regular lattice across the geographic extent of the fire airshed. Although the fixed coordinates make it difficult for grid models to track the effect of individual plumes, grid models are more practical for examining the cumulative effects from several plumes combined with anthropogenic emission sources. The structured grid also facilitates modeling chemical transformations that may occur as pollutants interact with both themselves and the environment. This makes grid models especially useful for evaluating the effect of smoke on regional haze and ozone.

The USA EPA Community Multiscale Air Quality (CMAQ) modeling system is a third-generation air quality model designed for a wide range of applications covering regulatory and policy analysis as well as research questions concerning atmospheric chemistry and physics. CMAQ is a comprehensive atmospheric chemistry and transport modeling system capable of simulating ozone chemistry, particulate matter (PM), toxic airborne pollutants, visibility and acidic and nutrient pollutant species throughout the troposphere. A key feature of CMAQ is its ‘one-atmosphere’ model design philosophy that allows CMAQ to address the complex couplings among several air quality issues simultaneously across a range of spatial scales. Although CMAQ is widely used in the United States due to its connection with the EPA, it is not the only grid model to be used to examine wildland fire related effect on air quality. The CHIMERE model has been used to examine the effect of particulate matter emissions during the summer on air quality in Europe. The results suggest that wildfire events may have significant effects on regional photochemistry and atmospheric stability that need to be considered in chemistry-transport models.

A potential limitation of grid models, as with box models, is the assumption of instantaneous diffusion of emissions evenly throughout a grid volume. Although there is little that can be done to reduce this limitation with respect to horizontal diffusion, beyond reducing the model grid spacing to achieve finer resolution, the vertical distribution of emissions can be dramatically improved through the use of a plume in grid technique to more fully describe the plume rise process.

Full Physics Models
In grid models, the horizontal extent of the grid volumes are such that the smoke plume at the fire source fits completely within the volume. This prevents the model from resolving any of the relevant dynamic plume processes. Reducing the horizontal extent of the grid volumes allows the model to explicitly resolve processes that influence plume development, such as entrainment. This level of resolution removes the need for a plume rise parameterization as these models incorporate the buoyant flux of pollutants directly into solution of the equations governing atmospheric dynamics. Models operating at this level of detail are based on a form of the Navier-Stokes equations of fluid dynamics and are referred to as full physics models.

One full physics plume model that has been applied to wildland fire is the active tracer high-resolution atmospheric model (ATHAM). ATHAM simulated a prescribed burn in north-western Washington that closely approximated measured elevations and concentrations of smoke. An interesting derivation from the full physics model is the ALOFT plume model from the United States National Institute of Standards and Technology (NIST). ALOFT (A Large Outdoor Fire plume Trajectory model) predicts the downwind distribution of smoke particulate and
combustion products from large outdoor fires by solving the fundamental fluid dynamic equations for the smoke plume and its surroundings. This allows the model to simulate many observed plume features such as the twin counter-rotating vortices frequently observed. The primary simplification that separates ALOFT from the complexities of a full physics model is that ALOFT solves the steady-state form of the convective transport equations using constant ambient atmospheric conditions.

Smoke Modeling Frameworks
Although the dispersion models discussed represent a broad range of approaches to simulating the transport and dispersion of smoke from a wildland fire, they only represent a fraction of the complexity of the smoke modeling problem. Tools for describing fuel loading, calculating fuel consumption and converting that consumption to emissions, as well as tools for estimating plume rise, are all required to fully treat the smoke management problem. The vast array of expertise required in using these tools can be daunting to land managers. Reducing this learning curve is the job of smoke management frameworks, a term that describes a modeling structure that combines a set of tools for each component of the smoke modeling process (fuel load, consumption, emissions, plume rise and transport and dispersion) into a unified tool chain that hides much of the underlying complexity from the end users.

The BlueSky Smoke Modeling Framework (BlueSky) was developed as part of a multi-agency effort to simulate and predict smoke from approved or planned prescribed fires, agricultural fires and wildfires. It couples off-the-shelf weather, fuels, consumption, emissions and dispersion models in a modular framework in order to produce these real-time predictions. By gathering and using information on all fire activity in a region, BlueSky not only predicts the smoke PM$_{2.5}$ effects from a single fire, but also predicts cumulative smoke effects from multiple fires. BlueSky supports a wide array of potential configurations as there is a range of options for each link in the tool chain. For example, options for dispersion modeling include CALPUFF and HYSPLIT, and CMAQ-ready emissions output can also be generated. Validation efforts for BlueSky have found the predicted plume footprints to agree well with satellite observations; the older version of the framework showed a tendency to underestimate near-field surface smoke concentrations while potentially overestimating far-field surface smoke concentrations. However, a comparison study between BlueSky-CMAQ output and observations for the 2008 northern California wildfires showed BlueSky predicting PM$_{2.5}$ concentrations near observed values the majority of the time. Splitting fires into multiple emissions sources to mimic the concept of multiple-core updraft plumes offered improvements to the surface smoke predictions without altering the agreement with satellite detected plumes. Several smoke modeling systems have been developed from BlueSky including regional systems in the Pacific Northwest and elsewhere utilizing web-based custom modeling.

The NOAA Smoke Forecasting System integrates the NOAA National Environmental Satellite, Data and Information Service's satellite information on the location of wildfires with NOAA National Weather Service weather inputs from the North American Mesoscale model and smoke dispersion simulations from the NOAA ARL HYSPLIT model to produce a daily 48-hour prediction of smoke transport and concentration. The model framework also incorporates U.S. Forest Service estimates for wildfire smoke emissions based on vegetation cover. This system is intended as guidance to air quality forecasters and the public for fine particulate matter emitted from large wildfires and agricultural burning which can elevate particulate concentrations to unhealthful levels.
References:

Chapter 8 Smoke Predictive Toolkit

Introduction
The use of prescribed fires is a viable and well-utilized tool for forest ecology and fuels management in many regions of the U.S. From 1998-2013, more than 34,851,079 acres of prescribed fire were carried out in the U.S. by Federal, State, and other agencies/groups, and more than 93 million acres of total wildland fire (National Interagency Fire Center 2015). Wildland fire suppression costs for the same period was $21,651,782,000. In addition to their use by land managers for fuel reduction, prescribed fires are also used by farming communities for burning agricultural debris. Unlike major wildfires that are more intense, spread rapidly, and may pose significant threats to resources, property, and even life, prescribed fires are typically low intensity and carefully managed so that they are confined to a small area and do not spread into surrounding communities. However, smoke from low-intensity prescribed fires can degrade local air quality in the vicinity of those fires and also be transported to surrounding smoke sensitive areas where it can cause health concerns. This is particularly relevant for prescribed fires occurring in wildland-urban-interface zones in the eastern U.S. Smoke from low-intensity prescribed fires can also create travel hazards on surrounding roads and highways, and interact with fog to create superfog, a combination of smoke and fog that cause white out conditions.

Given the potential health and safety concerns associated with smoke generated from low-intensity prescribed fires, operational predictions of the impacts of prescribed burning on DoD installation missions and local air-quality could provide natural managers with an additional tool for the planning and management of prescribed fires. There are a variety of predictive air-quality models and systems currently available to the operational fire and air quality management communities for prescribed fire planning. These include box models (e.g. Atmospheric Dispersion Index, Ventilation Index); Gaussian plume models (e.g. VSmoKe, SASEM); puff models (e.g. CALPUFF, HYSPLIT); particle models (e.g. FLEXPART, DaySmoke, PB-Piedmont); Eulerian grid models (e.g. CMAQ, AERO-RAMS, WRF-Chem); and smoke modeling frameworks (e.g. BlueSky). All of these models and systems have enhanced the effectiveness of fire management activities in the U.S. and many have contributed to an increased understanding of smoke dispersion processes.

Desktop Smoke Dispersion Models

HYSPLIT

What is HYSPLIT
The HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory) Version 4 model is a wildland fire air quality prediction system for computing simple trajectories to complex dispersion and deposition simulations. The dispersion of an air pollutant is calculated by assuming either puff or particle dispersion model theory. In the puff model, puffs expand until they exceed the size of the meteorological grid cell (either horizontally or vertically) within the grid’s geographical extent and then split into several new puffs, each with its share of the air pollutant mass. In the particle model, a fixed number of initial particles are advected about the model’s geographic domain by the mean wind field and a turbulent component. The model's default configuration assumes a puff distribution in the horizontal and particle dispersion in the vertical direction. In this way, the greater accuracy of the vertical dispersion parameterization of the particle model is combined with the advantage of having an ever expanding number of
particles represent the pollutant distribution.

**Model Inputs and Outputs**
The modeling system includes dispersion models, graphical displays, and text forecasts with model outputs that are easy to use for both fire managers and scientists. The model consists of a modular library structure with trajectory and air concentration applications. New features include improved advection algorithms, updated stability and dispersion equations, a new graphical user interface, and the option to include modules for chemical transformations. Without the additional dispersion modules, HYSPLIT computes the advection of a single pollutant particle, or simply its trajectory. Gridded meteorological data, on a latitude-longitude grid or one of three conformal (Polar, Lambert, Mercator) map projections, are required at regular time intervals. The input data are interpolated to an internal sub-grid centered. Air concentration calculations require the definition of the pollutant's emissions and physical characteristics. The routine meteorological data fields required for the calculations may be obtained from existing archives or from forecast model outputs already formatted for input to HYSPLIT. In addition, several different pre-processor programs are provided to convert NOAA, NCAR (National Center for Atmospheric Research) re-analysis, or ECMWF (European Centre for Medium-range Weather Forecasts) model output fields to a format compatible for direct input to the model. The modeling system includes a graphical user interface to set up a trajectory, air concentration, or deposition simulation. The post-processing part of the model package incorporates graphical programs to generate multi-color or black and white publication quality Postscript printer graphics.

**Where Can I Get Additional Information**
The HYSPLIT4 model can be found at the NOAA Air Resources Laboratory website: [http://ready.arl.noaa.gov/HYSPLIT.php](http://ready.arl.noaa.gov/HYSPLIT.php). The website contains HYSPLIT-WEB (the internet-based interactive version), PC Windows-based HYSPLIT (download for unregistered and registered model versions), Apple-based HYSPLIT (Apple registered model version), HYSPLIT-compatible Meteorological Data, Documentation (Overview, Documentation, and Publications), and On-Line Training/Presentations. The registered PC version is complete with no computational restrictions, except that user's must obtain their own meteorological data files. The unregistered version is identical to the registered version except that it will not work with forecast meteorology data files. The user guide can be downloaded from: [http://199.128.173.141/vsmoke/Brief_Instructions_031510.pdf](http://199.128.173.141/vsmoke/Brief_Instructions_031510.pdf)

**VSMOKE, VSMOKE-GIS, and VSMOKE-Web**

**What Is VSMOKE**
The VSMOKE and VSMOKE-GIS models were developed in the 1996 by Leonidas Lavdas, USDA Forest Service, to estimate the impact of particulate matter emissions from wildland and prescribed fire on highway visibility and human health in flat and rolling hill topography. These smoke dispersion models are classified as Gaussian models with plumes that disperse in a bell-shaped distribution pattern. The plume method assumes that the smoke emissions from the fire travel in a straight line under constant speed and direction during the time period of the model’s
VSMOKE estimates hourly downwind particulate matter and carbon monoxide concentrations at 31 fixed distances and estimates the dimensions of the plume above the ground at each of the 31 distances. VSMOKE Version 2 provides an interface and adds an interface to the Forest Emissions Production Simulator (FEPS). The FEPS model estimates hourly PM$_{2.5}$ and heat release rates which are used to predict the downwind particulate matter concentrations. The models are used throughout the Southeaster U.S. by federal, state, and NGOs conducting prescribed fires.

VSMOKE-GIS uses many of the same algorithms as VSMOKE but the output is displayed in ESRI ArcMap and ArcView GIS software. The model predicts the maximum detectable downwind distance of PM$_{2.5}$. The user interface allows for up to 10 particle concentrations to evaluate or to use the 5 particle concentrations that were determined by the U.S. Environmental Protection Agency’s air quality index (AQI).

**Model Inputs and Outputs**

VSMOKE is a smoke prediction model that is weather driven and incorporates emissions information from weather forecasts and the Fire Emissions Production Simulator. Prescribed burn locations are entered by latitude and longitude or by the interactive pointer on a map. Weather forecast inputs include: wind speed and direction, mixing height, and atmospheric stability. The burn parameters include fuel types (12 classes), fuel moisture, fuel loading, burn unit size, and ignition method. Fuel loads (tons/acre) are input for each fuel type, but prescribed fire specialist can input more accurate individual site measured information. The fuel consumption and air pollution emissions information is used by VSMOKE to produce the plume characteristics and the visual outputs.

**Where Can I Get Additional Information**


References:

**SASEM**

**What is SASEM?**

The Simple Approach Smoke Estimation Model (SASEM) Version 4.0 model calculates the consumption of fuel, emission of particles, and dispersion of these pollutants produced by prescribed burning of forest and range vegetation. SASEM calculates emissions from fire line intensity, average fuel loading and the type of fuel which is burned. Plume rise is calculated from the fuel type (which is used to determine fire front heat production), wind speed and stability. The particulate concentrations are obtained from the emission rate, plume rise, wind speed and stability using the Gaussian dispersion formula for a line source (or point sources in the case of...
slash piles). The model determines the maximum concentration and if any, the distance range over which applicable standards might be violated. Reduction in visual range at selected receptors is obtained from calculation of a simple scattering coefficient based on particulate concentration at the receptor. The concentration used is from the plume calculations or a simple 'box model' type calculation.

**Model Inputs and Outputs**
SASEM requires data on: burn name, burn date, burn type fuel model, fuel loading (fine, small, large, very large, extra large, stump, and duff), burn area, burn duration (hours), and number of piles. The Emission Production Model within SASEM has a dialog box which requires user inputs for: region, ownership, lat/long, harvest date, snow off month, species, slope, fuel moisture, days since rain, and ignition pattern. Meteorology inputs include: min/max wind speed and direction, atmospheric stability, mixing height, wind speed and stability conditions for the burn.

The primary output from SASEM describes whether the selected air quality standards would be exceeded by the proposed burn and under what conditions any indicated exceedance would occur. A separate table is produced for each air quality standard that was selected in the General Info entry dialog. These results are presented for each combination of stability and wind speed in the prescription (subject to the reasonable meteorology constraints if selected). For each of these combinations, the maximum concentration, the distance downwind of that concentration, and the plume rise are reported. If the maximum concentration for a wind speed and stability does not exceed the standard for that report table, then No Exceedence will also be displayed. If the maximum concentration does exceed the standard, then the minimum and maximum distance downwind where the standard would be exceeded is reported.

**Where Can I Get Additional Information**
SASEM, Version 4.0 can be found at the FRAMES website which will direct the user to the Arizona Department of Environmental Quality web site. The web links can be found at: https://www.frames.gov/rcs/0/983.html and http://www.azdeq.gov/environ/air/smoke/fires.html. The .exe file and user instructions for the model are include in the web links.

References:


**CALPUFF, CALMET, and CALPOST**
**What is CALPUFF, CALMET, and CALPOST**
CALPUFF Version 5 is an advanced non-steady-state meteorological and air quality modeling system developed by Exponent scientists. It is maintained by the model developers and distributed by Exponent. The model has been adopted by the U.S. Environmental Protection Agency (USEPA) in its Guideline on Air Quality Models as the preferred model for assessing long range transport of pollutants and their impacts on Federal Class I areas and on a case-by-case basis for certain near-field applications involving complex meteorological conditions. The modeling system consists of three main components and a set of preprocessing and post-
processing programs. The main components of the modeling system are CALMET (a diagnostic 3-dimensional meteorological model), CALPUFF (an air quality dispersion model), and CALPOST (a post-processing package). CALPUFF is a transport and dispersion model that advects puffs of air pollutants emitted from the burn sources, simulating dispersion and transformation chemical process along the path. CALMET is a meteorological model that estimates hourly wind and temperature fields on a three-dimensional gridded fire domain. Two-dimensional fields for mixing height, surface characteristics, and dispersion properties are produced by CALMET. CALPOST is used to process files from CALPUFF and CALMET, producing summary tabulations of the model simulations. CALFULL has been coupled to the Emissions Production Model (EPM) and provides time-dependent emissions and heat release data for modeling of prescribed fires and wildfires.

Each of these programs has a graphical user interface (GUI). In addition to these components, there are numerous other processors that may be used to prepare geophysical (land use and terrain) data in many standard formats, meteorological data (surface, upper air, precipitation, and buoy data), and interfaces to other models such as the Penn State/NCAR Mesoscale Model (MM5), the National Centers for Environmental Prediction (NCEP) Eta/NAM and RUC models, the Weather Research and Forecasting (WRF) model and the RAMS model.

Where Can I Get Additional Information
The CALMET, CALPUFF, and CALPOST model codes and associated processing programs are provided by Exponent, Inc. with a no-cost, limited-use license subject to restrictions and can be found at: http://www.src.com/calpuff/calpuff_eula.htm. A user’s guide can be found at: http://www.exponent.com/calpufftraining/#tab_overview. Exponent’s Atmospheric Sciences offers training on all aspects of the CALPUFF model, available as 3-day, 4-day, and 5-day courses. Course details can be found at: http://www.exponent.com/calpufttraining/#tab_overview.

SIS

What is SIS?
The Smoke Impact Spreadsheet (SIS) is a simple-to-use planning model for calculating particulate matter (PM) emissions and concentrations downwind of wildland fires. SIS conservatively predicts (that is, estimates higher than actual) downwind PM concentrations for comparison with appropriate Federal or State air quality standards. SIS is an easy-to-use replacement for the SASEM model. SIS has three main components:

- An Excel-based graphic user interface for easy data entry, model execution, and display of results.
- An emissions module that calculates emissions for broadcast burns and wildfires using the First Order Fire Effects Model (FOFEM5), and for pile burns using the CONSUME 2.1 pile wizard.
- A dispersion module that calculates downwind concentrations using the CALPUFF dispersion model.
**Model Inputs and Outputs**

SIS requires minimal input data and setup time by the user. The results are easy to read and understand and may be copied into other reports. Specific inputs include: burn name, burn type, burn acres, FOFEM5 fuel type, and fuel loading by size. Pile burn inputs include: pile shape, dimensions, packing ratio, fuel type for pile burns, and number of piles per burning period. Broadcast burn input include: subunits, starting hour, strip width, strip length, number of strips, strip spacing, ignition rate (ft/min), and ignition time (hours). Meteorology inputs include: burn date, latitude, 10-meter wind speed (mph), wind direction offset (degrees), maximum temperature, Pasquill-Gifford stability class. And terrain inputs include: maximum distance, average elevation of burn, terrain profile.

**SIS is not an operational tool for making go/no-go decisions for prescribed burns.** The uses for the tool include: project development, NEPA documents, Burn Plans, and state smoke permitting.

**Where Can I Get Additional Information**

The SIS setup file and users guide may be downloaded from the following Web site: [http://airsci.com/sis/](http://airsci.com/sis/)

**References:**


**Web-Based Dispersion Models**

**BlueSky**

**What is BlueSky?**

BlueSky is a modeling framework. BlueSky modularly links a variety of independent models of fire information, fuel loading, fire consumption, fire emissions, and smoke dispersion. The BlueSky smoke modeling framework requires a series of processing steps, containing datasets or individual component models, sequentially linked together, starting with fire information and fuel loading, progressing to fuel consumption, and ending with smoke emissions or smoke transport. BlueSky is not a ‘model’ in the traditional sense; it is a modular framework that integrates existing datasets and models into a unified structure. In doing so, BlueSky can be and has been implemented to create smoke forecasts and decision-support information. BlueSky’s modeling steps are designed to answer a sequence of questions that end with smoke impacts:

- The lookup of fuels information from fuel maps
- The calculation of total and hourly fire consumption based on fuel loadings and weather information
- The calculation of speciated emissions (such as CO₂ or PM₂.₅) from a fire
- the calculation of vertical plume profiles produced by a fire
- the calculation of likely trajectories of smoke parcels given off by a fire
- the calculation of downstream smoke concentrations.
**Model Inputs and Outputs**

The BlueSky framework is modular, which allows for great flexibility. Each modeling step in the chain can be implemented in a variety of ways using a variety of existing models. To facilitate this, the BlueSky framework is defined in terms of interfaces between the model types. Because of this, the framework can be started and stopped at any interface point, allowing subsets of the framework to be used without the need to run the rest of the framework. Two file standards are used in the interfaces – the simple text comma separated values standard (CSV) and the binary gridded Unidata NetCDF standard.

Data flow through the framework to and from the currently implemented component models is executed by a wrapper that also translates the data from the interface standard into the specific input required by the component model and similarly translates the model output into the next interface standard. This modularity allows for ease of implementation of additional models and advances in model components, and intermodal comparison at each level of the framework. The specifics of the available component model choices are described in the following sections.

BlueSky requires three-dimensional (x, y, z) gridded meteorological data on an hourly time step in order to run the dispersion and trajectory models. Currently, BlueSky can easily use model output from a variety of models including the National Center for Atmospheric Research/Penn State Mesoscale Meteorological Model (MM5) Version 3 or later, or its successor, the Weather Research and Forecasting (WRF) model.

The minimum fire information input data required by BlueSky are fire location and daily fire growth. Additional fire information needed is either supplied by a collection of user-modifiable default values or produced by the component models. Any additional information about the fire, such as fuel loadings, fuel moistures, or fire type, included as input are carried through the framework and used preferentially, replacing the default or modeled values.

Fuel loadings for each fire location are needed in order to continue through the BlueSky modeling pathway. When available, these fuel loadings are obtained from the fire activity input data; otherwise they are acquired via fuel map reference tables in BlueSky’s fuel loading process step. The default fuel map is from the Fuel Characteristic Classification System (FCCS); other implemented options are from the US National Fire Danger Rating System (NFDRS).

After fire location, size, and fuel loadings are known, fire consumption for every unit area burned can be determined. BlueSky splits the consumption step into two pieces: total consumption and the time rate of consumption. Total fire consumption is calculated because it is most easily measured: using field plots before and after the fire make this step more accurate and verifiable than the hourly time rate of consumption. Total consumption calculations are done separately for each day’s fire growth.

Once the total amount of fuel consumed is calculated, the consumption is allocated over time using a time profile. All of the models for this step use relatively simple, idealized profiles or curve fits for this purpose. For a wildfire, the default time profile is from the Western Regional Air Partnership’s wildfire profile, which allocates 68% of the emissions to an afternoon active fire period (1300–1700 hours local time), but also contains a smoldering component that continues throughout the night. For a prescribed burn, the internal equations in EPM or FEPS (default) can be used, which are based on simple rise and decay curves. FEPS also includes a long-term low-level smoldering component.

BlueSky model framework outputs include emissions from three emissions models: EPM, FOFEM, and FEPS. BlueSky is most often used to model fine particulate matter with aerodynamic diameters less than 2.5µm (PM$_{2.5}$), however, several other chemical species are also
available through these emissions models. EPM calculates emissions of CO, CO₂, CH₄, total PM, PM₁₀, PM₂.₅, NOₓ, SO₂, NH₃, and non-methane hydrocarbons (NMHCs) based on vegetation type. BlueSky uses CALPUFF to calculate surface concentrations of smoke, currently PM₂.₅. Owing to its two-dimensional nature, CALPUFF cannot be used to examine concentrations in the vertical layers of the atmosphere. Trajectories are simulated using the HYSPLIT Lagrangian three-dimension particle-puff model. Twelve-hour trajectories are computed from each burn location. As an alternative to CALPUFF and HYSPLIT, BlueSky emissions can also be incorporated into the Sparse Matrix Operations Kernel Emissions (SMOKE) preprocessor used by the EPA’s Community Multiscale Air Quality (CMAQ) model.

Where Can I Get Additional Information
BlueSky is a web based modeling framework application that is designed to run from a desktop computer. The user starts a web-based application, the BlueSky Playground, which is available at the web link: http://www.airfire.org/data/playground/. The tool is available at the web link: http://playground.airfire.org. The user must create an account to log in. The BlueSky Playground can be used to model fires, estimate pollutant emissions, and predict downwind smoke concentrations. To get started the user creates one or more emissions scenarios to model the fires. The user specifies the size, type, and location of the fires; then chooses to accept defaults, or modify specific details about fuel loading, moisture, etc. After creating an emissions scenario, the user can choose to create a dispersion scenario.

Creating a dispersion scenario allows the user to choose associated fires, meteorological data, and the date of the fire(s) to generate a map of the predicted hourly PM₂.₅ concentrations. The user can create new emission scenarios to model the fire's emissions view emission scenarios to vie and edit emission scenarios or create dispersion scenarios, and view dispersion scenarios to view and edit saved dispersion scenarios.

BlueSky is also available on the Wildland Fire Air Quality Tools, WFDSS Integrated Tools v0.9 web site at: http://firesmoke.us/wfdss/. In addition to the customized fuels, consumption, & smoke modeling tool, there are additional tools for: Smoke guidance point forecast, smoke guidance regional maps, diurnal surface wind pattern analysis, climatological ventilation index point statistics, current air quality condition maps, and fire information & smoke trajectories.

References:

HYSPLIT-Web

What is HYSPLIT-Web
The HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory) Version 4 model is a wildland fire air quality prediction system for computing simple trajectories to complex dispersion and deposition simulations. The dispersion of an air pollutant is calculated by assuming either puff or particle dispersion model theory. In the puff model, puffs expand until they exceed the size of the meteorological grid cell (either horizontally or vertically) within the grid’s geographical extent and then split into several new puffs, each with its share of the air pollutant mass. In the particle model, a fixed number of initial particles are advected about the model’s geographic domain by the mean wind field and a turbulent component. The model's
default configuration assumes a puff distribution in the horizontal and particle dispersion in the vertical direction. In this way, the greater accuracy of the vertical dispersion parameterization of the particle model is combined with the advantage of having an ever expanding number of particles represent the pollutant distribution.

Model Inputs and Outputs
The modeling system includes dispersion models, graphical displays, and text forecasts with model outputs that are easy to use for both fire managers and scientists. The model consists of a modular library structure with trajectory and air concentration applications. New features include improved advection algorithms, updated stability and dispersion equations, a new graphical user interface, and the option to include modules for chemical transformations. Without the additional dispersion modules, HYSPLIT computes the advection of a single pollutant particle, or simply its trajectory. Gridded meteorological data, on a latitude-longitude grid or one of three conformal (Polar, Lambert, Mercator) map projections, are required at regular time intervals. The input data are interpolated to an internal sub-grid centered. Air concentration calculations require the definition of the pollutant's emissions and physical characteristics. The routine meteorological data fields required for the calculations may be obtained from existing archives or from forecast model outputs already formatted for input to HYSPLIT. In addition, several different pre-processor programs are provided to convert NOAA, NCAR (National Center for Atmospheric Research) re-analysis, or ECMWF (European Centre for Medium-range Weather Forecasts) model output fields to a format compatible for direct input to the model. The modeling system includes a graphical user interface to set up a trajectory, air concentration, or deposition simulation. The post-processing part of the model package incorporates graphical programs to generate multi-color or black and white publication quality Postscript printer graphics.

Where Can I Get Additional Information
The HYSPLIT4 model can be found at the NOAA Air Resources Laboratory website: [http://ready.arl.noaa.gov/HYSPLIT.php](http://ready.arl.noaa.gov/HYSPLIT.php). The website contains HYSPLIT-WEB (the internet-based interactive version and Documentation (Overview, Documentation, and Publications), and On-Line Training/Presentations. The model can be run interactively on the NOAA ARL’s web server through the Real-time Environmental Applications and Display sYstem (READY). The READY system executable code and meteorological data can be downloaded to a Windows PC. The Web version has been configured with some limitations to avoid computational saturation of our web server. The registered PC version is complete with no computational restrictions, except that user's must obtain their own meteorological data files. The unregistered version is identical to the registered version except that it will not work with forecast meteorology data files. The user guide can be downloaded from: [http://199.128.173.141/vsmoke/Brief_Instructions_031510.pdf](http://199.128.173.141/vsmoke/Brief_Instructions_031510.pdf)

VSMOKE-Web

What Is VSMOKE-Web
The VSMOKE model was developed in the 1996 by Leonidas Lavdas, USDA Forest Service, to estimate the impact of particulate matter emissions from wildland and prescribed fire on highway
visibility and human health in flat and rolling hill topography. These smoke dispersion models are classified as Gaussian models with plumes that disperse in a bell-shaped distribution pattern. The plume method assumes that the smoke emissions from the fire travel in a straight line under constant speed and direction during the time period of the model’s simulation. VSmoke-Web is a web-based implementation of VSmoke and is designed to assist with planning prescribed burns. VSmoke is a simple gaussian smoke dispersion model that calculates isopleths of surface smoke concentrations. Output from the model represents peak hourly concentrations of PM$_{2.5}$ or visibility (under development). Contour values and their colors correspond to the PM$_{2.5}$ thresholds for the Air Quality Index (AQI) and reflect potential health impacts ranging from moderate to hazardous (Visit AirNow for mode AQI info). Burn location can be set by clicking on the map or by entering the Latitude and Longitude. Note that the Latitude and Longitude should be entered in decimal degrees (30.38,-84.37) or degrees + decimal minutes (30 22.80, -84 22.20 - note the space between degree and minute values).

VSMOKE-Web is the easiest of the three versions to use as a simple planning tool; it provides satellite image or map-based projections of downwind smoke concentrations for your prescribed burn plan.

**Model Inputs and Outputs**

VSMOKE is a smoke prediction model that is weather driven and incorporates emissions information from weather forecasts and the Fire Emissions Production Simulator. Prescribed burn locations are entered by latitude and longitude or by the interactive pointer on a map. Weather forecast inputs include: wind speed and direction, mixing height, and atmospheric stability. The burn parameters include fuel types (12 classes), fuel moisture, fuel loading, burn unite size, and ignition method. Fuel loads (tons/acre) are input for each fuel type, but prescribed fire specialist can input more accurate individual site measured information. The fuel consumption and air pollution emissions information is used by VSMOKE to produce the plume characteristics and the visual outputs. In VSMOKE-Web, each color overlay represents expected downwind ground-level PM$_{2.5}$ concentrations that reflect the threshold values (e.g., moderate, unhealthy, hazardous) of the national Air Quality Index.

**Where Can I Get Additional Information**

VSMOKE-Web is available as a web-based version and can be found at the following web address: [http://shrmc.ggy.uga.edu/maps/vsmoke.html](http://shrmc.ggy.uga.edu/maps/vsmoke.html).

References:
Chapter 9 National and State Prescribed Fire Councils

One of the prescribed fire resources available at the national and state levels is the Coalition of Prescribed Fire Councils, Inc. The national organization is comprised of a diverse group of public and private leaders that formed the “National Coalition of Prescribed Fire Councils” in 2007. In 2009, the Coalition of Prescribed Fire Councils, Inc. was formally developed into a non-profit corporation. The coalition includes 29 established or developing state councils.

The Coalition’s core mission is to promote the appropriate use of prescribed fire for enhancing public safety, managing resources, and sustaining environment quality. In addition, the Coalition encourages and facilitates the organization of prescribed fire councils in states that lack active councils. Partnering prescribed fire councils’ efforts, which collectively represent twelve million acres of annual prescribed fire use, has created a forum to voice and address issues of national concern. The Coalition’s work facilitates communication among interested parties in the field of prescribed fire, provides a focal point for sharing ideas and information, and creates opportunities for prescribed fire collaboration.

Figure 2. Prescribed Fire Council Map
State Councils

**Alabama Prescribed Fire Council**
Link: http://www.alpfc.org/wp/homepage/

**Arizona Prescribed Fire Council**
Link: http://azprescribedfirecouncil.org/

**Arkansas Prescribed Fire Network**
Link: http://www.arfirenetwork.org/cms/

**Central Coast Prescribed Fire Council**
Link: http://www.centralcoastrxfirecouncil.org/

**Colorado Prescribed Fire Council**
Link: No web link available

**Florida Prescribed Fire Councils**
Link: http://www.freshfromflorida.com/Divisions-Offices/Florida-Forest-Service/Wildland-Fire/Prescribed-Fire/Prescribed-Fire-Councils-of-Florida

**Georgia Prescribed Fire Council**
Link: http://www.garxfire.com/

**Illinois Prescribed Fire Council**
Link: http://www.fsi.illinois.edu/content/outreach/fire%20council/

**Kansas Prescribed Fire Council**
Link: http://www.kglc.org/kansas-prescribed-fire-council

**Kentucky Prescribed Fire Council**
Link: http://www.kyfire.org/

**Louisiana Prescribed Fire Council**
Link: No web link available

**Michigan Prescribed Fire Council**
Link: http://firecouncil.org/

**Mississippi Prescribed Fire Council**
Link: http://www.msfirecouncil.org/

**Missouri Prescribed Fire Council**
Link: http://moprescribedfire.org/

**Nebraska Prescribed Fire Council**
Link: http://www.kglc.org/kansas-prescribed-fire-council

**New Hampshire Prescribed Fire Council**
Link: http://extension.unh.edu/New-Hampshire-Prescribed-Fire-Council
New Mexico Prescribed Fire Council
Link: http://allaboutwatersheds.org/groups/NMRxCouncil/home

North Carolina Prescribed Fire Council
Link: http://www.ncprescribedfirecouncil.org/

Northern California Prescribed Fire Council
Link: http://www.norcalrxfirecouncil.org/

Oklahoma Prescribed Fire Council
Link: http://www.oklahomaprescribedfirecouncil.okstate.edu/index.html

Oregon Prescribed Fire Council
Link: https://www.facebook.com/OregonPrescribedFireCouncil

Pennsylvania Prescribed Fire Council
Link: http://www.paprescribedfire.org/

Prescribed Burn Alliance of Texas
Link: http://pbatexas.org/

South Carolina Prescribed Fire Council
Link: http://www.clemson.edu/extension/pfc/index.html

Southern Sierra Prescribed Fire Council
Link: http://www.sosierrapfc.org/

Tennessee Prescribed Fire Council
Link: http://www.tnpfc.org/

Virginia Prescribed Fire Council
Link: http://www.dof.virginia.gov/fire/vpfc.htm

Washington Prescribed Fire Council
Link: http://www.waprescribedfire.org/

Wisconsin Prescribed Fire Council
http://prescribedfire.org/
State Fire Councils bring together natural resource professionals, public and private land managers, and others who support the use of prescribed fire into an organization to:

- Promote public education about the benefits of prescribed fire.
- Advocate for the ability to use prescribed fire as a land management tool now and in the future.
- Increase expertise in prescribed fire by sharing technical and biological information.
- Promote safety, training, and research in the art and science of prescribed fire.
- Review prescribed fire practices, regulations, and policies and suggest improvements.
- Promote best management practices that minimize smoke and air quality impacts from prescribed fires.
Chapter 10  Wildland Fire Training

National Fire Training

National Wildfire Coordinating Group

NWCG Online Courses
The NWCG will only acknowledge completion of courses by those who are affiliated with an NWCG member agency (through direct membership or agreement) or a member of a fire department. To receive credit from the NWCG for completing online courses you must have been directed to do so by a wildland fire agency or fire department, and you are working with a course administrator.

A course administrator is a person responsible for guiding a student through a self-paced course (computer based or paper based). Course administrators must meet qualifications set forth in the Field Manager’s Course Guide for each particular course; have general administrative knowledge of testing, certificates of completion and qualification system of record for the agency or agencies involved; and must be available in person, by phone, or by email to assist the student during the completion of the course. To obtain a course administrator, Federal and State government employees must go through their agency or state fire training staff. All students are encouraged to keep their NWCG online course certificates as proof of successful completion.

- L-180, Human Factors in the Wildland Fire Service (Online) 2014
- S-110 Basic Wildland Suppression Orientation (2014)
- S-260 Interagency Incident Business Management (2014)

Web Link: http://training.nwcg.gov/courses.html

NWCG Blended Courses
Blended courses are a combination on online training and instructor guided training. Each online module explains the concepts and skills that will be performed and evaluated on the field day exercise. All online courses require the use of a course administrator. A course administrator must be secured before attempting any course work.

- M-581, Fire Program Management
- S-130 Firefighter Training (Blended) (2008)
- S-219, Firing Operations (Blended) 2014
- S-230, Crew Boss (Single Resource) (Blended) 2012
- S-231, Engine Boss (Single Resource) (Blended) 2012
- S-273 Single Engine Air Tanker Manager (Blended) (2011)
- S-590, Advanced Fire Behavior Calculations - NAFRI (2014)

Web Link: http://training.nwcg.gov/blended.html
National Wildland Fire Training
The Training Information Communication System (TICS) committee was formed in June, 1999. Membership is comprised of a Training Specialist/Geographic Area Training Officer from each Geographic Area, and a few computer specialists as technical advisers. The TICS mission is to simplify the training communications system with an objective of improving service to the customer and reduce duplication in training administrative services.

To this end, this National Wildland Fire Training web site was developed to provide a central location for customers to find wildland fire training course information from all geographic areas. This site enables access to local area, geographic area, national, and other related Interagency Wildland Fire Training information. In the geographic area sections of the website, you can access information for a specific area's courses, workshops, meetings, selections, completions, logistics such as lodging, weather and road conditions, policy and current news, and other pertinent geographic area information. A national schedule of sessions (which includes session name, IQCS number, dates, location, nomination, coordinator information, and tuition) and course catalogue (including a list of all courses by category) is provided on the website.

Web Link: [http://www.nationalfiretraining.net](http://www.nationalfiretraining.net)

The Nature Conservancy
The Nature Conservancy (TNC) has conducted over 100 fire training sessions since 1986. Having served more than 3,700 students to date, the Conservancy has earned a reputation for its innovative, experiential approach to learning and dynamic, interagency cadre and student bodies.

Through a cooperative agreement with the USDA Forest Service and the U.S. Department of the Interior, each year we sponsor 3-6 fire training exchanges (TREX) in concert with local, regional and national partners. This innovative program reaches several hundred fire practitioners each year.

TNC also teach standard fire management classes from an ecological perspective, using examples and suggesting techniques for managing fire for ecosystem benefits. There are three standard courses in core curriculum: Crew Boss Academy, Engine Academy and RX-301/Workshop on Ecological Burning (WEB). TNC have had students from almost every state and a few foreign countries, and represent a mix of Conservancy staff, federal, state and local partners and private landowners. The Nature Conservancy is part of the Incident Qualifications and Certification System (IQCS), enabling Conservancy staff, volunteers, and selected partners to obtain Incident Qualification Cards.


National Interagency Prescribed Fire Training Center
The Prescribed Fire Training Center (PFTC) is headquartered in Tallahassee, Florida. Their mission is to provide opportunities for federal, state, local and tribal government agencies and other organizations to build skills and knowledge of prescribed fire, with an emphasis on field experience. Training locations are dispersed throughout Florida, Georgia, Mississippi, Alabama,
North Carolina, and South Carolina. Attendees travel to several remote sites during their stay to take advantage of prescribed burning and learning opportunities with a variety of agencies, fuel types, and challenges such as urban interface. The PFTC is a unique program blending maximum field prescribed burning experience with a flexible curriculum of classroom instruction on foundational topics for prescribed fire practitioners. Participants will have the opportunity to complete portions of their National Wildfire Coordinating Group (NWCG) approved prescribed fire task books under the guidance of invited training specialists.


**National Advanced Fire & Resource Institute**

The National Advanced Fire & Resource Institute (NAFRI) is a national level training center serving the interagency wildland fire community through the development and implementation of fire, fuels, resource, and incident management skills and educational processes. NAFRI partners with the National Wildfire Coordinating Group (NWCG) and Course Development Sub Committees, comprised of subject matter experts, to manage and deliver graduate school level curriculums. A total of 15 courses are supported by NAFRI staff. 12 of these are delivered on an annual, biannual and biennial basis. Course listing includes:

- CIMC - Complex Incident Management Course
- D-510 - Expanded Dispatch Supervisory Dispatcher
- L-580 - Leadership is Action
- M-580 - Fire in Ecosystem Management
- M-581 - Fire Program Management
- N-9048 - National Aerial Firefighting Academy 2
- N-9053 - Learning from Unintended Outcomes: FLA Workshop
- NANFDR - Advanced National Fire Danger Rating System
- NFML - Fire Management Leadership
- NNAFA - National Aerial Firefighter Academy
- RX-510 - Advanced Fire Effects
- S-495 - Geospatial Fire Analysis, Interpretation, and Application
- S-520 - Advanced Incident Management
- S-590 - Advanced Fire Behavior Interpretation
- S-620 - Area Command

Web Link: [http://www.nafri.gov](http://www.nafri.gov)

**Fire in the Field**

The Fire in the Field training programs provide a learning experience that offers accountability and flexibility to students with various Internet connections. This entry-level firefighter training programs FIF100 (equivalent to NWCG I-100, S-190, L-180, S-130, and G-130 courses), FIF200 (equivalent to NWCG S-131, S-133, S-231, and G-131) and is perfect for preparing all first responders to safely assist in wildland fire incidents. Fire in the Field offers instruction with remote oversight by an NWCG certified facilitator. Anywhere, anytime learning that reduces course time and expense for both participants and trainers. The Web-ROM program delivery combines the rich video capacity of CD-ROM with the network and database capabilities of the web to deliver a robust multimedia experience, regardless of internet connection. Real time student
tracking allows trainers to communicate with students and gauge learning.

Users follow steps:
1. Each student must register with the unique user ID number found on his or her Web-ROM packaging and supply personal information for the database. They then create a username and password.
2. Students must login with their username and password each time they view the program. Participant activity and progress is then recorded.
3. This progress data is available for the student using the program via a "Check Progress" screen. Instructors login to a website to view students' progress and learning, create reports on program usage and participant achievements, and file pertinent participant data for evaluation purposes.
4. After students have completed the online coursework, they meet with the instructor for one day of field exercises, a review of the content, and a proctored final NWCG written exam. To receive certification they must receive a passing score on the exam and fulfill the field exercise to the satisfaction of the instructor.

Web Link: [http://www.fireinthefield.net](http://www.fireinthefield.net)

**State Fire Training**

**Colorado Firecamp**
The Colorado Firecamp is a 501(c)(3) non-profit, wildland firefighter school, dedicated to expanding the opportunities for firefighters and those wishing to become firefighter to attend quality redcard wildfire training. The Firecamp primarily offers 100- and 200- level courses developed by the National Wildfire Coordinating Group (NWCG) in the areas of leadership, incident command and suppression skills. By working with local (Upper Arkansas Valley), zone (Pueblo dispatch) and regional (Rocky Mountain Area) training teams, Colorado Firecamp fills a niche in the wildland fire training market. They offer another option for fire management officers, fire chiefs, county sheriffs, and training officers to advance the skills of their firefighters. And, they give those without firefighting experience or previous firefighter training a chance to get a 'foot in the door' with the wildland agencies. Classes are taught using the conference facilities of the Ponderosa Lodge, located 12 miles west of Salida, Colorado. Firecamp sits in the middle of the Maysville-North Fork wildland/urban interface. Field exercises reinforce the classroom lessons. Classes include:

- S-130/190 Basic Firefighter
- S-131/133/211 Squad Boss
- S-212 Chainsaws
• S-230/231 Crew / Engine Boss  S-232 Dozer Boss
• S-234 Ignition Operations  Felling Boss
• S-290 Fire Behavior
• First Responder
• Fire Instructor I (M-410)
• Fire Officer I

Web Link: http://www.coloradofirecamp.com

New York Wildfire Academy
The Central Pine Barrens Commission's Wildfire Task Force conducts the Academy with a consortium of federal, state and county agencies including: (Federal) Brookhaven National Lab, Bureau of Land Management, National Park Service, United States Coast Guard, United States Forest Service, United States Fish and Wildlife Service; (State) Massachusetts Department of Environmental Management, New Jersey Forest Fire Service, New York State Department of Environmental Conservation (DEC), New York State Division of Homeland Security and Emergency Services (DHSES), New York State Office of Fire Prevention and Control, and (City, County and Other Organizations) Fire Department of New York (FDNY), Suffolk County Department of Fire, Rescue, and Emergency Services, and the Colorado Wildfire Academy. Courses put on by Academy staff include:

• I-300 - Intermediate ICS with NIMS
• S-130/190 - Basic Firefighting and Wildfire Behavior
• S-212 Wildfire Powersaws
• S-215 Fire Operations in the Urban Interface

Web Link: http://www.dec.ny.gov/education/73.html

Southwest Montana Wildland Fire Training Center
Southwest Montana Wildland Fire Training is a distinctive project jointly sponsored by the University of Montana and the Southwest Montana Geographic Zone of the Northern Rockies Coordinating Group. Initiated in 1998, Southwest Montana Wildland Fire Training is motivated by one major goal: to provide intensive, top-quality training to wildland firefighters. Most courses require that the students be minimally qualified as a squad boss (FFT1). This means that they have had a basic wildland firefighting course and have at least one season as a wildland firefighter. Some years the course offering include an entry level dispatcher course, and a course to train people who would like to work in the finance section of a fire. The dispatch and finance courses do not require previous firefighter experience.

Most courses are held in the James E. Todd Continuing Education building, which is on the SE corner of the University Center at the University of Montana. Occasionally courses will be held at other sites such as the Northern Rockies Training Center at the Aerial Fire Depot at the Missoula airport, or possibly at the Lubrecht State Forest, which is about 40 miles NE of Missoula. Courses offered by the SW Montana Wildland Fire Training Center include:

• S-200 Initial Attach IC
- S-215 Fire Operations in the Wildland Urban Interface
- S-230 Single Resource Boss
- S-231 Engine Boss
- S-234 Ignition Operations
- S-260 Intragency Incident Business Management
- S-261 Applied Interagency Incident Business
- S-262 NRCG Incident Contract Project Inspector
- S-290 Intermediate Fire Behavior
- S-390 Introduction to Fire Behavior Calculations
- S-300 Extended Attach IC
- S-330 Task Force/Strike Team Leader

Web Link: http://www.umt.edu/sell/fire/

Arizona Wildfire & Incident Management Academy
The Arizona wildfire Academy’s classes cover positions in all ICS areas; Command and General Staff, Operations, Plans, Logistics and Finance. Courses are conducted by the National Wildfire Coordination Group, FEMA, and independent instructors. The classes will be available for entry level positions up to Incident Commander. Classes are held at Embry Riddle Aeronautical University, 3700 Willow Creek Rd., Prescott, AZ. The web site include links to the course schedule and course descriptions. Classes include:

FEMA
- I-300 Intermediate ICS
- I-400 Advanced ICS

National Wildfire Coordinating Group Courses
- D-110 Dispatch Recorder
- L-280 Followership to Leadership
- M-410 Facilitative Instructor
- RT-130 Fireline Refresher
- RX-301 Prescribed Fire Implementation
- RX-310 Intro to Fire Effects
- RX-341 RX Fire Burn Plan Prep
- S-130/190 Basic Wildland Firefighting and Fire Behavior
- S-131/133 Advanced Firefighting
- S-200 Initial Attack Incident Commander
- S-203 Intro to Incident Information Officer
- S-211 Portable Pumps and Water Use
- S-212 Wildfire Saws
- S-215 Fire Ops in the Urban Interface
- S-219 Ignition Operations
- S-230 Crew Boss
- S-231 Engine Boss
- S-236 Heavy Equipment Boss
- S-260 Interagency Incident Business Management
- S-261 Applied Interagency Incident Business Management
- S-290 Intermediate Fire Behavior
- S-300 Extended Attack Incident Commander
- S-330 Task Force/Strike Team Leader
- S-339 Division/Group Supervisor
- S-340 Human Resource Specialist Refresher
- S-358 Communications Unit Leader
- S-359 Medical Unit Leader
- S-390 Intro to Fire Behavior Calculations
- S-404 Safety Officer
- S-430 Operations Section Chief
- S-440 Planning Section Chief
- S-445 Training Specialist

Web Link: http://www.azwildfireacademy.org

Florida Forest Service
In 1999 the Withlacoochee Training Center (WTC) was created by the Legislature to provide
needed training to the public and private sector in forest resource management, prescribed fire, and wildfire management. The center's training facility is located just north of Brooksville, in the Withlacoochee State Forest. Additionally, under the auspices of the WTC, training may be conducted at other locations on an as-needed basis. WTC’s curriculum objectives are comprehensive, flexible and ever-expanding in order to meet the needs of state and federal agencies, local fire departments and private sector land managers. WTC’s goal is to provide the highest quality training and meet the objectives of the center. WTC requires a minimal certification as FFT2 and does not offer introductory FFT2 courses. The web site include a schedule of classes, fees, and application forms.

Web Link: http://www.freshfromflorida.com/Divisions-Offices/Florida-Forest-Service/Education/For-the-Community/Withlacoochee-Training-Center-WTC

Georgia Basic Wildland Firefighter Training
Wildland Firefighter Training is available in two different delivery packages, either a CD based version, OR on-line internet through the U.S. Fire Administration. This allows trainees to take the classroom training through distance learning and then attend a two-day Field Exercise for final accreditation. There is no difference in the curriculum of either method, only the application on how taken - CD or Web-based. Certification for Wildland Firefighter Training is issued by the Georgia Forestry Commission (GFC), the "Authority Having Jurisdiction" for wildland fire certification in the state of Georgia, in the form of a training completion certificate and National Wildfire Coordinating Group (NWCG) Incident Qualification Card (Red card). Trainees completing all aspects of this course can also apply to challenge the written National Professional Qualifications (NPQ) exam administered by Georgia Firefighter Standards and Training Council (GFSTC) upon presentation of training issued by GFC.

Web Link: http://www.gfc.state.ga.us/forest-fire/wildland-firefighting/training/

Texas Interagency Wildfire and Incident Management Academy
The Texas Interagency Wildfire and Incident Management Academies provide training to wildland firefighters from Texas and through the United States to meet National Wildfire Coordination Group Standards. The Capital Area Academy, held in Bastrop, Texas during the month of October, and the East Texas Academy, during the month of May in Lufkin, Texas, provide classroom and “hands-on” training to more than 800 students in firefighting, supervisory, and prevention techniques. The web site includes the schedule of courses application, and online registration. Courses include introductory entry-level firefighter

Web Link: http://ticc.tamu.edu/Training/training.htm

Utah Fire and Rescue Academy
The UFRA's Wildland Fire Training Program is located at Utah Valley University. Its mission is to educate, train, and support the fire and emergency services at the highest quality level possible. The Utah Fire and Rescue Academy offers wildland fire training to Utah career and volunteer fire departments. All the wildland fire courses meet or exceed the requirements or standards of the National Wildfire Coordination Group (NWCG) and National Fire Protection
Agency (NFPA). The NFPA 1051 Wildland Fire Fighter Professional Qualification Standard designates the Basic Wildland Firefighter as Wildland Firefighter I. The Advanced Firefighter/Squad Boss is designated as Wildland Firefighter II. This is the exact opposite of the NWCG titles: Firefighter II is Basic Wildland Firefighter and Firefighter I is Advanced Firefighter/Squad Boss. The training courses listed on the career and volunteer firefighter pages use the NFPA terminology, Wildland Firefighter I and Wildland Firefighter II. Each class will include all course material as well as wildland equipment needed to practice for the skills portion of state certification. Wildland Firefighter I and II certification testing needs to be scheduled 30 days in advance.

Web Link: http://www.uvu.edu/ufra/training/wildland_home.html
Chapter 11  Wildland Fire Training & Job Opportunities for Veterans

Wildland fire management (including both prescribed fire and fire suppression) is an important part of the mission of the bureaus within the DOI, DoD, State forestry and wildlife agencies, natural resource non-governmental agencies, and the forestry and wildlife private sector. The majority of the duties performed by wildland firefighters are outdoors. Most duties are related to prescribed burning, wildfire suppression, and fire preparedness. These duties can include serving as a firefighter or engine operator during prescribed burning and wildfire suppression activities; conducting regular maintenance and repairs on various equipment; and serving as a crew member during firebreak preparation. When not involved with fire related activities, duties may include providing assistance in conducting natural resources related project work. There is the potential to assist federal or state agencies throughout the nation.

There are wildland firefighter opportunities that are unique to Veterans. A brief listing of some of the available opportunities to become a wildland firefighter or gain training experience with fellow Veterans is found in the following sites.

Department of Interior

Information and career transition advice is provided for Veterans to help improve the understanding of the types of jobs that could lead to finding a job or career in wildland fire management. Many veterans are already working in wildland fire. The DOI Webpage, “Welcome to the Wildland Fire Career Road Map”, provides information to assist in finding a job and guide career plans. Although the focus of this site is on assisting military or veterans in finding a job, the information is also helpful to anyone interested in working as a wildland firefighter or in wildland fire management.

This site has information divided into three sections, or phases, presented in a series of questions and answers to help improve your understanding of the types of jobs in wildland fire that could lead to finding a job or career in wildland fire management.

- The first will be guide the search of job opportunities and to find out if a job in wildland fire may be right for you.
- The second phase assists in the application for jobs.
- The third phase provides information about what to expect on the job and how you can make wildland fire fighting a career.

The site includes a Fire Management Career Ladders chart listing some of the most common jobs in a career progression in four of the most common career tracks in wildland fire management (operations, aviation, fuels, and dispatch), and a short description of jobs.

The Wildland Fire Program within the DOI is provides the information on their website as career transition advice for Veterans in support of promoting their recruitment, employment, training, and development.

Web Link: [http://www.doi.gov/pmb/owf/veterans_to_wildland_fire_employment.cfm](http://www.doi.gov/pmb/owf/veterans_to_wildland_fire_employment.cfm)
Wildland Firefighter Apprenticeship Program
The Wildland Firefighter Apprentice Program is an accredited, educational program designed to enhance and develop future Fire and Aviation Managers. The intent of the program is to take a career firefighter and provide education, training, and paid work experience over a 12 to 48 month period, depending on experience. Upon successful completion of all the requirements of the Apprenticeship Program, the apprentice will reach journey-level status as a wildland firefighter. Qualified veterans can apply for paid training in prescribed burns and wildland fire suppression with potential to continue valued national service by joining the ranks of professional firefighters with the U.S. Forest Service.

Web Link: [http://www.wfap.net/vets.html](http://www.wfap.net/vets.html)

New Mexico State Forestry, AD and Returning Heroes Wildland Firefighter Program
The first program of its kind in the U.S., NM State Forestry began the program in 2013 as a way to increase capacity for wildland firefighting in New Mexico and surrounding states. New legislation allows for a team of military veterans to serve as regular, year-round employees within the program. When not engaged in fire suppression activities, the crew helps with forest and watershed restoration projects.

Web Link: [http://www.emnrd.state.nm.us/SFD/FireMgt/ADandReturningHeroesWildlandFirefighterProgramInformation.html](http://www.emnrd.state.nm.us/SFD/FireMgt/ADandReturningHeroesWildlandFirefighterProgramInformation.html)

Veteran Ecological Restoration Team (VERT)
The VERT is a Veteran-created program designed to help Veterans find employment in the U.S Forest Service. This program allows veterans who are enrolled in the Department of Veteran Affairs non-paid work experience program to work with the U.S. Forest Service to gain on-the-job work experience and allows them to find a suitable position in the agency. Veterans will be exposed to a variety of work and will build a well-rounded resume, while at the same time helping the U.S Forest Service achieve its goal of restoring our forests. As of today, the VERT program has been picked up in California by the Modoc National Forest, Las Padre National Forest, Angeles National Forest, Wildland Fire Training and Conference Center Sacramento, Vandenberg Training Center, and the Northern California Operations Training Center. Veterans who are interested in this program should consult their local Department of Veteran Affairs office and ask how to join the non-paid work experience program.

California Conservation Corps, Veterans Forestry Crew
The California Conservation Corps are inviting military veterans between ages 18 to 29 years old to apply for an exciting opportunity that combines hands-on work experience and skills training in partnership with the U.S. Forest Service. Successful candidates will be enrolled in the CCC Veterans Program full-time for 1 year and receive USFS sponsored training in wildland fire training, chainsaw, tool use, safety, and crew organization. Veterans will work on fuel reduction, forestry and wildfire education projects. Participants who complete this program may be eligible for the USFS Wildland Firefighter Apprenticeship Program. Successful participation may lead to full-time positions with the USFS.

Web Link: [www.ccc.ca.gov/join](http://www.ccc.ca.gov/join)
**Montana Conservation Corps, Veteran Green Corps**
Veterans Green Corps is a field-based opportunity that allows participants to meet conservation needs while building on their existing skill sets. Throughout the season, VGC members receive exposure to a variety of resource management careers and practices in Montana. Applicants need to be ready to put others’ interests before their own, learn and support their peers’ learning, participate as a positive team member, work hard while serving long hours, live outdoors in all weather, and to lead by example. Applicants will serve in some of the Rocky Mountain’s most coveted regions, become efficient in chainsaw operation and maintenance, reinforce your leadership skills, and work in a high-performing team of peers. VGC is based in Helena, Montana in MCC’s Central Divide Region. Applicants may choose to serve during one or both of the 12-week sessions (summer and/or fall). Trainings are largely field based and projects partners include agencies such as USFS, NPS, USFWS, and BLM. Project work consistently involves the use of chainsaws for fuels reduction or thinning projects. However, it may also include trail maintenance, structure building, and addressing many other land accessibility issues in national forests. Participants will spend the majority of their time camping, so relocation is not necessary.


**Veterans Fire Corps**
Veterans Fire Corps is a collaborative initiative that builds upon the knowledge, leadership experience and training men and women who served in the armed forces, retraining them and refocusing their mission to protecting our public lands from the threat of wildfire. The model, a three tiered Firefighter Leadership Development Program, focuses on providing incrementally more challenging experiences for program participants. The curriculum and training is broken into incrementally more challenging work and training environments. Initial project work generally includes introductory fuels reduction, work, leadership training and minimum exposure to fire suppression. Veterans must be over 18 years of age and a U.S. citizen who has received a high school diploma or GED. All position offers might be conditional upon completion of an acceptable check of the National Sex Offender Public Registry and federal criminal background check. Applicants must be a veteran of the United States military and have the ability to provide DD214 or other proof of service and status of discharge.

Web Link: [http://www.veteransfirecorps.org](http://www.veteransfirecorps.org)

**Southwest Conservation Corps, Veterans Fire Corps**
The Southwest Conservation Corps (SCC) operates conservation service programs across Southern Colorado and Northern New Mexico that empower individuals to positively impact their lives, their communities and the environment. SCC has offices in Durango and Salida, CO and Acoma, NM. SCC has broad program offerings including individual intern placements in natural resource positions as well as crew based conservation service programs for youth (ages 16-18), young adults, (16-25) and post 9-11 era Veterans. SCC programs are rooted in the communities where we serve, addressing local public land issues and working to meet local community needs and interests. SCC seeks applicants who are interested in fully committing to the program, who are willing to overcome any challenges and those who will take advantage of the opportunities, skills and training that are offered throughout the term of service.
Arizona Conservation Corps, Veterans Fire Corps
Arizona Conservation Corps (AZCC) operates conservation service programs across Arizona that empower individuals to positively impact their lives, their communities and the environment. AZCC has program offices in Flagstaff and Tucson. Arizona Conservation Corps, a program of Conservation Legacy, aims to continue the legacy of the Civilian Conservation Corps of the 1930s. AZCC is focused on connecting youth, young adults and recent era military veterans with conservation service work projects on public lands. AZCC programs promote personal growth, experiential learning and an ethic of natural resource stewardship while incorporating the guiding principles of community, dedication, challenge, and integrity.

Web Link: [http://www.azcorps.org](http://www.azcorps.org)

The Student Conservation Association (SCA), Veterans Fire Corps
SCA was created in 2010 with the USFS for post 9-11 era Veterans to gain wildland fire training and on-the-job experience. SCA’s Veterans Fire Corps (VFC) offers the skills and certifications you need to become competitive in a wildland fire and/or forestry career. Members gain experience in disciplines like: wildlife ecology; botany; trail work; ecological restoration and resource management.

Participate in projects like:
- Fuels Reduction
- Fire effects monitoring
- Educational outreach
- Pre-fire preparation of burn units
- Prescribed burns

Internship Details:
- Teams consist of five members with one SCA project leader
- Schedule is typically four consecutive 10-hour days (where camping is required) and three days off
- 40-hour/week commitment; members must stay for duration of program

Training and Certifications:
- Two weeks of field based training
- Wildland Fire Chainsaw Certification
- Basic Wildlife Firefighter and Red Card Certification
- Wilderness First Aid, CPR

Fire Link
The websites FireLink and Military.com offer guidance to active duty and veterans in an article “10 Steps to Becoming a Firefighter – For Military Service Members”. The article outlines a ten step process for choosing a fire & rescue career path to transition a military background into a civilian firefighting.

Conclusions

Balancing DoD Natural Resource Wildfire Management, the Installation Mission, and the Public Interest

The strategies for DoD natural resource manager’s responsible and effective prescribed and wildfire smoke management cannot be developed without consideration of the ecological and the societal impacts of fire management and its impacts on the installation testing and training mission. The need to consider both perspectives is acknowledged by DoD’s goals for installation sustainability and uninterrupted installation operations, as well as by the U.S. Environmental Protection Agency (EPA), the primary Federal agency responsible for protecting air quality, and the individual state Smoke Management Programs.

The EPA’s Interim Air Quality Policy on Wildland and Prescribed Fires describes the public policy goals: (1) To allow fire to function, as nearly as possible, in its natural role in maintaining healthy wildland ecosystems; and, (2) To protect public health and welfare by mitigating the impacts of air pollutant emissions on air quality and visibility. The document comments on the responsibilities of wildland owners/managers and State/tribal air quality managers to coordinate fire activities, minimize air pollutant emissions, manage smoke from prescribed fires as well as wildland fires used for resource benefits, and establish emergency action programs to mitigate the unavoidable impacts on the public. In addition, EPA asserts that “this policy is not intended to limit opportunities by private wildland owners/managers to use fire so that burning can be increased on publicly owned wildlands.”

Prescribed fire programs across the United States are focused on emission reduction techniques and smoke management methods to minimize the ecological and human health impacts of smoke. DoD natural resource managers are faced with a complexity of state programs that vary from state to state. These programs can range from internet based, real-time, comprehensive programs that gather information on emission inventory calculations and smoke trajectory modeling to simple burn permitting program that do not collect extensive information and rely on user imposed burning constraints. In most states, smoke management programs are based on achieving the land management objectives of wildland fuel reduction to minimize wildfire risk and maximizing forest productivity. Each DoD installation must strive for federal and state compliance of fire emissions and smoke management of prescribed fire, while meeting the natural resource goals for installation sustainability and the operations goals of uninterrupted testing and training missions.

Wildland Fire

Fire is an essential component of the natural environment and many plants and animals have evolved with natural fire regimes and are dependent on fire for their productivity and survival. Evidence for the recurrence of past fires is found in charcoal layers of lakes and bogs, in fire-scars of long-lived trees, and in the morphological and life history adaptations of numerous native plants and animals. Fire acts at the individual, population, and community levels and can influence:

- Plant community succession.
- Wildland fire fuel accumulation and wildfire risk.
- Species composition of terrestrial and aquatic ecosystems.
- Disease and insect pathogens.
- Biotic productivity, diversity, and stability.
- Habitat structure for wildlife foraging and reproduction.
- Water quality and quantity.

Fire has always been part of the natural environment. Native Americans used fire to manage vegetation and increase wildlife populations, lightning ignitions keep shrubs and trees from invading grasslands across the western U.S., volcanoes ignited vegetation on the Hawaiian islands, and European settlers have ignited fires to clear forest and start the agrarian society that began America. The current emphasis on DoD installation sustainability calls for the maintenance of interactions between ecosystem functions and the support of the testing and training mission. Therefore, it is incumbent on both natural resource and operations managers to understand the range of historical frequency, severity, and aerial extent of past burns across their installations. This knowledge provides a frame of reference for applying appropriate management practices on DoD installation at the landscape scale, with the goals of natural resource management and wildland fire risk reductions in support of installation operations.

There is a large body of science that details the numerous effects of wildland fires on components of ecosystems. Some of the most compelling examples of fire dependency come from studies on plant reproduction and establishment. For instance, there are at least ten species of pines scattered over the United States that have serotinous cones that are sealed by resin and do not open and disperse seeds until the resin is exposed to the high heat of fire. Examples of fire dependency in herbaceous plants include flowering of wiregrass in Southeastern longleaf pine forests that is greatly enhanced by growing season burns, and the California chaparral community has a rich flora of species with different mechanisms for cuing germination to post-fire conditions. Heat shock triggers germination of certain species while other post-fire species that are chemically stimulated by combustion products. Animals as diverse as rare Karner blue butterflies in Indiana to whooping cranes in Texas benefit when fire is re-introduced into their habitats.

The knowledge of fire history, fire regimes, and fire effects allows DoD natural resource managers to develop informed management strategies. The application of prescribed fire may be one of the tools used to meet resource management sustainability objectives. The role of fire as an important disturbance process has been described as a landscape’s natural fire regime, the total pattern of fires that occur over time. Fire regimes are defined in terms of fire type and severity, typical fire sizes and patterns, and fire frequency, or length of return intervals in years. Most ecosystems in the United States have evolved under the consistent influence of wildland fire, establishing fire as a process that affects numerous ecosystem functions. Natural resource managers who apply prescribed burns or use wildland fire often attempt to mimic the natural role of fire in creating or maintaining ecosystems. Sustaining the productivity of fire-adapted ecosystems generally requires application of prescribed fire on the appropriate time interval and landscape scale to ensure that various ecosystem processes remain intact and wildland fire risk is
reduced to protect installation facilities, staff, and the public.

**Fire Regimes and Ecosystem Function**

Historically the management of fire frequency and severity on DoD installations, and other federal, state, and private lands was focused on wildland fire suppression. The active suppression of wildfires and the limited support of prescribed fire resulted in a loss of species diversity, site degradation, and an increase in the sizes and severity of wildfires. Fire researchers have concluded that altered fire regimes was the principal agent of change affecting vegetative structure, composition, and biological diversity of five major plant communities totaling over 350 million acres in the United States. An evaluation of the current acres of fire compared to the estimated land area burned 200-400 years ago to data from the contemporary conterminous United States suggests that ten times more acreage burned annually in the pre-industrial era than does today. After accounting for loss of wildland area due to land use changes from urbanization and agriculture the remaining wildlands in the United States are burned approximately fifty percent less compared to fire frequency under historical fire regimes.

Ecosystem indicators serve as early warnings of the effects of altered fire regimes on landscape structure and function. Land use changes, fire exclusion, prolonged drought, increased severity and frequency of major storms, and epidemic levels of insects and diseases have collided to increase forest mortality, changes in forest density and species composition, and impacted animal species home ranges and reproduction. In the western United States, trees have been killed across millions of acres in eastern Oregon and Washington, and the problems extend south into Utah, Nevada, and California, and east into Idaho. Denser stands and heavy fuel accumulations are also setting the stage for high severity crown fires in Montana, Colorado, Arizona, New Mexico, and Nebraska. Historically the long-needled pine forests experienced frequent low severity surface fires rather than extreme fire behavior that includes crown fires. Southeastern researchers quantified the dramatic effects of over 80-years of fire exclusion on tree species composition and stand structure in a longleaf pine forest. Since the 1960s, the trend has been towards more acres consumed by wild fires, despite advances in fire suppression technology.

The ecological consequences of past policies of fire exclusion have been foreseen for some time. In the 1940’s fire researchers were reporting that the suppression of forest fires in the ponderosa pine region of California, Oregon, Washington, northern Idaho, and western Montana has certain undesirable ecological and silvicultural effects. Recently concerns been expressed about fire suppression and the resulting loss of biodiversity. This issue may be especially pressing in the Eastern United States. For example, in southern longleaf pine ecosystems, at least 66 rare plant species are maintained by frequent fire. The ecological need for high fire frequency in large areas of Southeastern native ecosystems coupled with the region’s long growing season contribute to the rapid buildup of fuel and subsequent change in habitat structure.

**Federal Wildland and Prescribed Fire Policy**

The Review and Update of the 1995 Federal Wildland Fire Management Policy (January 2001) represents a single cohesive federal fire policy for the Departments of the Interior and Agriculture. The current policy clearly states that wildland fire analysis will carefully consider the long-term benefits in relation to risks both in the short and long term:

“Fire, as a critical natural process, will be integrated into land and resource management
plans and activities on a landscape scale, and across agency boundaries. Response to wildland fire is based on ecological, social, and legal consequences of fire. The circumstances under which a fire occurs, and the likely consequences on firefighter and public safety and welfare, natural and cultural resources, and values to be protected dictate the appropriate management response to fire.”

The policy asserts that “the planning, implementation, and monitoring of wildland fire management actions will be done on an interagency basis with the involvement of all partners.” The term “partners” is all-encompassing, including Federal land management and regulatory agencies; Department of Defense; tribal governments; State, county, and local governments; the private sector; and the public. Partnerships are essential for establishing collective priorities to facilitate use of fire at the landscape level. Smoke does not respond to artificial boundaries or delineations. Interaction among partners is necessary to meet the dual challenge of using fire for natural resource management coupled with the need to manage fire emissions and smoke impacts on human health.

The following guiding principles and policy statements are excerpted from the Review and Update of the 1995 Federal Wildland Fire Management Policy (January 2001). These are the foundation principles for Federal Wildland Fire Management Policy:

1. Firefighter and public safety is the first priority in every fire management activity.

2. The role of wildland fire as an essential ecological process and natural change agent will be incorporated into the planning process. Federal agency land and resource management plans set the objectives for the use and desired future condition of the various public lands.

3. Fire Management Plans, programs, and activities support land and resource management plans and their implementation.

4. Sound risk management is a foundation for all fire management activities. Risks and uncertainties relating to fire management activities must be understood, analyzed, communicated, and managed as they relate to the cost of either doing or not doing an activity. Net gains to the public benefit will be an important component of decisions.

5. Fire management programs and activities are economically viable, based upon values to be protected, costs, and land and resource management objectives. Federal agency administrators are adjusting and reorganizing programs to reduce costs and increase efficiencies. As part of this process, investments in fire management activities must be evaluated against other agency programs in order to effectively accomplish the overall mission, set short- and long-term priorities, and clarify management accountability.

6. Fire Management Plans and activities are based upon the best available science. Knowledge and experience are developed among all federal wildland fire management agencies. An active fire research program combined with interagency collaboration provides the means to make these tools available to all fire managers.

7. Fire Management Plans and activities incorporate public health and environmental quality considerations.
8. Federal, State, tribal, local, interagency, and international coordination and cooperation are essential. Increasing costs and smaller work forces require that public agencies pool their human resources to successfully deal with the ever increasing and more complex fire management tasks. Full collaboration among federal wildland fire management agencies and between the federal wildland fire management agencies and international, State, tribal, and local governments and private entities result in a mobile fire management work force available for the full range of public needs.

9. Standardization of policies and procedures among federal wildland fire management agencies is an ongoing objective. Consistency of plans and operations provides the fundamental platform upon which federal wildland fire management agencies can cooperate, integrate fire activities across agency boundaries, and provide leadership for cooperation with State, tribal, and local fire management organizations.
Appendices

DoD Instructions and Manuals Documents

Appendix 1. AFI 32-2001 Fire Emergency Services Program

Appendix 2. AFI 90-2001 Encroachment Management

Appendix 3. AR 200-1 Environmental Protection and Enhancement

Appendix 4. AR 200-3 Land, Forest, and Wildlife Management

Appendix 5. AR 420-90 Fire and Emergency Services
Web Link: http://www.afgefirefighters.org/media/draftar420-90.pdf

Appendix 6. DoDM 7515.03 INRMP Implementation Plan
Web Link: http://www.dtic.mil/whs/directives/corres/pdf/471503m.pdf

Appendix 7. MCO 11000.11 Fire Protection and Emergency Services Program
Web Link: http://www.marines.mil/Portals/59/Publications/MCO%2011000.11.pdf

Appendix 8. OPNAVINST 11320.23G Fire and Emergency Services Program

Appendix 9. DoDI 6055.06 DoD Fire and Emergency Services Program

National Fire Documents

Appendix 10. Canada/United States Reciprocal Forest Fire Fighting Agreement
Web Link: http://www.nifc.gov/nicc/mobguide/Chapter40.pdf
   Web Link: https://www.nifc.gov/policies/policies_documents/GIFWFMP.pdf

Appendix 12. Interagency Fire Management Plan Template

Appendix 13. Interagency Prescribed Fire Planning and Implementation Guide
   Web Link: http://www.nwcg.gov/pms/RxFire/pms484.pdf

   Web Link:
   Field_Guide_Color_final.pdf

Appendix 15. Military Use Handbook
   Web Link:
   06_2.pdf

Appendix 16. Provision of Temporary Support During Wildland Firefighting Operations

Appendix 17. Wildland Fire Qualification System Guide

Appendix 18. The National Strategy
   Web Link:
   execSec_FINAL_v3.pdf