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**Fire in California Ecosystems:
Integrating Ecology, Prevention and
Management**

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Fire in California Ecosystems: Integrating Ecology Prevention and Management

Preface

Catastrophic wildfires in California during the past few years have illustrated the need to integrate ecological principles, public concerns and safety issues in fire management. This symposium continued the tradition of Fuels and Fire Management conferences originally inspired by Dr. Harold Biswell and later held in his memory. This symposium featured an expansion of topics in the fields of ecology, prevention, fire management and many others. The focus of this symposium was promotion of an integrated approach to fire management in California ecosystems.

In California, human culture has maintained a complex relationship with wildland fire for thousands of years. Fire has played an important role in shaping California ecosystems and still has a great influence on human society. It can be argued that Anthropogenic changes to wildland fire regimes have had a greater impact on the state's biodiversity than any other human influence.

Conversely, fire continues to be an ecosystem process, which greatly influences human society in many ways. Despite decades of intensive efforts by society to reduce and eliminate wildfire, California's ecosystems continue to support numerous large wildfires annually. Wildfires continue to impact ecosystems, air and water quality, and to threaten residents living adjacent to wildlands.

The study and application of the principles of fire ecology, fire prevention and fire management have traditionally been quite separate. Land management and fire management are now the operating within the complex interface between human society and fire in wildlands. Fire is a complex social issue, ecological issue, and land management issue. As our society continues to increase its presence in and familiarity with wildlands, the distinction between fire in wildlands and fire in the wildland-urban interface continues to blur. We can no longer afford to separate the study and management of fire in ecosystems from societal interactions with wildlands and fire.

Integration of fire ecology, prevention and management is happening because the needs and scope of each area is expanding to overlap the other two. This trend cannot reverse without major changes in the development of our society. This conference does not originate, conclude or greatly change this integration, but represents a point at which we are acknowledging the need for and value of integrated programs. These proceedings document our progress within the individual fields of fire ecology, fire prevention and fire management and our progress toward integration up to this point in time.

With emphasis on California and Baja California, presentations include broad historic and conceptual overviews, specific research projects, and applications of integrated fire management, case studies and pilot programs. Additional presentations address broader topics and geographic areas and contribute to the understanding of California ecosystems.

Neil G. Sugihara

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The steering committee that did an exceptional job of defining and guiding this symposium consisted of:

Tom Nichols	Bob Burnham	Danny Jones
Suraj Ahuja	Barry Callenberger	Ken Nehoda
Margie Behm	Wayne Harrison	Christie Neill
Mark Borchert	Anne Hotchkiss	David Weise

Special thanks to the leadership of Mike McCoy who, besides co-chairing the symposium, taught us what it took to develop, plan and run a conference. Without your leadership this would never have occurred.

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From Burns to Baskets: California Indian Women's Influence on Ecosystems with the Use of Fire and Other Horticultural Techniques

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Introduction

To comprehend the diverse native cultures of California and why they coexisted with nature without depleting its biological diversity to any great extent, one must first understand the central role played by native women in these cultures and the deep responsibilities accorded them by their societies (Steer 1996). While there have been a plethora of books by and about Native-American women in the last two decades, none adequately address the central historical roles of women as subsistence providers, horticulturists, and shapers of the ecology of the land (Bataille and Sands 1984, Green 1992, Niethammer 1977, Powers 1986).

One might ask why rewrite history to better reflect native women's ecological contributions to it? First and foremost, indigenous women's contribution is extremely important to humanity's heritage, and if not acknowledged and documented it may be lost forever. Second, if native women's roles in gathering and vegetation management are adequately portrayed, they will revolutionize the way we view the female gender, empowering indigenous women as vital players and equal partners in the survival and success of their cultures (Green 1992, Lewenhak 1988, Maltz and Archambault 1995). Third, acknowledging their contribution will also drastically change the way in which we view cultural evolution, particularly the rise of agriculture, by placing it within a much richer and complex extended history of cultivation. Proto-agricultural techniques that have been used by early women as the tentative beginnings of selection and crop production will also be revealed (Anderson 1997; Turner 1995). Fourth, the subtle yet profound human influence on ecosystems, and the necessity of reintroducing some of these indigenous harvesting and horticultural techniques will also become more apparent, changing the way that resource managers and ecologists view the human place in the ecosystem, and resulting in the restoration of pre-European settlement conditions in different habitats. Fifth, it will also more fully disclose that history and ethnobiology are pragmatically valuable to the biological sciences, and it will also change the way the general public imagines wilderness.

This article reveals the rich roles that California Indian women assumed as gatherers, horticulturists, and providers and exposes how these roles have been drastically undervalued and under recorded in the anthropological and historical literature. Because the activities of native women have been marginalized, history portrays a skewed and incomplete picture of the indigenous cultures of California. This incomplete picture, in turn has led to an underestimation of the extent that native cultures have influenced California's landscapes. This article begins the attempt to correct this under representation and restores plant gathering as a significant activity. Women are portrayed as engaged in a host of important specialized activities, establishing mutual and complementary interdependence with that of Native-American men in indigenous societies. Additionally, this article outlines various methodologies that restorationsists,

conservation biologists, and land managers can utilize for better disclosing Native-American women's contribution to gathering and vegetation management. And finally, it advocates the necessity of including indigenous women in the design, implementation, and monitoring of land management projects that seek to restore pre-European settlement conditions and enhance cultural resources.

Stereotypes of California Indian Women

From the time of the first contact of Native-Americans with Euro-Americans, the side of native life most often viewed by Westerners has been the male half. Today, that male-dominated universe of native diplomacy, warfare, doctoring, and hunting is still captured in popular novels and films (Albers and Medicine 1983). Comic strips depict a false stereotypic division of labor between the sexes extending back to our human beginnings. For example, in comics of cave-dwelling natives, early man is portrayed as protector and provider, fending off wild animals from his family and providing most of the food supply. Early woman, on the other hand, warms the hearth, takes care of the children, cooks the meat, but her contribution to the subsistence economy is unknown or is negligible (Larson 1984).

An entrenched bias in the anthropological literature is the representation of male hunting and fishing activities as substantial and integral to survival, while women's plant gathering activities are peripheral and nonessential (Hunn 1981, Stahl 1984). The term "hunter-gatherer" was invented on the premise that hunting was the cornerstone of most subsistence economies of native people around the world. But recent research on contemporary hunter-gatherers has provided evidence to contest this conclusion. According to Lee (Reader 1988), of the 58 contemporary hunter-gatherer groups surveyed from around the world, only 11 are primarily dependent on hunting for their food. Also, in northwestern California, fishing has been emphasized for its major contribution to the food economies of tribes, while plant gathering has been downplayed (Hewes 1973, Hunn 1981). Wild plant gathering has also suffered from a negative image (Kroeber 1976). It reminded many early settlers of groveling in the dirt for an unsavory meal; thus, the derogatory term "digger" was a label commonly assigned to California Indians.

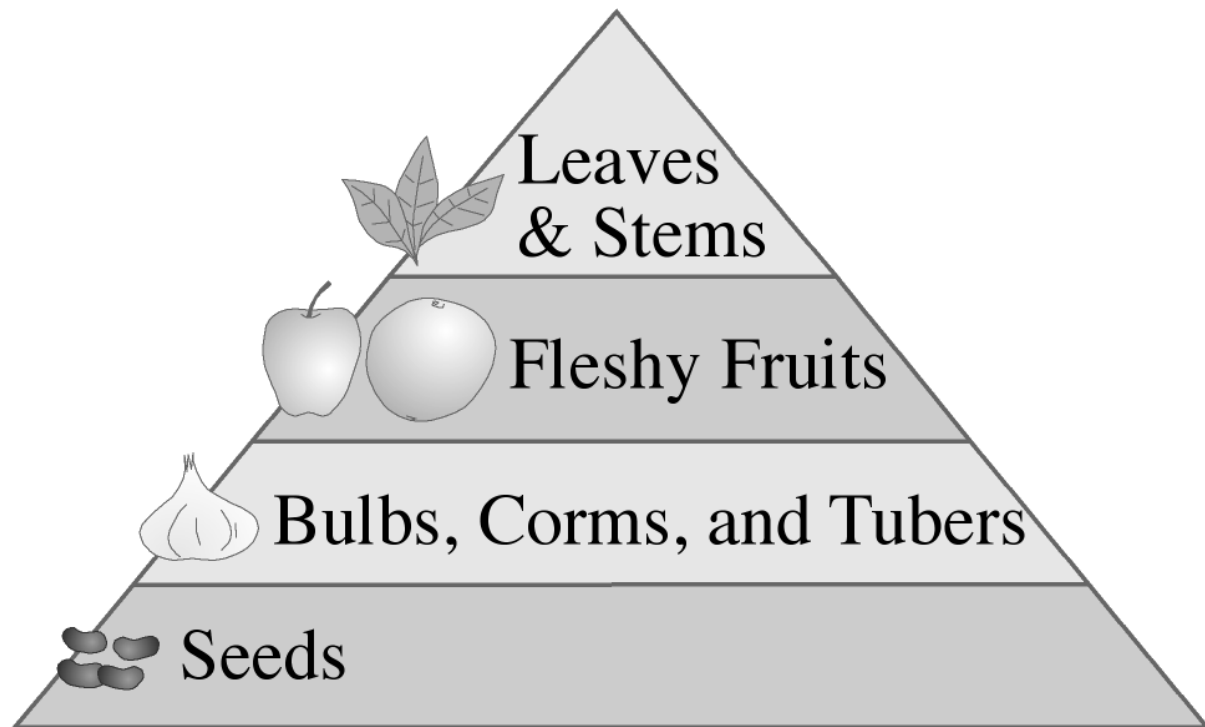
Indigenous Women's Contribution to the Subsistence Economies

By virtue of their daily use of plants, women acquired an extended and special knowledge of the life histories of plant species, and they understood how different harvesting strategies affected natural regeneration (Loudiyi and Meares 1993). Sustainable harvesting strategies included harvesting plants for their tubers after seeding, cutting shrubs during the dormant period, sparing individual plants for future regeneration, granting plant populations rest periods, and using appropriate technologies that did not destroy the ends (Anderson 1994).

During the historic and probably the prehistoric period, wild plant gathering for food was a traditionally female responsibility in most California tribal cultures, while hunting and fishing were male activities (Wallace 1978). Native women were critically important as ethnobotanists, contributing more than 60 percent of the food supply by gathering wild plants in different areas (Heizer and Whipple 1980). Because plants often made up a significantly greater portion of the

diet than animals in most regions of California, women were instrumental in ensuring the economic survival of their cultures. Unlike modern Western diets that rely upon a small number of plant species, traditional indigenous diets relied upon hundreds of plant species for food. For example, the Southern Sierra Miwok incorporated at least 159 edible species in their diets (Anderson 1988, Barrett and Gifford 1933).

Plant parts harvested for food include seeds, bulbs, corms, tubers, stems and leaves, and fleshy fruits. Not all plant parts contributed equally to the diet; the seeds and underground stems provided a much greater share of the plant-based diet (fig. 1). Not only acorns from oaks, but many different kinds of small seeds of wildflowers and native grasses were also consumed. Both the archaeological record and the historical literature substantiate that a tremendous variety of small seeds were gathered in great quantity by many tribes (Anderson 1993, Moratto 1984). Bulbs, corms, and tubers from many different kinds of wildflowers traditionally formed an important source of carbohydrates, protein, vitamins, minerals, and fiber in the diet and according to many ethnographic accounts, bulbs and corms were gathered in great abundance (Anderson 1997).



EDIBLE PLANT PART HIERARCHY

Figure 1. A ranking of the importance of plant parts to the food economies of California Indian tribes. Note the tremendous importance of seeds in the diet.

Besides foods, native plants were integrated into every facet of daily living: adornments, basketry, building materials, ceremonial events, clothing, cordage, cosmetics, dyes, foods, games, etc. The greatest volumes of living plant material (firewood excluded) gathered were collected in the cultural uses categories of cordage, construction materials, foods, and basketry. The two largest cultural use categories, basketry and foods, were by-and-large gathered by women. For example, basketry materials from plants formed 50 percent of the plant material culture; thus, women contributed substantially to the nonfood material needs of their cultures.

All vascular lifeforms were used, from herbs, grasses, sedges, rushes, shrubs, trees, and vines. If one were to peruse all of the ethnobotanies of the state and tally the number of plant species used by lifeform category, the broadleaved herbaceous plants would form the greatest diversity of plant species used by each tribe. Many of these herbs are disturbance-loving, shade-intolerant species that miraculously appear after fire in the understory of different vegetation types. Many of these species are now absent from the habitats where they were formerly gathered by Native-American women.

Indigenous Women's Roles as Horticulturists

It is likely that Native-American women were the major innovators regarding the testing, selecting, and tending of the wild plant world in California for thousands of years (Dahlberg 1981). They had a profound knowledge of the plants and ecological processes around them. And this is still true with Native-American women today. As horticulturalists, California Indian women tilled the soil, pruned shrubs, sowed the seeds of wildflowers and grasses, and in some cases set the fires that nourished their food and basketry crops. These techniques had subtle, yet nonetheless profound ecological impacts at the species, population, community, and landscape levels within a multitude of habitats in different parts of California. Yet the major role of Native-American women in vegetation management in the state has been undervalued and under-recorded. Anthropologists who documented Native-American history were usually male and their informants were usually men, giving us an incomplete picture of different cultures. Questions asked pertained strictly to vegetation management for hunting purposes or domesticated agriculture; other interventions in wildlands have been largely ignored.

In particular, the development of fire as a vegetation management tool enabled women and men to systematically alter the natural environment on a long-term basis and massive scale (Blackburn and Anderson 1993). The most important reasons for burning were to create specific ecological consequences. The reasons mentioned most frequently in the literature for burning include: drive game, drive grasshoppers; increase forage for wildlife; communications; warfare; increased visibility; stimulate growth of tobacco; decrease brush; increase yield of seeds and fruits. Most of these reasons benefit male activities. There are additional reasons to burn different landscapes that are underrecorded in the historical literature including: increase edible tubers, and greens; increase mushrooms; decrease insects and diseases of wild foods; increase quality and quantity of medicinal plants; increase quantity and quality of basketry materials; decrease detritus; increase sprouts for household items; recycle nutrients; decrease plant competition; and increase material for cordage. Many of these purposes benefit plants gathered by women (Anderson 1993a, 1993b, 1996).

Potential Methods for Reconstructing Former Species Lists and Indigenous Disturbance Regimes

Among the Federal, State, and County agencies that manage public and private lands, there is increasing interest in Native-American traditional ecological knowledge. Academicians and government scientists have recently acknowledged that restoration and management of California's wildlands must be grounded in *historical* as well as ecological research and not rest on the illusion that the prehuman, original ecosystems are still intact and self-sustaining (Anderson and Moratto 1995). Today many of California's ecosystems are biologically impoverished, unable to support the diversity of plant and animal species that resided there prior to European contact. To restore this biological diversity, it is necessary to use ethnobiological and historical approaches.

Ethnobiology is the study of how different societies interact with the natural environment. Major topics include ways that different cultures perceive, classify, and evaluate biological resources, and ways that societies organize ecosystems for their own needs. Comparative research on how biotic resources are used, maintained, and changed by different societies is useful for developing general theories and methods for managing and conserving these resources. There are three major methods to gain information important for academicians, restorationsists, landowners, and resource managers interested in restoring and conserving the biodiversity in wildland ecosystems: museum artifact analysis; historical literature reviews; and contemporary ethnographic research (fig 2).

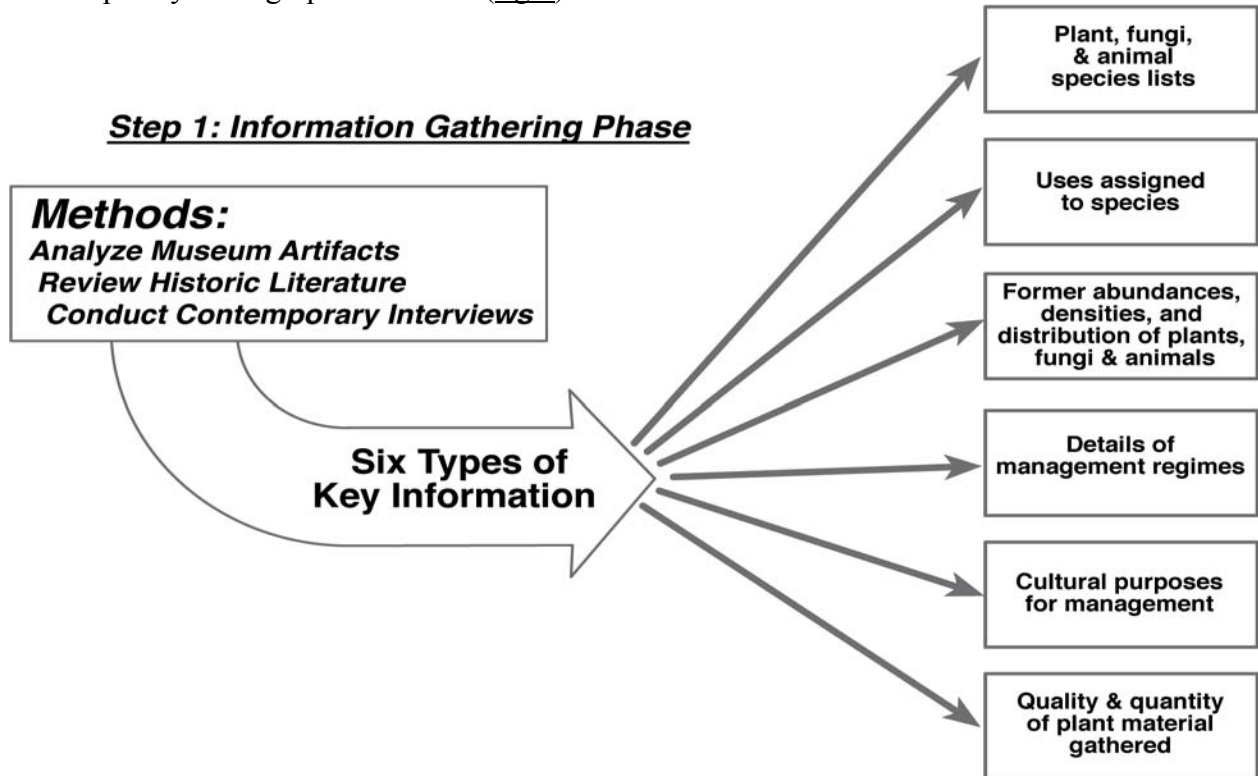


Figure 2. Historical and ethnobiological methods are invaluable approaches for reconstructing pre-European settlement vegetation such as the former diversity, distribution, and abundance of plant, animal, and fungi species that occurred in different ecosystems that were useful to Native tribes. If the assembled species lists are compared with what is found in the wild environment today, often this will reveal biologically impoverished landscapes.

Analysis of Museum Artifacts

Museums could contribute substantially to deciphering former Indian-nature relationships. The cultural artifacts and the bundles, bags, and jars of raw or processed plant materials and animal parts when analyzed and identified, often describe the historical biodiversity of specific regions that Native-Americans depended upon. When these artifacts and materials are linked to published and unpublished ethnographic field notes they may reveal valuable information about Native-American land use history of places.

Historical Literature Reviews

Missionaries, surveyors, early Euro-American settlers, and anthropologists depicted native lifeways in reports, logs, diaries, books, and unpublished field notes for different geographic regions housed in libraries, museums, historical societies, and government archives. Particularly valuable are the unpublished or published ethnobotanies and ethnozoologies of different tribes. These documents can disclose plant and animal species that were important to native people, where they were gathered, and in some cases how abundant they were. This information is important for environmental and cultural reconstruction and for assessing present-day ecosystem health.

Contemporary Ethnographic Research

This involves qualitative and quantitative interviews with Native-American respondents. Questions need to be designed in a way that is nontechnical and easily understandable to the respondent, yet discloses information that is detailed, pertinent to, and can be replicated by scientific fields such as restoration ecology, conservation biology, and fire ecology. In addition to interviews, it is important to view native consultants in different situations, such as those individuals out in the field in direct contact with nature (Agar 1980, Jorgensen 1989).

Information derived from these methods, in turn, can be further analyzed in various ways. For example, comparative analysis of plant uses between tribes may reveal repetitive patterns of use of the same plant species across linguistic boundaries and geographic regions. These common species that are managed over large geographic areas can be mapped and investigated further to uncover details about former indigenous disturbance regimes and the structure and function of a culturally modified ecosystem (fig. 3).

The Role of California Indian Women in Restoration

The efforts of conservation biologists and restorationists in restoring species to viable population numbers and preserving or restoring ecosystems involves captive breeding of animals, propagation, cultivation and outplanting of plants, establishing and managing reserves, and restoring functioning habitat (McNeely and others 1990). An often overlooked, but important component for preserving and restoring biodiversity in parks and reserves is the folk scientific knowledge of native women. This includes both the application of native knowledge

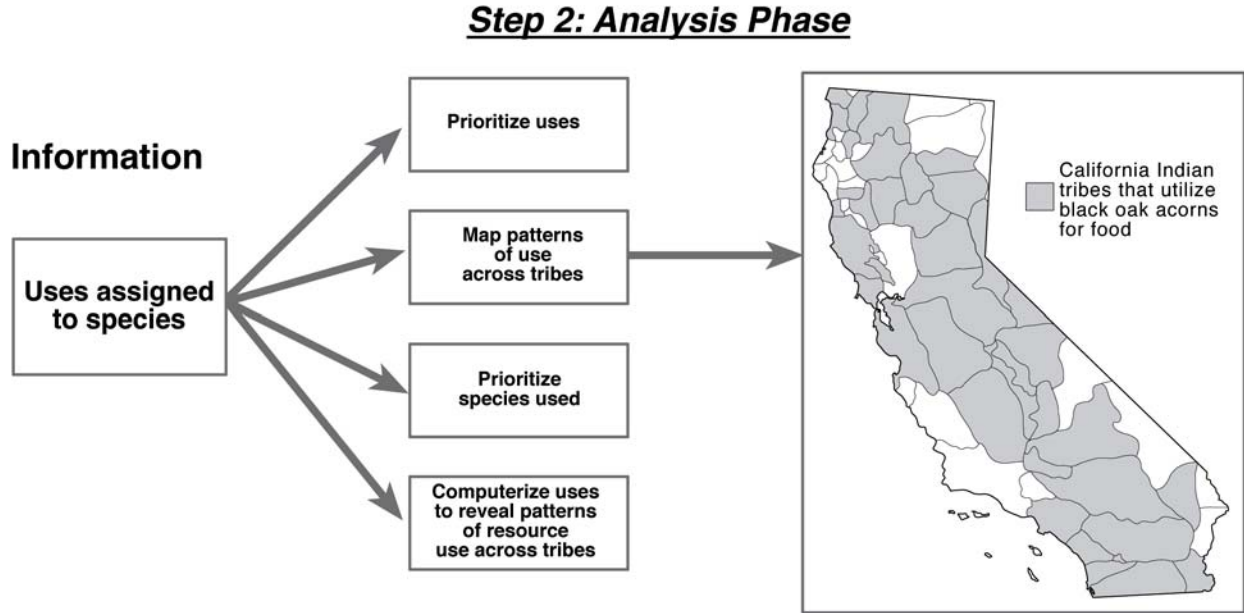


Figure 3. Information derived from historical documents and ethnobiological methods can be subjected to rigorous analysis to search for patterns of resource use. For instant, patterns of resource use that cross linguistic boundaries can be mapped for one plant species, black oak (*Quercus kelloggii*), to demonstrate its high desirability as a food source among multiple tribes.

to wildland management, and the preservation of long-term ecological associations between native women and wildland environments. The *in situ* conservation of native people-land relationships is a complement to other strategies to preserve biodiversity.

The field of ecological restoration would benefit from incorporating women as participants in restoration projects. Not only would Native-American women provide tremendous knowledge about the uses and management of plants, but they would also reveal important information about the former abundance, densities, and assemblages of plant species and disturbance regimes. Because women are still gathering plants for basketry, foods, medicines, and cordage, they feel the effects most immediately of land degradation and the extinction of plant species. Native women are in positions to be strong, vocal advocates for conservation, partly because they see the loss of species, but also because they stand the most to gain from the restoration of traditional gathering sites (Loudiyi and Meares 1993).

Acknowledgments

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“State/Local Fire Policy: What's new?”

Nikki Clay
California Board of Forestry

Thank you for inviting the California Board of Forestry to be part of this panel and speak on the issue of state/local wildland fire policy. You may be wondering, who is the Board of Forestry, and why are they interested in wildland fire policy? The Board of Forestry is comprised of nine members who are appointed by the Governor and confirmed by the Senate. Bob Kerstiens, our Chairman, represents the range livestock industry; Herb Baldwin, Tharon O'Dell, and William Snyder represent the forest products industry; and Dale Geldert, Richard Rogers, Raymond Flynn, Robert Heald, and I represent the general public. The legislature mandates the Board to protect and enhance the State's unique forest and wildlife resources. That means providing fire protection and stewardship to over 31 million acres of the State's privately-owned watershed area, and providing fire and related emergency service to an additional 11 million acres of local government lands.

Historical Origins

Before I discuss the new issues, I will digress and discuss the history of the Board of Forestry. The Board's involvement in wildland fire policy is as old as the Board itself. The California Board of Forestry was created by Governor Stoneman in 1885. It is the first such State level forest policy board in the nation. From the start, Californians recognized the key role of resource management in the quality of life for our citizens. This early Board was vested with policy setting authority and the authority to regulate private land management activities to enact those policies. In the 1880's some of the issues included mining, logging, and wildfires.

This Board also recognized the need for administrative leadership and pushed for the creation of a State forester position in 1905. The state forester worked through County boards of supervisors to implement forest policy. By 1927, the Board of Forestry and the Governor recognized that California's fire and forestry issues went beyond the scope of individual counties and the division of forestry was organized to give State level coordination.

In the 1930's, the nation was thrown into the depths of the great depression and our State forester realized that the earlier practice of conscripting "volunteer labor" to fight fires was counter-productive, as fires were intentionally set to create work. President Roosevelt responded to this national labor crisis by creating the Civilian Conservation Corps. However, the Board recognized the need for a policy shift toward a core professional wildland firefighting force. With a mandate from the legislature, the board prepared and adopted a fire plan for organized wildland fire protection. World War II created a strong need to secure California's forest resources for the war effort and coincided with the Board's 1940 fire plan. This plan became the foundation for much of CDF's current fire suppression system.

Current Issues

During our recent review and update of the Fire Plan some disturbing trends and findings come to light. First of all, more people are living in California's wildlands and our population is expected to grow. Our citizens place a higher value on our wildlands, both for supporting local and regional economies and for contributing to the quality of life that we enjoy in this State. We also know that much of California has a mediterranean climate with mild winters and long dry summers, optimum conditions for wildland fires. Our vegetation is adapted to this climate, which means our vegetation is adapted to fire, and in many cases, fire-dependent. Fire is no stranger to our hills and mountains. We experience thousands of fires and hundreds of thousands of acres burn each year.

What are new issues? Fires have always burned in California. Our firefighting agencies put them out. What is the problem? The old strategy of just adding more fire engines doesn't work. Californians are suffering greater losses, public safety is becoming a greater issue, and our firefighting emergency fund and disaster relief costs are continuing to climb. In the mid-1980's, our emergency fund was \$10-\$20 million. Today it is almost three times that much. The 10-year average cost of wildfire in terms of cost and loss of property at local, State and Federal levels is \$1.2 billion.

In some locations, our fire suppression efforts have limited the low intensity fires, which are nature's way of reducing fuel loading, and our land management practices have grown dependent on fire exclusion. This practice equates to a worsening fire problem in California. Thus, because of these trends, we revised the Fire Plan with the following goals:

- Improve safety and reduce cost and loss from wildfire
- Protect lives and community assets
- Reduce wildfire size, severity and damage

The latest revision of the Fire Plan recognizes these goals and calls for new solutions. A solution that recognizes the role of fire in our ecosystems. A solution that prepares our citizens to live with fire. A solution that we can afford. A solution that creates coalitions based on information and trust. We call these new solutions the prefire management initiative, a way to reduce the fuel load and make people aware of the problem and some solutions. However, the Board is not dismantling our fire suppression organization. In fact, because of our strong initial attack system, we stop 95 percent of the fires in the first burning period. Our initial attack and large fire suppression organization effectively allows us to take the next step toward a proactive pre-fire management approach. We are looking to our fire suppression system at our local ranger units to provide the organizational expertise, project management and implementation skill, and sound scientific understanding of fire that is going to be needed by Californians as we learn to live with fire. We are also looking to our resource management organization to deliver that expertise to the landowners and to integrate pre-fire management into land management practices. Lastly, we are looking to our State fire marshal's organization to engineer pre-fire management into structure design and community development and to train our fire professionals in the latest pre-fire technologies.

Local Steps of Pre-fire Management

First of all, we are focusing on those 5 percent of fires that are large and damaging fires and how to reduce the potential for damage before it happens. Second a 1995 revision resulting name change from the Board of Forestry's Fire Plan to the California Fire Plan. Wildland fire in California does not respect political boundaries. Any real solution to the fire problem is going to require all of us working together toward common goals. It will require partnerships. Our wildland fire agencies have created firescope to allow firefighters to work together to suppress fires. We need our fire agencies to form new coalitions and to work with land managers, communities, industry, local government, environmental groups, and other stakeholders to design and implement pre-fire management plans. We have a California fire problem and we need a California fire plan and a new coalition to design pre-fire management plans to address that problem.

Third, pre-fire management calls for the use of local stakeholder forums to create appropriate solutions. Our fire problem is bigger than just suppression and is growing every day. Our solutions have to bring more local resources to bear on the problem. Bringing planning from Sacramento to local ranger units and involving local stakeholders at the beginning helps to ensure that the best solutions fit the local situation. Fire isn't something that we deal with once and then it goes away. Our local forums will continually address local fire issues. A number of partnership models are currently being used: fire safe councils, resource conservation districts, watershed groups, coordinated resource management projects, alliances, and more. The key to a successful local forum is the empowerment of those participating. This is not a form of big government telling people how to live. Rather, successful forums will understand the problem and create their own solutions using the government, private, and volunteer sector resources at their disposal.

Fourth, the California fire plan sets up an assessment framework using sophisticated new tools such as satellite imagery, global positioning system and computer modeling of fire behavior and smoke dispersal. This assessment evaluates our fire suppression force's initial attack level of service, hazardous fuel conditions, frequency of severe weather, and the risk to the assets being protected, all validated by people who know the local conditions. The assessment uses a mapping system that effectively combines the best available science with the best local knowledge. Because the fire problem in California is huge, the assessment can be used to help local stakeholder groups set priorities on where to work first. More importantly, the visual nature of the mapping system helps our stakeholders and fire managers communicate areas of common concern.

Fifth, pre-fire management solutions are designed locally to improve safety and reduce cost and loss. By using the assessment system and local knowledge, stakeholders and local fire managers can design solutions that address their specific problem. If fuel loading is the issue, then fuels management may be the solution. If large expanses of vegetation pose a risk to a community, then a community defense zone may be the solution. Often, fire proofing the asset at risk may be a viable solution. Prescribed fire, biomass, fuel breaks, clearance and other management tools can be used alone or integrated to create the desired results.

Summary

The California Fire Plan's emphasis on pre-fire management is new because it requires non-traditional partnerships and coalitions; it has moved its planning from Sacramento to the local ranger units; and because it calls for local understanding of the problem and the local creation of solutions to the problem.

The California Fire Plan is not sitting on the shelf; it is being enthusiastically implemented by ranger units and their various stakeholder groups all over California. Already pre-fire management plans are being implemented, and Californians are understanding the fire problem and designing solutions to protect their communities. This is truly not business as usual.

Federal/State Wildland Fire Policy And the State/Local View of Pre-fire Management: What's New?

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The California Board of Forestry has recognized the growing fire problem in California. In their 1996 revision of the Fire Plan, the Board of Forestry recommended an emphasis on dealing with the fire problem before the fire occurs. Their pre-fire policy recognizes the role of fire in the environment and sets the stage for land managers, stakeholders, and fire service providers to work together to best integrate fire's role in the ecosystem to meet local land use objectives.

Two years ago, Governor Wilson, as part of his program of preventative government, supported a Pre-fire Management Initiative for California. This Initiative implements the Board of Forestry's California Fire Plan framework. The legislature concurred with the administration and the Board's policy by funding a three-year phased implementation. Basically, this budget change resulted in a fire captain specialist from (Pre-fire Engineering) in every ranger unit and in the six contract counties. Two regional battalion chiefs (Pre-fire coordinators) and additional support staff in Sacramento were also included. In addition, the Initiative added vegetation management coordinators to all of the contract counties and ranger units. Thus, the Governor and Legislature have supported pre-fire management by funding a \$2.5 million program in the California Department of Forestry and Fire Protection.

Governor Wilson has also taken pre-fire management a step further. In June 1996, he called a summit meeting with the primary wildland fire service agencies and the stakeholder community. They discussed wildland fire from a number of perspectives. At the conclusion of this summit, they formed an Alliance for a Fire- Safe California. This Alliance is composed of Richard Wilson, Director of the California Department of Forestry and Fire Protection; Lynn Sprague, Regional Forester, U.S.D.A. Forest Service; Ed Haste, State Director, U.S.D.I. Bureau of Land Management; Ron Coleman, State Fire Marshal; Jerry Davies, representing the California Fire Safe Council; and P. Michael Freeman, Chief of Los Angeles County Fire Department, representing local government wildland fire service providers. This Alliance reflects a commitment by these agencies to implement pre-fire management solutions. The Alliance has identified a number of local and regional projects that demonstrate their commitment. The Alliance partners are committed to removing barriers that stand in the way of getting the job done.

The California Department of Forestry and Fire Protection (CDF) is implementing pre-fire management into existing organizational structure, but it is not creating a new bureaucratic structure for pre-fire management. Pre-fire is the approach of all of our programs, with each program playing a role in implementing projects. CDF's pre-fire approach coordinates the various forest management and fire protection services the ranger units provide by preparing a strategic vision for the ranger unit. We call this the Ranger Unit pre-fire Management Plan. This strategic view of fuels and fire is created with the help of stakeholders, CDF's resource management professionals, and CDF's fire professionals.

The pre-fire engineer coordinates the assessment of the fire problem, collecting information from stakeholders and from program managers. A pre-fire plan is prepared. This plan is a strategic document, aimed at coordinating activities both within and external to the Department. Our program managers and stakeholders implement the solutions.

How does this plan work? First, our ranger unit staff assess wildland fire in their ranger unit. This assessment has four primary components – fuels, assets at risk, the level of service provided by the fire agencies, and frequency of severe fire weather. The assessment is based on mapped information, automated in a geographic information system database. The mapped data is run through a series of models to produce assessments of large costly fire potential.

One key strategy for this automated assessment process is “programming” enough of the calculations to make the process easy to use, yet leave enough manual steps to allow for local needs. The Department uses off the shelf software – the ESRI Corporation’s ArcView product¹ and some custom software created in-house. We are investing in three days of formal classroom training for the ArcView product and many weeks of on-the-job training. The desired effect of this “semi-” automated system is to remove the “black box” stigma associated with modeling programs. CDF’s pre-fire engineers know the strengths and weaknesses of their data.

A second key strategy is to use a “layered” database approach so that our stakeholders can effectively participate in the process. An early step in the assessment process is to field validate the assessment data. CDF’s, pre-fire engineers are asked to work with stakeholder groups to get the most accurate and updated information. This process also helps to focus efforts where the interest is greatest. Stakeholders will focus their efforts where their interests are at risk. CDF is purchasing laptop computers for this purpose. We want to make it easy for stakeholders to participate. Laptop computers provide the mobility for our pre-fire engineers to go to the stakeholders. We are now finding stakeholders with their own databases willing to contribute to the assessment. This greatly enhances the validation process. Stakeholders also contribute to defining priority areas for projects and getting projects completed.

This brings up the third key strategy: stakeholder involvement early and often. CDF units are using a number of strategies to involve stakeholders. Fire Safe Councils, Biodiversity Councils, Coordinated Resource Management Groups, Watershed Groups, Homeowners Associations, Resource Conservation Districts, and regional alliances are all examples of locally or regionally formed groups that focus on the wildland fire issues in their community. For example, the Fire Safe Councils offer an opportunity to involve any and all who are focused on the wildland fire issues in their area of concern. In addition to the Statewide Fire Safe Council, there are currently twelve local councils and the number is growing. Another approach is the Biodiversity Council. Local, State, and Federal partners are actively involved in California’s Biodiversity Councils.

The Fire Plan assessment focuses on areas most likely to suffer a costly damaging fire. The database includes information for a problem analysis of key elements that are driving the fire problem. These elements may be topography, excessive fuels, a lack of wildland fire fighting service, too many ignitions, or frequently severe fire weather.

The assessment includes an analysis of the wildland fire agencies level-of-service. This measure is a simple percent success score that can be used to compare one area to the next. The fuels assessment starts with available vegetation maps, converts to the Fire Behavior Prediction System fuel models, updates the fuels by including larger fires since the maps were created, and ranks the fuels into a low/medium/high ranking. The assets at risk rankings considers the impact of large costly wildfires on 15 layers of assets. Each asset is modeled independently and the

result is added together to show areas of high risk. The weather assessment considers how often areas experience severe fire weather.

On the basis of this assessment, decisions are made about priorities and prescriptions. The solution may be fuels treatments, community defense zones, ignition management plans, improved survivability to the assets at risk, or most likely, a coordinated approach to all of these.

What do stakeholder groups do? First, they help validate the data in the assessment process--primarily the assets at risk layers. This analysis helps improve the accuracy and completeness of the Fire Plan. More importantly, it creates a communication link between the wildland fire service providers and the recipients of that service. This communication will become critical as projects are developed and implemented. Stakeholders help the fire professionals plan projects that can work in their community. There are a number of approaches to the fire problem and there are compromises between solutions, cost-effectiveness, and environmental appropriateness (including the human environment). Stakeholders play a critical role in defining appropriate solutions and agreeing to compromises. Without their involvement, successful completion of pre-fire projects is highly unlikely. Most importantly, stakeholders play a critical role in funding and executing pre-fire projects. CDF does not have all of the resources to do all of the fuels management work in the State of California. Stakeholders are critical to acquiring funding so that the most important work can be accomplished.

Funding is a difficult issue. CDF is setting priorities for the resources (fiscal and personnel) within our control. Pre-fire projects are a top priority for our fire crews. Our forest advisors are focusing stewardship effort toward pre-fire. Our prevention inspections are being focused on high priority areas. CDF also prepared a budget change proposal for pre-fire project funding. However, this is not its only endeavor. Once again, stakeholders and collaborative partnerships are the key strategy. CDF is training pre-fire engineers and other ranger unit staff on Foundation funding and grants. Because this is a new area for many of us, we are trying to learn from the experience of other organizations. There are many opportunities. Already ranger units are working with Resource Conservation Districts seeking watershed improvement grants under "Proposition 204." Ranger units are also working with non-government organizations seeking funds for environmental enhancement projects.

The fire problem did not occur over night. It is a growing problem with decades of accumulated fuel, growth of communities into the wildlands, and a growing appreciation for our wildland assets. The solution is not an easy one. CDF is planting the seeds for solution today in the form of a strategic, integrated, partnership approach. The solution is not to eliminate fire from its natural role in the environment. After 90 years of organized fire suppression, fire has still not been eliminated. The task ahead is to learn to live with fire. The solution will require growth in our understanding of fire effects, our ability to work together as partners, and design and build fire safe communities, and our tolerance of natural processes. The solution is to learn to live with fire.

¹ Mention of trade names of products is for information only and does not imply endorsement by the California Department of Forestry and Fire Protection or the U.S. Department of Agriculture.

Ecology, Prevention, and Fire Management It's Not Rocket Science But It Does take Teamwork

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Key words

The two key words of this symposium presentation, are “integrating” and “teamwork”. Have been defined by *Merriam - Webster* (1974) as integrating *vb.*: 1 to form into a whole: unite, 2 to incorporate into a larger unit, and teamwork *n*: the work or activity of a number of persons acting in close association as members of a unit. The cadre members for this symposium recognized that the separate disciplines must integrate for the successful reintroduction of fire into the natural ecosystems of California. Integration of ecology, fire prevention and fire management is not the end but only the beginning of the work to be accomplished. After we realize that there is strength in unity, the next step is working together as a team. In order to be successful, we must learn to work together. Team work and the importance of team leadership in accomplishing the goals of this symposium are the focus of this presentation.

Throughout the history of the United States, the people have had to rise to a higher level, to dig a little deeper to achieve goals that some felt were not achievable. For instance the highly publicized space program has accomplished some noteworthy examples. comparisons. Three examples come to mind... Yeager breaking the sound barrier in 1947, America landing the first human on the moon in 1969, and more recently the Pathfinder mission to Mars. Likewise the wildland management community is also facing some difficult challenges. The public and the scientific world have called for the restoration of forest health to the declining fire dependent ecosystems in the United States. According to Mike Dombeck's, the new Chief of the Forest Service, a high priority of the agency under his leadership “is to protect and restore the health of the land. Failing this, nothing else we do really matters. Let me repeat...” The Secretaries' of the Department Interior and Agriculture have challenged us to return fire to the ecosystem and to restore healthy forests with resistance to the modern destructive nature of forest fires. How can we do this...?

It's not Rocket Science but it does take Teamwork.

Shortly after the successful Pathfinder mission to on Mars, July 4, 1997, the director of the project stated the reasons for the success of the mission included: a mission, a charter, freedom to be creative, the latitude to take risks, and team work.

Similarly the leader of the Mars program at the Jet Propulsion Laboratory, Pasadena, Ca, Donna Shirly, stated that creating an atmosphere of teamwork was one of her primary goals: “We're in a very exciting era of new programmatic strategies.... a whole enterprise focus at working together to get the missions done and doing what you need to do rather than every center for itself and every program for itself.” Ms Shirly concluded that forming alliances with

other public and private industries and programs was helping to fill the empty gaps in JPL's ability to do everything: "We're leading the charge in that whole strategic alliance regime, which is underpinning a lot of modern business"

Teamwork is not something new to the fire agencies in California. Teamwork has been the cornerstone of successful suppression of wildfires for the past two decades. The Incident Command System developed in the mid-1970's is a prime example of a structure that has proven successful. What does the Incident Command System philosophy stress? It stresses the need for teamwork, communication, and strong leadership.

The team I want you to think about is a team with folks from Fire Ecology, Fire Prevention, Fuels Management, Air Quality Management, and Fire Suppression disciplines. What does this team need to be successful at the task of reintroducing fire into the ecosystem? There are several attributes that a strong team needs to possess to be successful:

- A common goal and the willingness to work together to achieve it.
- Strong leadership.
- Willingness to take risks.

Leadership

Leadership is the key to making the team work. One example of leadership can be found in a book by Wess Roberts (1987) that focuses on that famous conqueror of the civilized world, Attila the Hun. This acclaimed book provides time-tested principals of leadership, including:

- Stewardship as a caretaker to serve in a manner that encourages confidence, trust, and loyalty.
- Courage to face obstacles without becoming bewildered in the presence of adversity.
- Desire for an inherent commitment to influence people, processes, and outcomes.
- Tenacity to accomplish assignments
- Dependability in carrying out roles and responsibilities.

Another important aspect of teamwork is focusing on results. "Huns should be taught to focus on opportunities rather than on problems"(Roberts 1987, p.m).

Retired General Colin Powell in a speech recently said, "We need to stop constantly criticizing, which is the way of the malcontent, and instead get back to the can-do-attitude that made America". Likewise, Secretary of the Interior, Bruce Babbitt in a speech on February 11, 1997 at Boise State University, said "I challenge you the American people, to recognize how fire and smoke—rising from the ashes like the mythical phoenix—can and must continue to play an essential, natural role in the life cycle of the wildlands we live in and love." Thus, if we are truly

serious about restoring forest health then we must move forward with vigor to accomplish the challenges that lie ahead for this newly formed alliance of fire ecology, prevention and management. The work ahead will take teamwork, strong leadership, and new alliances to achieve the goals of reintroduction of fire into the fire dependent ecosystems.

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Smoke Management, an Air District's Dilemma

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The vegetation is dense and ladder fuels are prevalent throughout the California landscape. The ecosystem has had fire exclusion for a long time. One match at the wrong time can turn it into a killer wildfire, turning green vegetation into charcoal. But at the right time, the use of fire can change the landscape restoring it to its natural state.

The reintroduction of fire into the ecosystem is a dilemma for Air Districts. The responsibility of Air Districts is to protect public health, while the responsibility of a land manager is to apply an ecosystem approach to the management of public lands. Therefore, how can we increase the use of fire as a management tool, while protecting the air we breathe?

Through the enactment of the Federal Clean Air Act (FCAA) in 1963 and through its subsequent amendments, states are required to achieve and maintain compliance with the National Ambient Air Quality Standards (NAAQS). (Attachment 1) To do this, states in conjunction with local Air Districts, develop a State Implementation Plan, called a SIP, outlining how emissions to the air will be reduced for those areas that exceed NAAQS, or how emissions to the air will be limited so that a new violation of NAAQS will not occur. Once the Federal Environmental Protection Agency (EPA) approves a state's SIP, federal agencies must comply with the all applicable commitments, which may include restrictions on the use of prescribed fire on public lands.

On November 30, 1993, as part of the FCAA, the U.S. EPA published the General Conformity rule. States and local Air Districts in federal non-attainment areas were required to adopt the General Conformity rule, which applies to federal actions and projects. This rule sets acceptable emission levels, for the different degrees of non-attainment of the NAAQS, which are called de minimis thresholds. If a federal action or project exceeds these thresholds based on an applicability analysis, then a general conformity determination is required which documents that the federal action will conform to the emission budgets allocated in the SIP. In other words, it must be shown that emissions from the action or project were included in the SIP.

Through the National Environmental Protection Act (NEPA) of 1969, federal agencies must disclose the environmental impacts of planned projects. The environmental document typically includes appropriate mitigation measures in relation to air quality impacts.

Placer County Air Pollution Control District's (APCD) role throughout the NEPA process is to assure that air quality impacts are adequately addressed. While prescribed fire is a temporary source of air pollution, it creates a large volume of smoke which can be seen and breathed for miles. Thus, the review of documents by the Placer County APCD through the NEPA and General Conformity processes is essential in increasing communication between those burning and those regulating to assure that a wildland burn minimizes emissions and smoke impacts to sensitive receptor areas to the extent feasible. For the purposes of this paper a sensitive receptor area is one which can be adversely effected by smoke from wildland fires. This can include small or large populated areas and Class I areas or areas treated like Class I.

The following five items reflect the aspects of the air quality element in a NEPA document that addresses the Placer County APCD's concerns.

1. Has the project has been analyzed for the right setting/location?

California has 35 local air pollution control districts/air quality management districts. (Attachment 2 and 3) These air districts have been further grouped into 14 air basins. (Attachment 4) Placer County alone is located within 3 air basins: the Sacramento Valley, the Mountain Counties, and Lake Tahoe. (Attachment 5) Each of these air districts or portions thereof have been designated attainment, non-attainment or unclassified for federal and state ambient air quality standards. (So different General Conformity "de minimis" thresholds apply in these various air basins.)

2. Is there a discussion of the proposed activity in relation to air quality in the affected environment?

A NEPA document would analyze the air quality impacts of the proposed project. This includes the impacts on the affected environment such as smoke impacts from prescribed fire activities.

3. Is there a discussion of alternatives?

Even though prescribed fire may be the preferred activity identified in a NEPA document, it is not the only way to reduce a fire hazard and still help restore the landscape. The use of mechanized equipment such as a slashbuster or chipping operation can reduce ladder fuels and dense vegetation. Larger material can be firewooded. The dilemma between air quality districts and land managers can lead to benefits for everyone when these alternatives are not only explored but used.

4. Is there a General Conformity applicability analysis? Is the project above or below de minimis thresholds? If above, how will the project emissions be lowered to below the threshold levels? (Attachment 6)

The General Conformity applicability analysis can often be overlooked or forgotten. General Conformity should not to be mixed up with Transportation Conformity and its requirements. General Conformity is only required in areas of federal non-attainment or maintenance areas. Placer County is non-attainment for the federal ozone standard and for the carbon monoxide standard in two areas (Placer County has applied to the U.S. EPA to change the carbon monoxide designation to attainment. If the change occurs, these areas would become maintenance areas.). Also, the recently promulgated NAAQS for ozone and PM2.5 may result in new non-attainment areas.

The following is an overview of the General Conformity process as applied to prescribed fire. General Conformity is applicable to federal actions, and emissions

directly related to them. This includes activities on federal land or use of federal money. For example, in Placer County, the Bureau of Reclamation owns land administered by the California State Parks Department. The California Department of Forestry and Fire Protection will conduct a prescribed burn on this property in 1998 for wildlife enhancement and fire hazard reduction. Since the activity will be conducted on federal land, a General Conformity applicability analysis is required

To determine whether General Conformity is applicable, an emissions analysis must be completed taking into consideration all activities associated with the project. In Placer County, the analysis would be for ozone precursors, and where applicable, carbon monoxide due to the non-attainment status. The corresponding de minimis thresholds would be 25 tons/year for ozone and 100 tons/year for carbon monoxide. In other federal non-attainment areas, particulate matter and other pollutants may be included.

Emissions are calculated and are either above or below de minimis thresholds. If emissions are below the de minimis thresholds, than the project can proceed. If the emissions are above de minimis thresholds, than sufficient mitigation must be proposed to reduce the emissions to below de minimis thresholds. If this is not possible, then credits can be purchased or otherwise obtained to offset the emissions (Attachment 7).

There are no current proposals to include attainment areas or non-federal activities under General Conformity. Also, the General Conformity rule requires federal agencies to comply with all applicable state and local rules.

5. Are there proposed mitigations? This may include the submittal of a smoke management plan.

As there are alternatives with a project there are also mitigations to reduce an impact. With air quality, a combination of mitigation measures can assure that a project can have minimum impacts. Mitigations can include different lighting techniques, public information requirements, burning only on a permissive burn day, or a combination of alternatives which could include chipping, firewooding and the use of fire for more effective fuels treatment and the minimizing of emissions. Examples of other mitigations, including alternatives for prescribed fire are in Attachment 8)

Once the NEPA and General Conformity documents are approved, the implementation of the mitigation measures can begin. For a prescribed fire project, this would include complying with an air district's rules and regulations. Each air district's rules are different. In Placer County the following requirements are applicable:

- Submit a burn plan for the projects. This includes:
 1. acreage covered by the burn plan;

2. location of the burn site;
 3. type of fuel and objectives of the burn;
 4. direction and distance to populated or sensitive receptor areas;
 5. project burn schedule (ignition to burndown);
 6. meteorological prescription for the burn;
 7. specifications for monitoring and verifying project parameters;
 8. procedures for notifying the public and other agencies of the burn.
- Obtain a Placer County APCD burn permit
 - Burn on a Permissive Burn Day as determined by the California Air Resources Board.
 - Burn only dried vegetation.
 - Burn vegetation with a minimum of smoke and free from dirt.

Each burn permit issued by the Placer County APCD can have additional conditions specific to that burn. These conditions may include burning only under certain wind conditions which would transport smoke away from a sensitive receptor area, or requiring further onsite meteorological information to be gathered prior to burning. This may include a weather balloon released which can collect data concerning inversion heights and winds aloft and their speed and direction. The inclusion of mitigation measures as part of NEPA and General Conformity documents could be additional conditions of the burn permit.

With an increase in prescribed burning, the Placer County APCD may consider the use of a smoke management plan to minimize smoke impacts on sensitive receptor areas. "The basic components for a smoke management plan could include the following:

- a. identify sensitive receptor areas;
- b. evaluate smoke dispersion;
 - 1) review and evaluate site specific smoke impacts;
 - 2) assess the atmospheric capacity for smoke dispersal;
 - 3) transport smoke away from sensitive receptor areas;
- c. authorize burn planning;
- d. educate the public;
- e. notify affected parties;
- f. review and assess the program effectiveness;
- g. enforce smoke management plans and contingencies.

These basic components are part of a draft smoke management program document obtained from C. Campbell at the Colorado Department of Public Health and Environment June, 1997.

Additionally, a smoke management plan may include emission calculations which were not part of a General Conformity applicability determination. The methodology used to determine project emissions should be approved by the air district.

The most sensitive concern regarding prescribed fire is the management of smoke to prevent complaints. Most of the time when a complaint is made, the smoke is a nuisance. More than likely there has not been a violation of air quality standards. However this same smoke can cause both health and safety problems in sensitive receptor areas and populated areas

With the increase in the foothill population in Placer County and throughout California, more of the public sees the smoke from prescribed fires. With this can come an increase in complaints. Complaints occur because there is too much smoke, because "I just don't like burning", or because not enough is being done to restore the landscape to its natural state and reduce the fire hazard. Regardless of the reason, the Placer County APCD has an obligation to respond to the public's concerns. Furthermore, land managers must remain sensitive to these concerns regarding smoke and its impact on others in order to achieve their goals

As the use of prescribed fire increases, both air districts and land managers are faced with the increased challenge of protecting the public's health while minimizing air quality impacts. It is imperative that good communication and a cooperative working relationship be established and maintained between the air districts and land managers. This relationship can increase the public's confidence in the use of wildland fire for changing the landscape for ecosystem restoration. It can also help air districts and land managers to achieve their respective goals of protecting the public's health and using fire as an important tool for managing the landscape in the ecosystem.

Attachment 1

Ambient Air Quality Standards

Pollutant	Averaging Time	California Standards ¹		Federal Standards ²			
		Concentration ³	Method ⁴	Primary ^{3,5}	Secondary ^{3,6}	Method ⁷	
Ozone (O ₃)	1 Hour	0.09 ppm (180 µg/m ³)	Ultraviolet Photometry	0.12 ppm (235 µg/m ³) ⁸	Same as Primary Standard	Ethylene Chemiluminescence	
	8 Hour	—		0.08 ppm (157 µg/m ³)			
Respirable Particulate Matter (PM ₁₀)	Annual Geometric Mean	30 µg/m ³	Size Selective Inlet Sampler ARB Method P (8/22/85)	—	Same as Primary Standard	Inertial Separation and Gravimetric Analysis	
	24 Hour	50 µg/m ³		150 µg/m ³			
	Annual Arithmetic Mean	—		50 µg/m ³			
Fine Particulate Matter (PM _{2.5})	24 Hour	No Separate State Standard		65 µg/m ³	Same as Primary Standard	Inertial Separation and Gravimetric Analysis	
	Annual Arithmetic Mean			15 µg/m ³			
Carbon Monoxide (CO)	8 Hour	9.0 ppm (10 mg/m ³)	Non-dispersive Infrared Photometry (NDIR)	9 ppm (10 mg/m ³)	None	Non-dispersive Infrared Photometry (NDIR)	
	1 Hour	20 ppm (23 mg/m ³)		35 ppm (40 mg/m ³)			
	8 Hour (Lake Tahoe)	6 ppm (7 mg/m ³)		—			
Nitrogen Dioxide (NO ₂)	Annual Arithmetic Mean	—	Gas Phase Chemiluminescence	0.053 ppm (100 µg/m ³)	Same as Primary Standard	Gas Phase Chemiluminescence	
	1 Hour	0.25 ppm (470 µg/m ³)		—			
Lead	30 days average	1.5 µg/m ³	AIHL Method 54 (12/74) Atomic Absorption	—	Same as Primary Standard	High Volume Sampler and Atomic Absorption	
	Calendar Quarter	—		1.5 µg/m ³			
Sulfur Dioxide (SO ₂)	Annual Arithmetic Mean	—	Fluorescence	0.030 ppm (80 µg/m ³)	—	Pararosaniline	
	24 Hour	0.04 ppm (105 µg/m ³)		0.14 ppm (365 µg/m ³)			
	3 Hour	—		—			0.5 ppm (1300 µg/m ³)
	1 Hour	0.25 ppm (655 µg/m ³)		—			—
Visibility Reducing Particles	8 Hour (10 am to 6 pm, PST)	In sufficient amount to produce an extinction coefficient of 0.23 per kilometer—visibility of ten miles or more (0.07—30 miles or more for Lake Tahoe) due to particles when the relative humidity is less than 70 percent. Method: ARB Method V (8/18/89).		No Federal Standards			
Sulfates	24 Hour	25 µg/m ³	Turbidimetric Barium Sulfate-AIHL Method 61 (2/76)				
Hydrogen Sulfide	1 Hour	0.03 ppm (42 µg/m ³)	Cadmium Hydroxide STRactan				

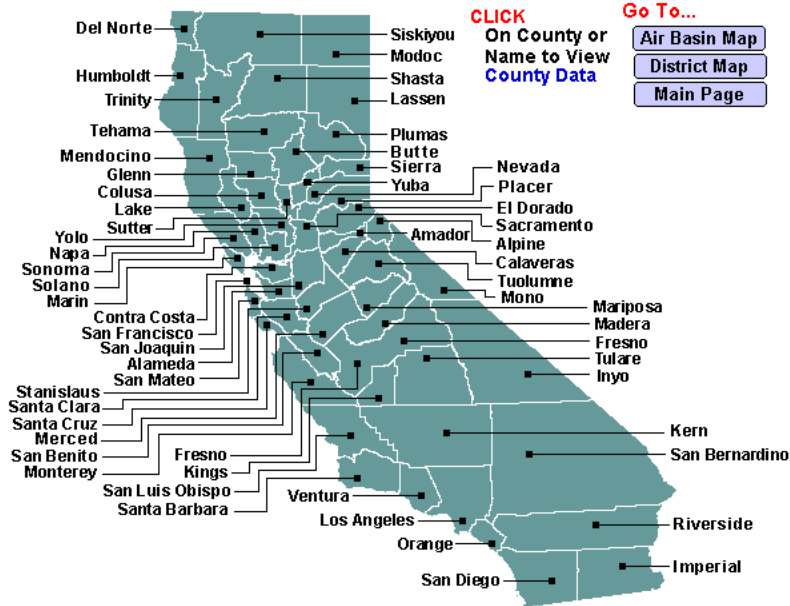
Attachment 1(Cont.)

1. California standards for ozone, carbon monoxide (except Lake Tahoe), sulfur dioxide (1 and 24 hour), nitrogen dioxide, suspended particulate matter—PM10, and visibility reducing particles, are values that are not to be exceeded. All others are not to be equaled or exceeded. California ambient air quality standards are listed in the Table of Standards in Section 70200 of Title 17 of the California Code of Regulations. In addition, Section 70200.5 lists vinyl chloride (chloroethene) under “Ambient Air Quality Standards for Hazardous Substances.” In 1978, the California Air Resources Board (ARB) adopted the vinyl chloride standard of 0.010 ppm (26 mg/m³) averaged over a 24-hour period and measured by gas chromatography. The standard notes that vinyl chloride is a “known human and animal carcinogen” and that “low-level effects are undefined, but are potentially serious. Level is not a threshold level and does not necessarily protect against harm. Level specified is lowest level at which violation can be reliably detected by the method specified. Ambient concentrations at or above the standard constitute an endangerment to the health of the public.” In 1990, the ARB identified vinyl chloride as a Toxic Air Contaminant and determined that there was not sufficient available scientific evidence to support the identification of a threshold exposure level. This action allows the implementation of health-protective control measures at levels below the 0.010 ppm ambient concentration specified in the 1978 standard.
2. National standards (other than ozone, particulate matter, and those based on annual averages or annual arithmetic mean) are not to be exceeded more than once a year. The ozone standard is attained when the fourth highest eight hour concentration in a year, averaged over three years, is equal to or less than the standard. For PM10, the 24 hour standard is attained when 99 percent of the daily concentrations, averaged over three years, are equal to or less than the standard. For PM2.5, the 24 hour standard is attained when 98 percent of the daily concentrations, averaged over three years, are equal to or less than the standard. Contact U.S. EPA for further clarification and current federal policies.
3. Concentration expressed first in units in which it was promulgated. Equivalent units given in parentheses are based upon a reference temperature of 25°C and a reference pressure of 760 mm of mercury. Most measurements of air quality are to be corrected to a reference temperature of 25°C and a reference pressure of 760 mm of mercury (1,013.2 millibar); ppm in this table refers to ppm by volume, or micromoles of pollutant per mole of gas.
4. Any equivalent procedure which can be shown to the satisfaction of the ARB to give equivalent results at or near the level of the air quality standard may be used.
5. National Primary Standards: The levels of air quality necessary, with an adequate margin of safety to protect the public health.
6. National Secondary Standards: The levels of air quality necessary to protect the public welfare from any known or anticipated adverse effects of a pollutant.
7. Reference method as described by the EPA. An “equivalent method” of measurement may be used but must have a “consistent relationship to the reference method” and must be approved by the EPA.
8. New federal 8-hour ozone and fine particulate matter standards were promulgated by U.S. EPA on July 18,1997. The federal 1-hour ozone standard continues to apply in areas that violated the standard. Contact U.S. EPA for further clarification and current federal policies.

Attachment 2

California is divided into 58 counties

California Counties



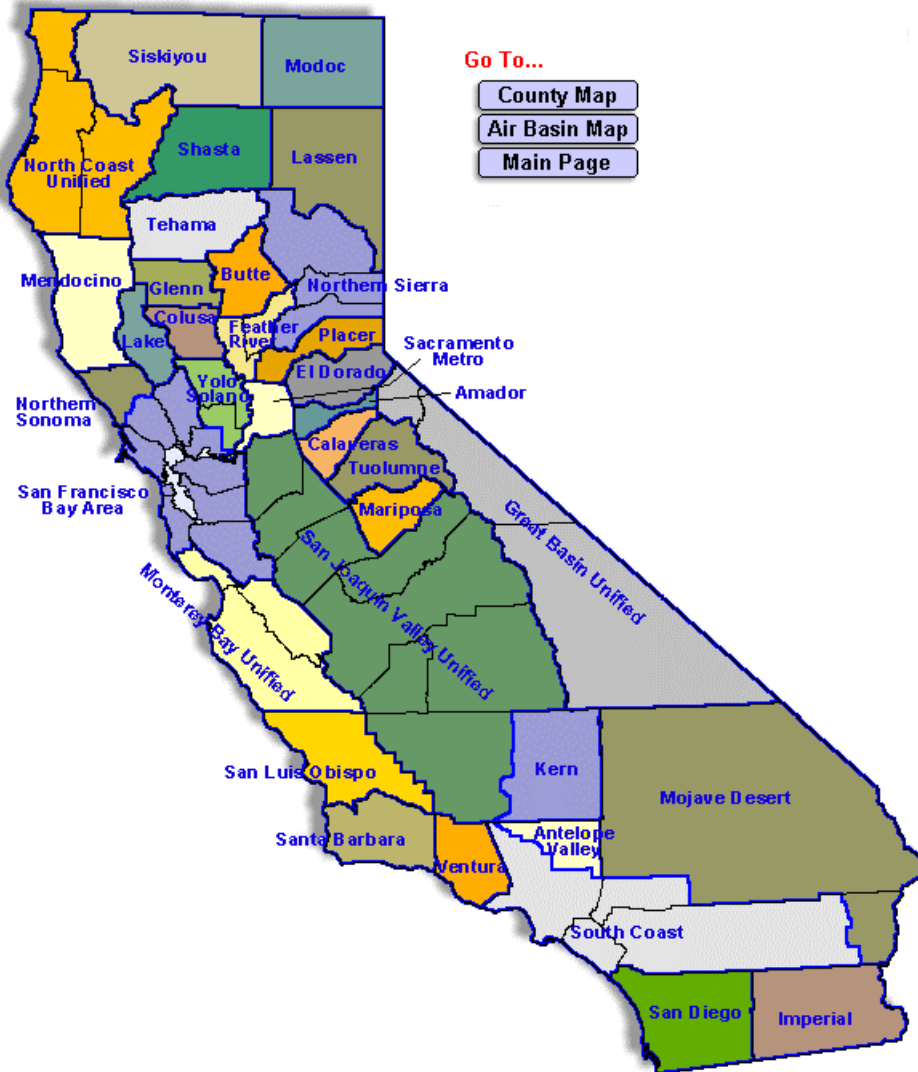
Select a County for Tabular Emissions Data

<ul style="list-style-type: none"> • Alameda • Alpine • Amador • Butte • Calaveras • Colusa • Contra Costa • Del Norte • El Dorado • Fresno • Glenn • Humboldt • Imperial • Inyo • Kern 	<ul style="list-style-type: none"> • Kings • Lake • Lassen • Los Angeles • Madera • Marin • Mariposa • Mendocino • Merced • Modoc • Mono • Monterey • Napa • Nevada • Orange 	<ul style="list-style-type: none"> • Placer • Plumas • Riverside • Sacramento • San Benito • San Bernardino • San Diego • San Francisco • San Joaquin • San Luis Obispo • San Mateo • Santa Barbara • Santa Clara • Santa Cruz • Shasta 	<ul style="list-style-type: none"> • Sierra • Siskiyou • Solano • Sonoma • Stanislaus • Sutter • Tehama • Trinity • Tulare • Tuolumne • Ventura • Yolo • Yuba
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Attachment 3

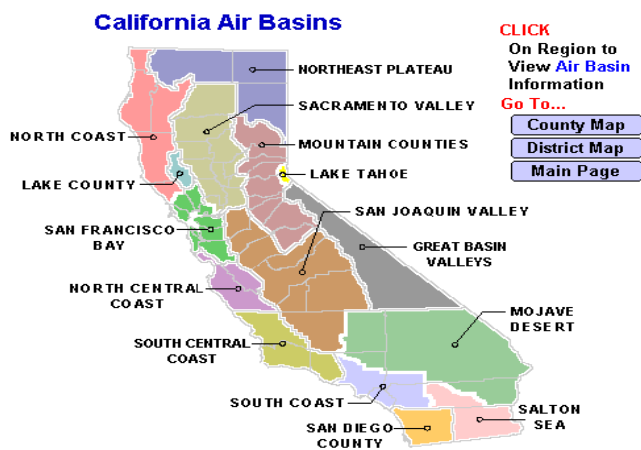
The State is divided into Air Pollution Control Districts (APCD) and Air Quality Management Districts (AQMD), which are also called air districts. These agencies are county or regional governing authorities that have primary responsibility for controlling air pollution from stationary sources. The following map is for informational purposes and shows the Air District Boundaries. This map can be used to access the County and Air Basin pages to view emissions data.

California Air Districts



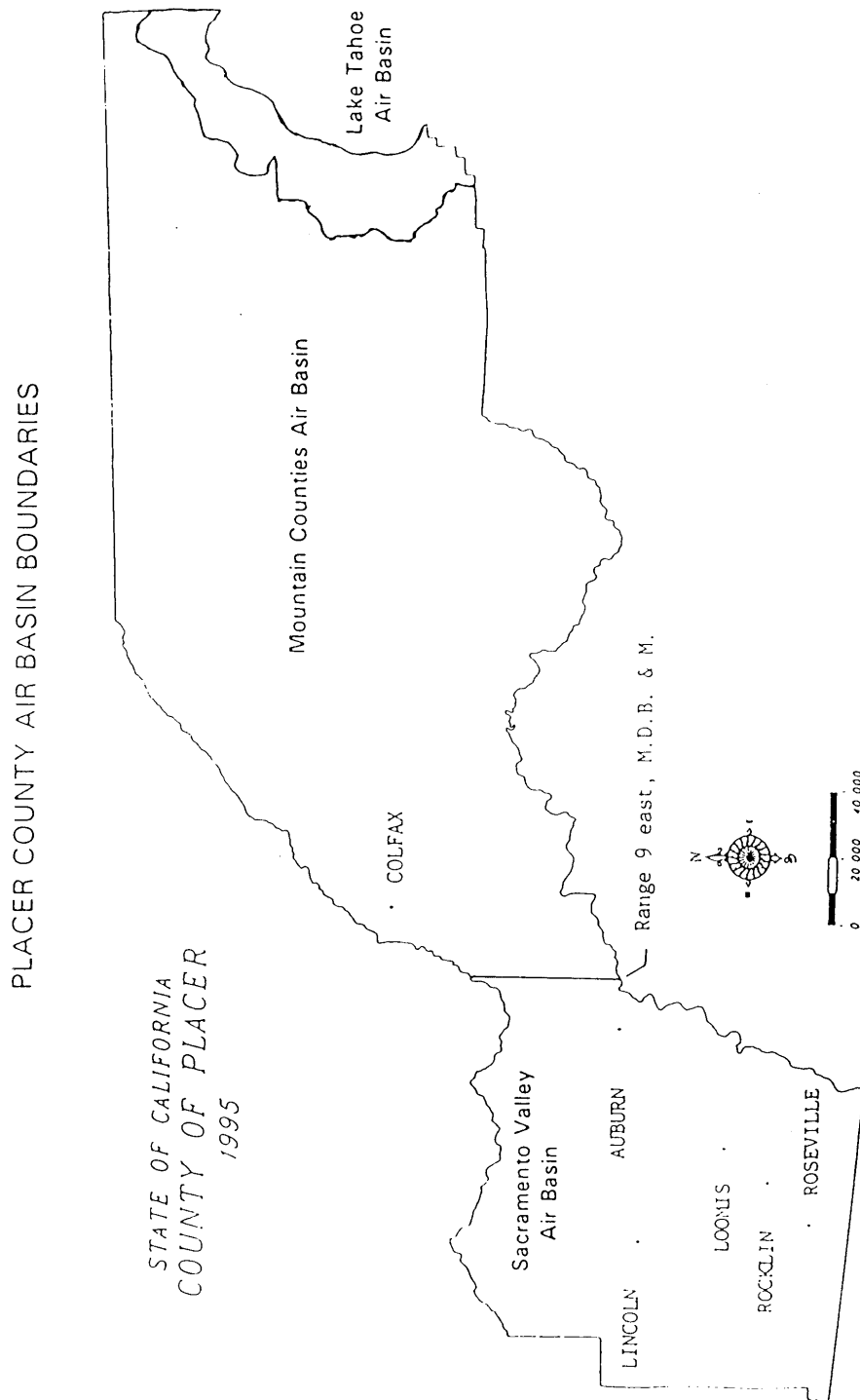
Attachment 4

California is divided geographically into air basins for the purpose of managing the air resources of the State on a regional basis. An air basin generally has similar meteorological and geographic conditions throughout. The State is currently divided into 15 air basins. The names of the basins are listed below on the state map.



California Air Basins and Counties	
AIR BASINS	COUNTIES
Great Basin Valleys	Alpine, Inyo, Mono
Lake County	Lake
Lake Tahoe	El Dorado, Placer
Mojave Desert	Kern, Los Angeles, San Bernardino, Riverside
Mountain Counties	Amador, Calaveras, El Dorado, Mariposa, Nevada, Placer, Plumas, Sierra, Tuolumne
North Central Coast	Monterey, San Benito, Santa Cruz
North Coast	Del Norte, Humboldt, Mendocino, Sonoma, Trinity
Northeast Plateau	Lassen, Modoc, Siskiyou
Sacramento Valley	Butte, Colusa, Glenn, Placer, Sacramento, Shasta, Solano, Sutter, Tehama, Yolo, Yuba
Salton Sea	Imperial, Riverside
San Diego	San Diego
San Francisco Bay Area	Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, Solano, Sonoma
San Joaquin Valley	Fresno, Kern, Kings, Madera, Merced, San Joaquin, Stanislaus, Tulare
South Central Coast	San Luis Obispo, Santa Barbara, Ventura
South Coast	Los Angeles, Orange, Riverside, San Bernardino

Attachment 5



ATTACHMENT 6

General Conformity of Federal Actions

“De Minimis” Thresholds

(Section 51.583(1) of the Federal General Conformity Rule)*

(1) The following rates apply in **non-attainment areas (NAAs)**:

	<u>Tons/Year</u>
Ozone (Vocs or Nox)	
Serious NAAs	50
Severe NAAs	25
Extreme NAAs	10
Other ozone NAAs outside an ozone transport region	100
Marginal and moderate NAAs inside an ozone transport region	
VOC	50
Nox	100
Carbon monoxide	
All NAAs	100
SO2 or NO2	
All NAAs	100
PM-10	
Moderate NAAs	100
Serious NAAs	70
Pb (Lead)	
All NAAs	25

(2) The following rates apply in maintenance areas:**

	<u>Tons/Year</u>
Ozone (Nox), SO2 or NO2	
All Maintenance areas	100
Ozone (VOCs)	
Maintenance areas inside an ozone transport area	50
Maintenance areas outside an ozone transport region	100
Carbon monoxide	
All Maintenance Areas	100
PM-10	
All Maintenance Areas	100
Pb	
All Maintenance Areas	25

* Federal Register, Vol. 58 No.228, 40 CFR Parts 6, section 93: and the applicable local air district’s adopted version of the Federal General Conformity rule.

** Areas that have attained the Federal air quality standard for a criteria pollutant

ATTACHMENT 7

**U.S. Forest Service, Tahoe National Forest,
Foresthill Ranger District
Placer County
Cavanah Multi-Resource Management Project
“De Minimis” Threshold Determination**

The de minimis threshold for ozone in a severe non-attainment area is 25 tons per year.

Activity	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
Harvesting	1.00	1.00	1.00				
Processing	.61	.61	.61				
Skidding	.48	.48	.48				
Loading	.47	.47	.47				
Hauling	5.39	5.39	5.39				
Mastication				.63	.63	.63	
Pile Burning				2.80	2.80	2.80	2.80
Underburning			16.29	16.29	16.29	16.29	16.29
Total Tons Per Year	7.95	7.95	24.24	19.72	19.72	19.72	19.09

Emissions by Activity in Tons Per Year

This chart represents harvest over three years and burning over five years. Due to varying meteorological conditions, burning could take longer.

Reference for Emissions Quantifications: NEPA Air Quality Analysis Desk Reference Guide, for both area and mobile sources.

Attachment 8

U.S. EPA's Prescribed Burning Background Document and Technical Information Document for Prescribed Burning Best Available Control Measures, September, 1992.

The Best Available Control Measures listed in the U.S. EPA's Prescribed Burning Background Document and Technical Information Document for Prescribed Burning can be used as mitigations measures.

1. Reduce pre-burn fuel loadings. Less fuel is consumed when the burn is conducted. This can include three of four fuel bed components. (There is very little in order to reduce the burning of the duff layer.)

Live Fuel Component

- burn outside the active growing season
- burn soon after timber harvest
- burn frequently (e.g., 3-year frequency versus 5-year frequency)

Small Fuel Component

- whole tree harvesting (removes limbs along with tree boles)
- burn frequently
- schedule underburns before litter fall

Large Fuels

- harvest before burning
- isolate the large fuels from the fire by burning the small fuel in piles

For rangelands, increased grazing to remove biomass in an effort to reduce fuel loading prior to burning.

2. Reduce fuel consumption.

Live Fuel Component

- burn during period of high fuel moisture
- burn during phenological stages when flammability is low (season of low flammability, high relative humidity)

Small Fuel Component

- burn when the litter layer is moist
- limit smoldering consumption by using a backing fire

Large Fuels

- burn when moisture content is very high
- use mass-ignition techniques that produce a short-duration fire

Duff Component

- burn when duff is wet
- reduce large fuel consumption (in conifer stands other than pine the amount of duff consumed is linked to the mass of large fuel consumed)

Attachment 8 (Cont.)

3. Reduce the number of acres to be burned from what could be burned. This can include using alternative treatment methods.

Alternatives

- no burn
 - manual/hand labor
 - chemical treatments
 - alternate mechanical treatment
 - 1) mastication
 - 2) chipping
 - 3) piling and scarification
 - 4) burying
 - 5) disking, plowing harrowing for rangeland residues
 - air curtain destructor although a combustion process offers four advantages over open burning
 - 1) increased amounts of oxygen are added to the fire;
 - 2) particulate matter and smoke are confined within the pit;
 - 3) particles are held in suspension in the incoming air stream long enough for essentially complete combustion;
 - 4) only a small land area is affected by heat (important for reforestation later).Disadvantages include:
 - 1) limited practicality in steep terrain;
 - 2) high handling cost of hauling materials to pit site;
 - 3) limited availability of roads for hauling material to site.
4. To reduce pre-burn fuel loading includes, firewooding and chipping.
 5. Keep burn piles small and minimize the amount of soil in them so surface water can pass through and the debris can dry quickly.
 6. Pile when the ground surface is dry (less soil compaction will take place and considerably less soil will end up in the piles).
 7. Allow material to dry first before piling, since the centers of the piles take a long time to dry.
 8. Piles that contain little soil and are constructed to allow some air movement will result in a burn that consumes significantly more of the debris and produces less smoke. More efficient burning and greater heat output will lift smoke higher, reducing smoke concentrations near the ground.
 9. Take steps to prevent stumps from burning.
 10. Use of different firing techniques as appropriate.
 11. Mop up for residual smoke.

The appropriateness of any of these techniques will depend on the resource management objective. In addition each burn should be evaluated on a burn-specific basis.

Potential Impacts of Fire Emissions on Public Health

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Abstract

Because of 100 or more years of active fire suppression in the wildland areas of the United States forests have become overgrown and unhealthy. These forests have dangerously high biomass loadings just waiting to fuel the flames of the next series of characteristically devastating wildfires. It has become critical to reestablish a more natural balance in the forest ecosystems. Many have suggested the key to improving forest health, as well as reducing threat to the life and property of many thousands of people who live in wildfire prone wildland/urban interface areas of the nation, is the reintroduction of prescribed fire. However, the reestablishment of healthy forests through the use of prescribed fire may be costly to public health if the resulting smoke is not managed properly. It is estimated that prescribed burning will increase ten to thirty fold in the next several decades. Emissions from increased use of prescribed fire have the potential to significantly impact air quality and public health. Where there is fire there is smoke, and smoke contains many harmful air pollutants. In addition to carbon monoxide, oxides of nitrogen, a variety of toxic hydrocarbons and other cancer causing organic compounds, emissions from biomass burning include significant amounts of particulate matter. Particulate matter (PM₁₀ --inhalable particles 10 microns in size or smaller) is an especially harmful air pollutant. Particles 10 microns in size or smaller are respirable. They readily bypass the body's normal upper respiratory defense mechanisms and can become lodged deep in the lungs. There they cause a variety of health effects. Perhaps of greatest concern, particulate matter exposure has been linked to decreased life expectancy (premature death), especially in the elderly. More than 90-95 percent of all particles from smoke are PM₁₀. In fact, 70-95 percent are actually smaller than 2.5 microns in size, i.e. PM_{2.5}, which many believe may be even more harmful to humans. Increased use of prescribed fire, to the extent suggested, has the potential to release many 100,000 tons of PM₁₀ and PM_{2.5} into the air each year. As a consequence, the potential impact of fire emissions on public health is staggering.

Introduction

In the wildland areas of the United States, many forests are overgrown and unhealthy because of 100 or more years of active fire suppression. Fire suppression contributes to greater biomass fuel loadings and these forests have dangerously high biomass loadings just waiting to fuel the flames of the next series of characteristically life threatening and economically devastating wildfires. It is estimated that 39 million acres in the National Forests system alone are at risk for catastrophic wildfire. Most land managers agree that most forests will burn, but it is difficult to determine when they will burn and with what intensity (Gascoyne 1996). As a result, it has become critical to reestablish a more natural balance in the forest ecosystems.

Many have suggested the key to improving forest health, as well as reducing threat to the life and property of many thousands of people who live in wildfire prone wildland/urban interface areas of the nation, is the reintroduction of low- to moderate-intensity prescribed burning (California Board of Forestry 1997, Mutch 1994). However, the re-establishment of healthy forests through the use of prescribed fire may be costly to public health if the resulting smoke is not managed properly.

Potential Emissions

Nationwide, an average of 5 million acres a year are treated by prescribed burning. In order to reestablish a more natural balance in the forest ecosystems, it has been suggested that prescribed burning be increased ten to thirty fold in the next several decades. If realized, this goal could pose a substantial public health threat. Where there is fire there is smoke, and smoke contains many harmful pollutants. Biomass burning emits many thousands of tons of water vapor and many thousands of tons of carbon dioxide--the main products of complete fuel combustion--but it also produces several tons of other kinds of emissions (table 1). In addition to carbon monoxide, oxides of nitrogen, a variety of toxic hydrocarbons and other cancer causing organic compounds, emissions from biomass burning include large amounts of particulate matter. While water vapor is primarily a visibility concern and carbon dioxide may have global warming implications, the remaining major emissions from biomass burning have the potential to significantly affect air quality and public health (table 2). For fireline personnel and individuals exposed to high concentrations of smoke, the emissions of greatest health concern are carbon monoxide, hydrocarbons (in the form of aldehydes and benzene compounds) and respirable particulate matter (Reinhardt and others 1994). However, the pollutant of greatest overall concern to the public is respirable particulate matter (PM).

Table 1. Major emissions and emission factors for biomass burning.

Emissions	Factor (lbs/ton)¹
Water vapor	500-1,500
Carbon dioxide	2,000-3,500
Nitrogen oxides	1-9
Carbon monoxide	20-500
Hydrocarbons	4-40
Particulate matter (PM ₁₀)	10-100

¹Assume a fuel loading of 2 tons/acre grassland and 15 tons/acre forested land to calculate total pounds of emissions per acre burned (California Air Resources Board 1997).

Biomass fuels when burned emit from 10 to 100 pounds of particulate matter per ton of fuel consumed (table 1). The actual amount released depends on the conditions under which it is burned and the kind and density of the fuel consumed. Nationwide, if more than 5 million acres a year are treated by prescribed burning, then about 573,000 tons of particulate matter (PM₁₀ -- particles 10 microns in size and smaller) are currently emitted annually (Ward and others 1991). If prescribed burning is increased by even 10 fold in the United States, then potentially more than 5,730,000 tons of particulate matter could be emitted each year. These numbers rival or

Table 2. Public concerns and health effects associated with emissions from biomass burning

Emission	Public concerns	Health effects¹
Water vapor	Visibility	-----
Carbon dioxide	Global warming	-----
Nitrogen oxides	Air pollution, health	Worsening of asthma, respiratory illness, and lung damage.
Carbon monoxide	Air pollution, health	Decreased motor skills and mental acuity, dizziness, nausea, headache, weakness, heart attack, death.
Hydrocarbons (acrolein, formaldehyde and benzene, and others)	Air pollution, health	Eye, nose and throat irritation, dizziness, headache, nausea, liver and kidney damage, chronic respiratory disease, reduced lung function, cancer.
Particulate matter (PM ₁₀)	Air pollution, health, visibility	Increased asthma attacks, aggravated bronchitis, reduced lung function, respiratory disease, possibly cancer, premature death.

¹Health effects observed in order of increasing concentration and/or prolonged exposure.

even exceed those for wildfires, which in 1994 alone burned more than 3.5 million acres in the United States and annually burn 2.5 million acres nationwide (Babbitt and others 1994). This is disturbing to air quality and public health professionals because particulate matter is an especially harmful air pollutant. It is the only criteria air pollutant that has been associated with premature death.

This paper discusses the nature of particulate matter air pollution, its causes, and why it is potentially harmful.

Particulate Matter Air Pollution

Definition

Particulate matter air pollution, often referred to as PM₁₀ or PM_{2.5}, is an air pollutant defined entirely by size. The size cut for particulate air pollution is based on human physiology. Particles 10 microns in size or smaller, i.e. PM₁₀, are respirable; that is, they readily bypass the human body’s upper respiratory defense mechanisms and can become lodged deep in the lungs (fig. 1). PM₁₀ also contains smaller sized particles. These include “Fine” PM, which has been defined as particles 2.5 microns in size and smaller, i.e., PM_{2.5}. Many have become concerned that while PM_{2.5} is a subset of PM₁₀--that is PM_{2.5} is found in PM₁₀-- these fine particles tend to penetrate the lungs more easily and deeply than those particles larger than 2.5 microns but smaller than 10 microns in size (fig.1). Because particulate matter is defined by size, it is a complex air pollutant made up of many different kinds as well as sizes of particles. This makes PM as an air pollutant very different from other criteria pollutants, such as carbon monoxide (CO) and sulfur dioxide (SO₂), which have specific and clearly defined chemical compositions.

In addition, particulate matter air pollution is made up of both primary particles; those released directly into the air, and secondary particles. Secondary particles are formed in the atmosphere from precursor components very much like ozone (O₃), which is formed from oxides of nitrogen and volatile hydrocarbons in the presence of sunlight and moisture.

Sources

There are many different sources of particulate air pollution. Primary particulate emissions include dust from paved and unpaved roads, construction and demolition operations, wind erosion of disturbed soil, and agricultural operations. They also include combustion products, such as carbon, which comes from residential wood burning, prescribed burning for both forest management and agricultural practices, and motor vehicle tail pipes, especially diesels. Secondary particles are typically formed from products of combustion. Secondary particulate emission sources include fossil fuel combustion sources such as automobiles and trucks, small engines, stationary industrial processes and power generation facilities. Other secondary sources result from vegetative fuel burning such as residential wood burning, and biomass burning from forest management and agricultural practices.

Health Effects

A variety of health effects have been associated with particulate air pollution exposure in humans, especially in sensitive individuals. These have been well established by epidemiological studies conducted throughout the world (Dockery and others 1993, Greenburg and others 1967, Knight and others 1989, Martin, 1964, Pope and others 1991, Samet and others 1981, Stern and others 1989). These health effects include an increase in the number and severity of asthma attacks (Whittemore and Korn 1980, Schenker 1993), the aggravation of bronchitis, reduced lung function (Pope and others 1991, Pope and Kranner 1993, Stern and others 1989), the development of lung disease (Schwartz 1993), and possibly the development of cancer. Health effects have also been observed in occupational settings. Lung function was decreased from pre-shift to both mid-shift and post-shift in fireline personnel exposed to smoke during normal work shifts (Betchley and others 1997). Similarly, significant decreases in lung function and an overall increase in airway “irritability” or responsiveness were observed in wildland/forest firefighters from pre-season to post-season (Liu and others 1992). Perhaps of greatest concern, particulate exposure has also been linked to decreased life expectancy (premature death), especially in older people who have pre-existing heart and/or lung disease (Dockery and others 1993, Schwartz, 1993).

National Ambient Air Quality Standards (NAAQS)

To protect the public from harmful levels of particulate matter exposure, national ambient air quality standards (NAAQS) for respirable particles have been set ([table 3](#)). The previous air pollution indicator was 10 microns in size, i.e., PM₁₀, which was determined by human physiology. However, more recently, considerable attention has been focused on “Fine” particles, i.e. PM_{2.5}. This is because these smaller particles tend to penetrate the lungs more easily and deeply than those particles larger than 2.5 microns but smaller than 10 microns in size

(fig. 1). There is also concern because the kinds of particles that make up $PM_{2.5}$ are largely derived from combustion processes and they may have the potential to be inherently more toxic than the larger coarse particles (fig. 2).

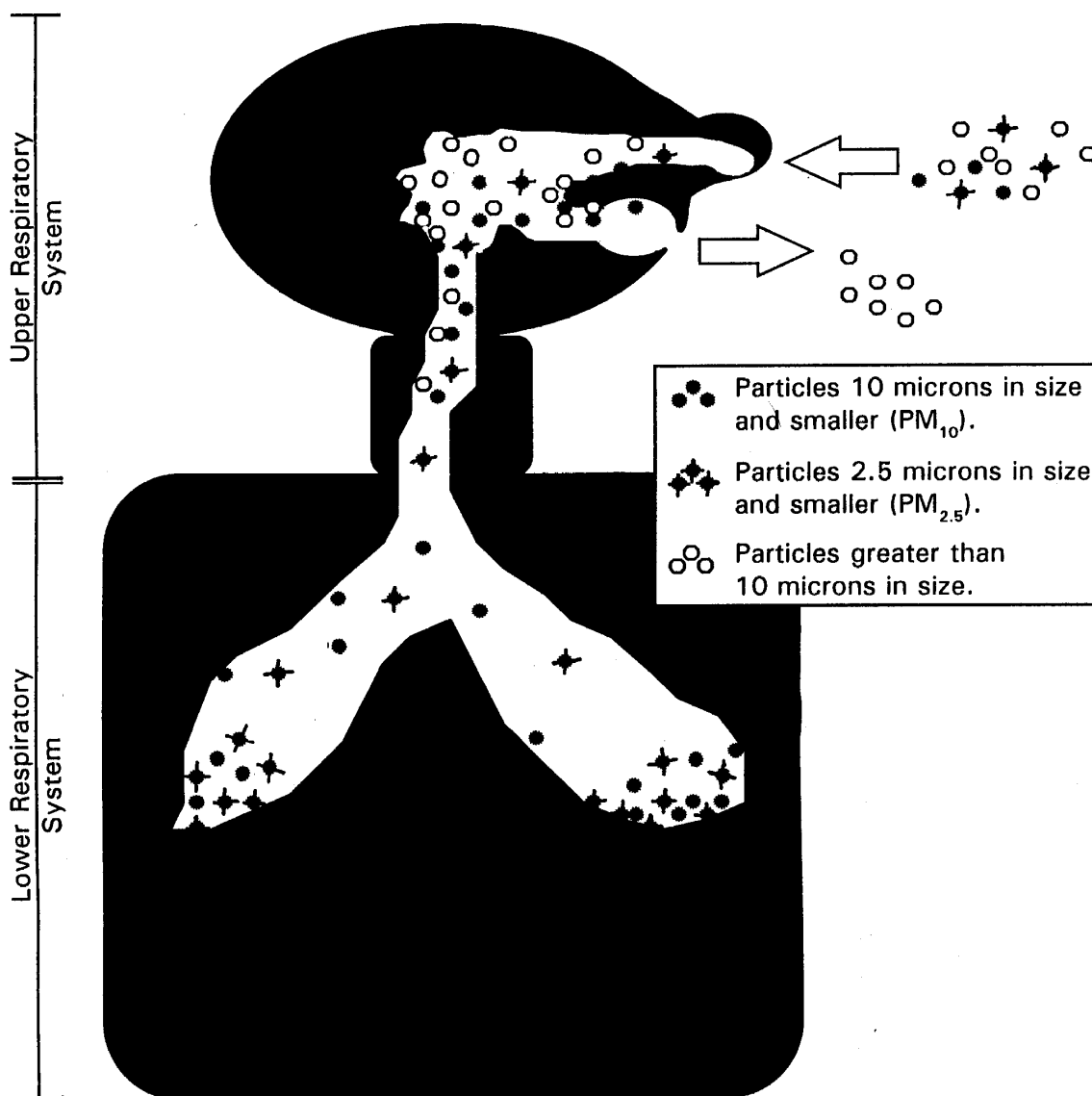


Figure 1. Particles larger than 10 microns in size are trapped by the body's normal upper respiratory defense mechanisms and are expelled from the body by sneezing, coughing, and other physical means. However, respirable particles 10 microns in size and smaller (i.e. both PM_{10} and $PM_{2.5}$) bypass the body's defense mechanisms and become lodged deep in the lungs where they are not as easily removed. $PM_{2.5}$ is a subset of PM_{10} —that is $PM_{2.5}$ is found in PM_{10} —and it tends to penetrate the lungs more easily and deeply those particles larger than 2.5 microns but smaller than 10 microns in size.

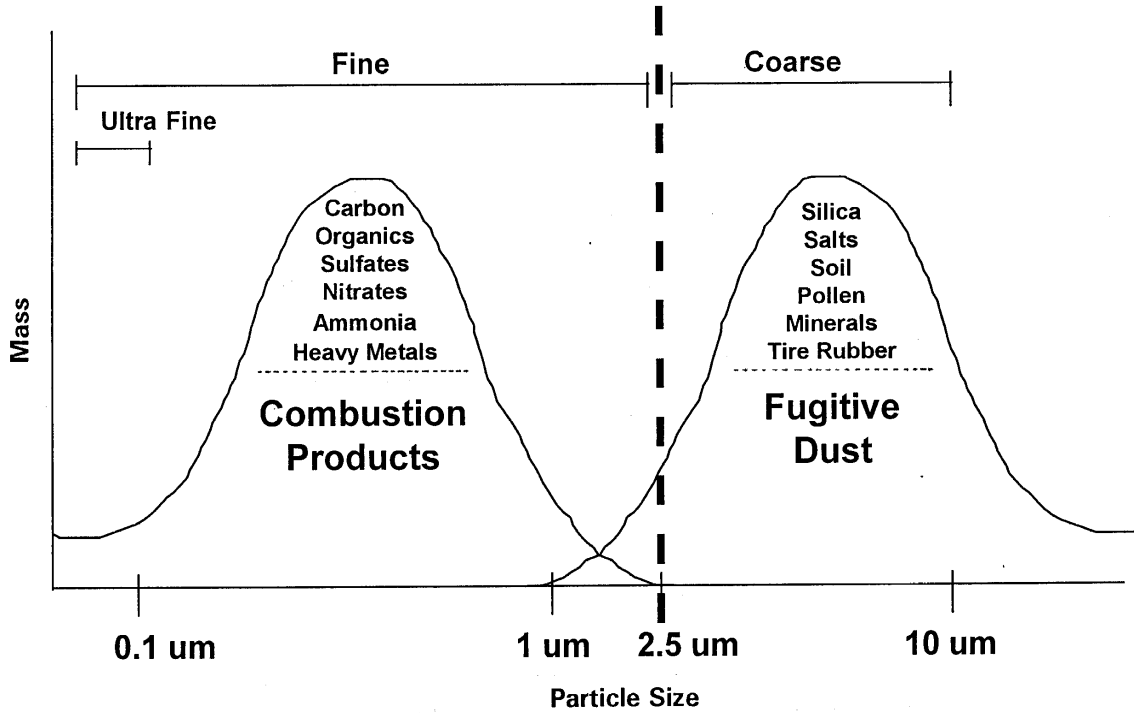


Figure 2. The size and composition of coarse and fine particulate matter air pollution.

The U.S. EPA has recently promulgated NAAQS to address both 24-hour and annual levels of PM_{2.5}, as well as 24-hour and annual levels of PM₁₀ (table 3). The recent emphasis on particulate air pollution, and more specifically PM_{2.5}, should be of considerable concern for land managers and resource agencies because 90-95 percent of all particles from smoke are PM₁₀. In fact, anywhere from 70-95 percent of the total mass can actually be smaller than 2.5 microns in size, i.e., PM_{2.5}. Increased use of prescribed fire has the potential to release not only many 100,000 tons of PM₁₀ into the air each year, but many 100,000 tons of PM_{2.5} as well. These emissions could impact areas that currently attain the national ambient air quality standards for particulate matter air pollution and could worsen existing non-attainment situations.

Table 3. National ambient air quality standards (NAAQS) for respirable particulate matter (U.S. EPA 1996).

Previous ¹			Newly Proposed		
PM ₁₀	24 hour	150 Φ g/m ³	PM ₁₀	24 hour ²	150 Φ g/m ³
PM ₁₀	Annual	50 Φ g/m ³	PM ₁₀	Annual ³	50 Φ g/m ³
				-and-	
			PM _{2.5}	24 hour ⁴	65 Φ g/m ³
			PM _{2.5}	Annual ⁵	15 Φ g/m ³

¹No averaging of monitored values or percentile exceedance allowances.

²The 3-year average of 99th percentile at each monitor.

³The 3-year arithmetic average of monitored values with no spatial averaging.

⁴The 3-year average of 98th percentile at each monitor.

⁵The 3-year arithmetic average of monitored values with spatial averaging.

The California Example

The majority of Californians already breathe, on a routine basis, harmful levels of particulate air pollution from many different sources. This situation is in part due to the large population of California and resulting human activities. However, it is also due to the state's climate and topography, which often inhibits the dispersion of air pollutants. There are 10 areas in California that exceed the previous National Ambient Air Quality 24-hour Standard of $150 \mu\text{g}/\text{m}^3$ for PM_{10} . This represents more than 5 out of the 14 air basins, encompasses fully one third of the state in geographic area, and affects more than 60 percent of all Californians (fig. 3).

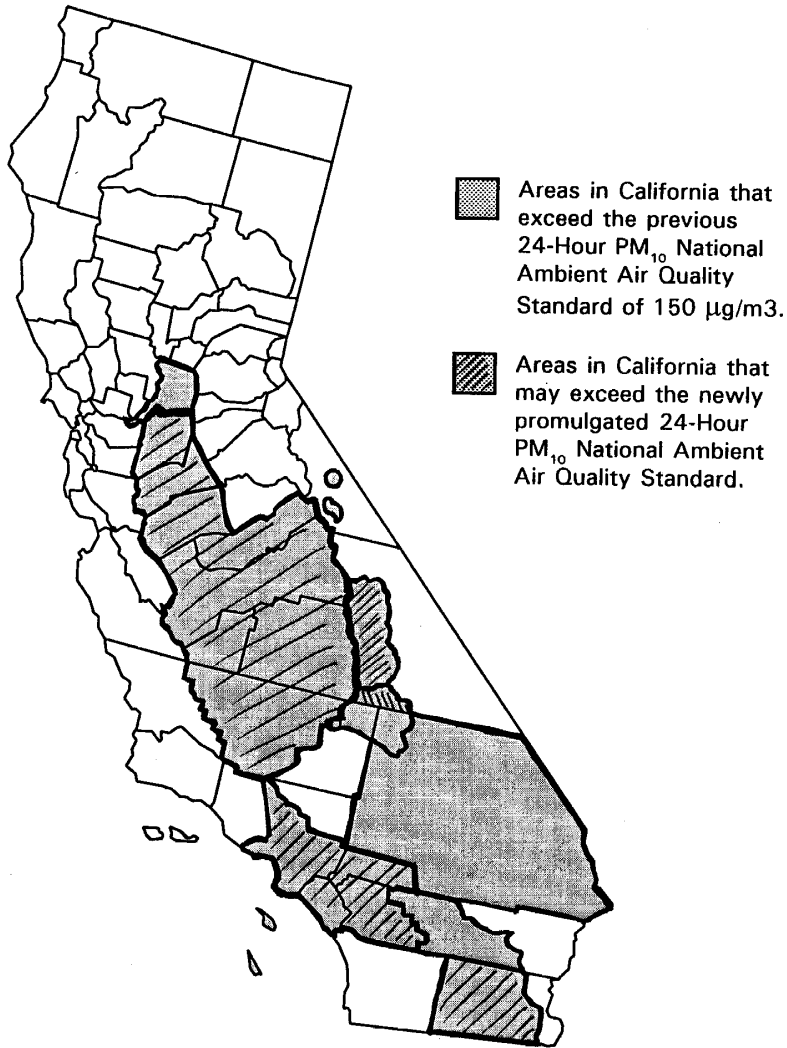


Figure 3. Areas in California that exceed the previous 24-hour PM_{10} National Ambient Air Quality Standard (NAAQS) of $150 \mu\text{g}/\text{m}^3$ and areas in California that will likely exceed the newly promulgated PM_{10} 24-hour NAAQS. The newly promulgated PM_{10} 24-hour NAAQS is still set at $150 \mu\text{g}/\text{m}^3$, but is overall somewhat less stringent because of new statistical considerations for defining nonattainment. Area classifications resulting from the newly promulgated NAAQS for $\text{PM}_{2.5}$ are still pending the outcome of extensive nationwide $\text{PM}_{2.5}$ air quality monitoring efforts.

While the number of federal nonattainment areas in California may be reduced to five, because of statistical allowances under the newly promulgated 24-hour PM₁₀ NAAQS, the majority of Californians are still exposed to unhealthy particulate air pollution 24-hour PM₁₀ levels that are greater than 150 $\mu\text{g}/\text{m}^3$. Depending on ambient conditions, particulate matter emissions from biomass burning may affect air basins hundreds if not thousands of miles away from the original source of the smoke. The areas in California potentially affected by smoke and emissions from increased prescribed burning would be, in many cases, the same areas that already contain dangerously high levels of particulate pollution from a variety of sources. Thus, the concept of increasing the amount of particulate matter air pollution in these air basins is difficult for air quality professionals to fathom.

Discussion

In addition to many other kinds of harmful emissions, biomass burning emits many thousands of tons of PM₁₀ and PM_{2.5}. With nationwide concern about particulate matter air pollution, the idea of increasing the amount of smoke and harmful emissions in the air we breathe is difficult to consider. To increase biomass emissions contradicts the fundamental mission of air quality professionals, which is “to promote and protect public health through the effective and efficient *reduction* of air pollutants...”

Although human exposures to smoke from increased prescribed burning may be mitigated somewhat through effective burn planning and smoke management practices, the potential air quality and public health threat that emissions may pose can not and should not be underestimated. There is no question that the potential impact of fire emissions on air quality and public health is staggering. This is especially true in areas of the western United States, including California, where extensive urban populations already contribute large amounts of air pollutants and natural topography and climate routinely inhibit the dispersion of air pollutants. However, air quality professionals also have, as part of their mission, an obligation to “...promote and protect human welfare and ecological resources in recognition and consideration of effects on the economy”. This means that air quality professionals, public health specialists, land managers and resource agencies have in reality the same mission—that is to find the balance between human health and welfare and wildland/forest ecosystem viability.

Suppression of wildfire provides a short-term benefit to air quality by reducing the amount of biomass material that would have burned if the fire were allowed to run its course. However, fire suppression techniques have in part replaced a natural background level of frequent, less intense fires with less frequent, large, catastrophic wildfires. In many cases what is prevented from burning today may simply end up burning next year. Because it is widely accepted that fire is a natural part of wildland ecosystems, it has been argued that it is better to take control and burn these same fuels under prescribed burning conditions. Many would argue as well, that in addition to the issues of fireline personnel and public safety, emissions from wildfires are greater than those from more “natural” prescribed fire regimes. This theory is debatable, although it is true that wildfire emissions might be more concentrated in space and time relative to more controlled and dispersed smoke from prescribed burning. However, inherent in all of these arguments is the assumption that air quality and public health must be affected under either scenario. This is not necessarily true.

The best solution from an air quality perspective is to reduce biomass loadings and prevent catastrophic wildfires, yet not increase fire emissions at all. This scenario is largely feasible but it would require a great deal of financial resources, creativity and commitment on the part of land managers and resource agencies. However, even with mechanical removal of biomass fuels, it is well understood that prescribed burning may still be needed since it might be the only effective tool available in some wildland areas of the nation. The challenge is to reconcile the *guaranteed* emissions from prescribed fire with the emissions that *might*, albeit with increasing certainty, result from wildfires.

Conclusions

Wildland/forest health is currently compromised and resulting wildfires are devastating, expensive, and intolerable. Prescribed burning is one effective tool to bring these ecosystems back into balance and to minimize wildfire occurrences. However, the potential air quality and public health impacts of fire emissions from prescribed burning are great. Clearly, there is a need to explore other options to reduce biomass fuel loadings without having to burn them. But if prescribed burning is used, we need to recognize that it is critical to use effective strategies to minimize human exposure to the resulting smoke. Lastly, land managers and resource agencies must work closely with air quality professionals and public health experts to ensure impacts to air quality and public health are minimized or perhaps even avoided all together.

Acknowledgements/Disclaimer

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Monitoring Fire Emissions to Notify the Public - Mobile Monitoring

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Abstract

Wildland fires are on the increase. One of the major fire pollutants in the smoke is Particulate Matter (PM). The Environmental Protection Agency (EPA) has set 24-hour-average and annual- average health based standards for PM10 (particulates equal to or smaller than 10 microns) at a concentration level of 150 and 50 micrograms/ meter cube respectively. Recently, the EPA has also announced new standards for PM2.5. Eighty percent of the wildland fire emissions are PM2.5.

The state has a network of fixed monitoring stations that are located in populated areas and are used for National Ambient Air Quality Standards (NAAQS) compliance. Physically, most of the regulatory monitors are heavy, not easily transportable to remote locations, and require an outside power source. Wildland fires generally occur in remote areas but the pollutants can be transported by wind to populated or sensitive areas. Unfortunately, remote areas are rarely monitored and public notification of pollutant levels rarely occurs. In contrast, nuisance calls from the public are on the increase.

A DataRAM DL2000 has been purchased through the funds provided by the InterAgency Air and Smoke Council (IASC). The monitor weighs only 7 Ibs, is easily transportable, provides real time data and does not require an outside power source. The monitor can be employed at or near the burn site and data can be used to notify the public. This data will not be used for NAAQS compliance. A burn protocol will have to be developed and used for quality control and data consistency.

Introduction

Guay and Kennedy (1997) submitted a paper to the Science and Technology sub-group of the Wildland Fire Air Quality Policy Group. The paper suggested the development of monitoring protocols before conducting monitoring.

A team gathered at Portland on February 4-5, 1997 to develop a protocol for monitoring smoke emissions from prescribed understory burning activities on federal lands in Oregon, Washington and Northern California currently managed under the 1994 President's Plan (lands inhabited by the Northern Spotted Owl).

The total fuel consumption and fire intensities found in prescribed understory burns are less than those found in a typical clear cut slash burn or pile burn. The smoke is less buoyant and produces higher ground level smoke concentrations in the vicinity of the burn. It is difficult to find a best monitoring location because topography and weather conditions may change over the course of the burn, and the burn may last for days or weeks. The paper describes the protocol developed for the northern spotted owl, associated problems and modifications needed.

The Problem

Part of the difficulty in developing a plan is that different combinations of burn types and monitoring objectives can lead to entirely different monitoring protocols. The plan to monitor smoke impacts include short term monitoring of fire events with portable or semi-portable instruments following an established protocol.

Monitoring Instruments

Some monitors are certified as Federal Reference Method Monitor (FRM) while others are not but do show comparable results. The FRMs are closely associated with SLAMS. These are generally large, not easily transportable, require a line power source and are labor intensive. The portable monitors are ambient samplers and an OSHA or indoor sampler. Ambient sampler is filter based and is similar to FRM sampler while the OSHA monitor correlates back scattering of light off the particles in the gas stream to produce a concentration. The monitors can be:

- **Real Time** e.g TEOM, DataRAM, Beta Gauge
- **Lag Time** e.g. Mini-Vols, Hi-Vols

Only DataRAM is discussed here. DataRAM combines an OSHA type nephelometer with a portable particulate sampler to provide a real time continuous monitor with a filter collection capability (See Figure 1). The limitation is that these types of monitor may not be as accurate as FRMs and the data may not be certified for compliance purposes.

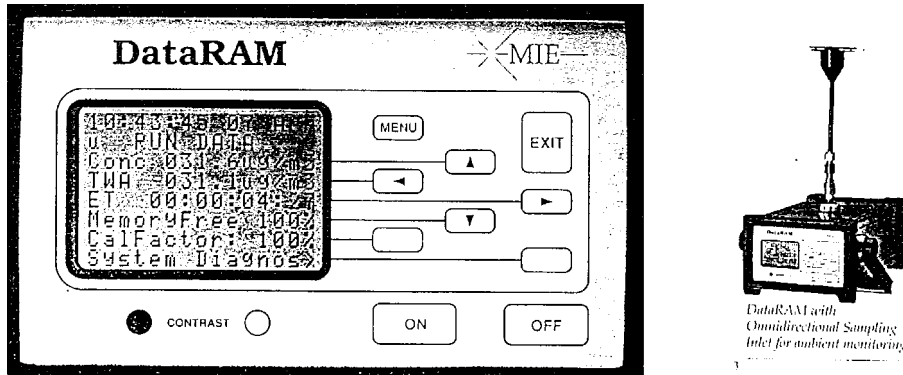


Figure 1. DataRAM digital display of data

The Protocol

Monitoring technologies are recommended for **real time** PM/Community/event and visibility/class I/event monitoring and for **lag time** PM/Community/event monitoring.

The recommended protocol for **real time** includes the use of at least two MIE Inc. Model DR-2000 DataRAM PM samplers. The samplers should be placed in community/Class I area that have the greatest likelihood of impact based on the screening procedures (see Figure 2 & 3). The samplers can be placed separately in two different locations

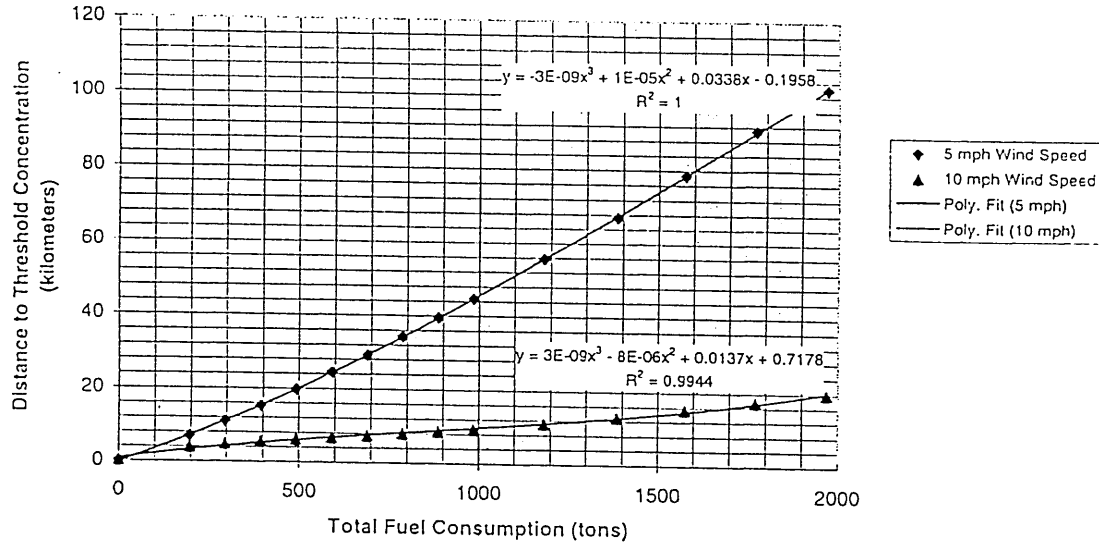


Figure 2. Relationship between Fuel Consumption and Distance to Nuisance threshold of $30 \mu\text{g}/\text{m}^3$ (Adapted from CH2M Hill 1997)

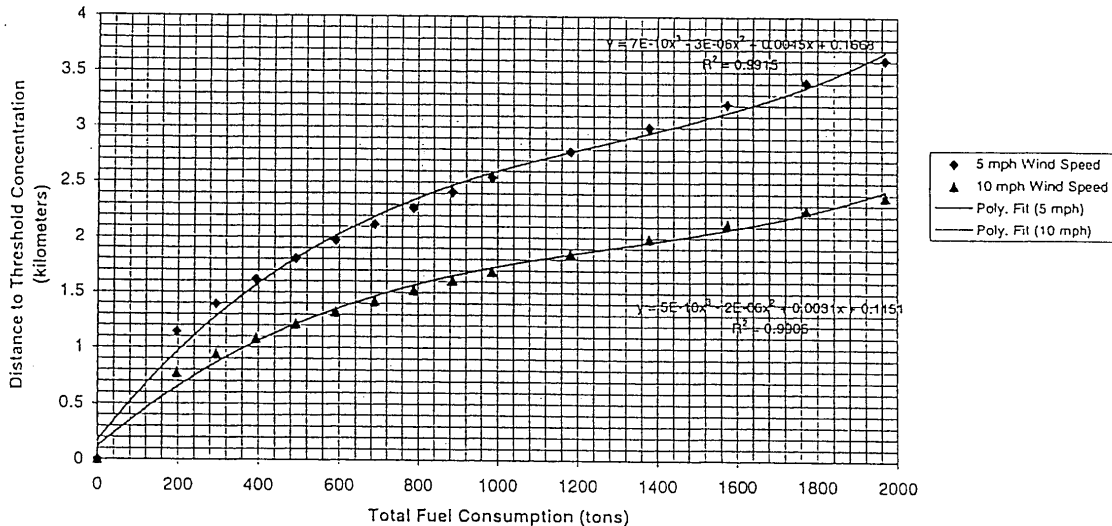


Figure 3. Relationship between Fuel Consumption and Distance to NAAQS Threshold Concentrations of $150 \mu\text{g}/\text{m}^3$ (Adapted from CH2M Hill 1997)

The recommendation for **lag time** includes the use of at least five Airmetrics Mini-Vol samplers. This includes two samplers at each site for continuous 24-hrs-per-day sampling and one back up sampler. The two Mini-Vols at each location should be operated 12 hour per day on a rotating basis.

These should be deployed 7 days prior to the burn and should stay deployed during the burn and up to 48 hours after the burn.

Guay and Kennedy (1997) suggested that "monitoring plan can be adjusted to what makes sense. Sampling duration can be adjusted to shorter periods to facilitate advisory updates. Where immediate operational decisions and public notification are being based on the data results, only real time monitoring information should be used. In a post burn data analysis mode, the entire data set can be used to assess smoke dispersion patterns, validate air quality models, fine tune action plans to improve public notification systems, and revise smoke management plans".

IASC Mobile Monitoring Venture

Interagency Air and Smoke Council (IASC has agreed to locate three mobile units to monitor PM10/PM2.5 at three Province Air Quality Specialist duty stations. The NPS, BLM, EPA and USFS have contributed funds to purchase a DR2000 DataRAM. The equipment will be located at Willows with the Northern Province Air Quality Specialist.

The monitor weighs less than twelve pounds and is easily transportable to remote locations. It does not require an outside power source It will be used to monitor PM 10/PM2.5 concentrations for wildland fires. Based on the results the public will be notified accordingly.

Differences Between Wildland Fire and NAAQS Compliance Monitoring

The protocol being discussed is a recommendation for conducting particulate matter concentrations in support of wildland fire operations. It is not intended for compliance with National Ambient Air Quality Standards (NAAQS). The difference between these two types is:

- Monitoring for NAAQS compliance requires a long term fixed network which meets the State and Local Air Monitoring Station (SLAM) criteria.
- Monitoring for NAAQS compliance requires the use of federal reference or equivalent methods.
- States are responsible for deployment of SLAMS network. A state may decide to locate a SLAMS or special purpose monitor (SPM) in any populated area where repeated or anticipated levels of smoke exposure is high. Should the NAAQS be violated at a fixed SLAMS or SPM site due to smoke impacts, that violation is considered valid under the Clean Air Act.

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Using Airborne Remote Sensing to Map Near-Ground Smoke at Night

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Abstract

After prescribed burning becomes a widespread practice in California ecosystems, the wildland/urban interface problem will shift from fire to fire and smoke. Smoke will eventually become the most serious problem. For instance, smoke on the ground at night poses a serious hazard to transportation. Visibility reductions caused by smoke or a combination of smoke and fog have been implicated in multiple-car pileups, numerous physical injuries, heavy property damage, fatalities, and litigation. A Xyberion intensified multispectral video camera capable of amplifying light up to 15,000 times was mounted in a Beech Craft King Air aircraft and flown at approximately 1,500 m (5,000 ft) above ground level over an experimental burn site in western Alabama. The purpose of the project was to test the hypothesis: If smoke can scatter headlight beams from automobiles, then smoke can also scatter moonlight and can be observed from an aircraft. Smoke movement was recorded for two night-time prescribed fires timed to coincide with moonlight and clear sky and near calm weather conditions. Selected images for the first night, March 20-21 1997, are presented to demonstrate the technology. The results also show night-time smoke movement is exceedingly difficult to predict. Small variations in elevations such as gaps in ridges were critical to smoke movement. Successful smoke dispersion models must include terrain on a scale that enables realistic prediction of smoke travel.

From Wildfire to Prescribed Fire

The catastrophic wildfires in California during recent years have led to rethinking of fire suppression strategies. Fire prevention practices in many California ecosystems over the past 50 years have allowed buildup of flammable plant material. Destructive stand replacement fires and fires that destroy dwellings are linked to the heavier fuel loadings.

In addition, fire is recognized as a fundamental ecological process in many forest and rangeland ecosystems throughout the U.S. Ecotypes depend upon fire for health, reproduction, and protection from invading species. The USDA Forest Service supports an increase in the use of prescribed fire on National Forest System lands and supports its use on non-Federal lands to maintain and restore the health of fire-dependent ecosystems. Thus, prescribed fire is seen as having the benefits of restoring fire-dependent ecosystems and reducing or eliminating fuel loadings that support catastrophic wildfire.

Southern Experience with Prescribed Fire

The southern states are leaders in using prescribed fire and understanding its effects. About 200 million acres of forest land are found within the 13 states that make up the South--states roughly south of the Ohio River and from Texas eastward. Although these states have about 24 percent of the land area, they comprise 40 percent of the forest land in the United States.

From 6-8 million acres per year are treated with prescribed fire. Southern land managers have found that prescribed fire can economically reduce fuels, remove species that compete for nutrients, enhance habitat of endangered species, lower danger of wildfires that can destroy fragile ecosystems, reduce commercial fiber, and threaten urbanized areas.

California and the South

Although there are vast differences between California and the South regarding terrain, climate, vegetation, and population distribution, there are also a number of similarities. Both regions have extensive coastlines and similar land/sea circulations, mountainous areas, wildland/urban interfaces, road systems, retirement communities, and tourist activity.

Therefore, both regions face some similar fire management problems. To reduce fuels by prescribed fire, we must consider human health and safety; community protection; forest, range, and watershed health; wildlife habitat needs; and plant community restoration and protection.

The Smoke Problem

Where there is fire, there is smoke. The effects of prescribed fire on air quality are a serious concern. Visibility reductions caused by smoke or a combination of smoke and fog have been implicated in multiple-car accidents, numerous physical injuries, heavy property damage, and fatalities. Many of these incidents have led to litigation. As population increases and the numbers of tourists driving to resort areas increases, the number of accidents related to smoke and fog can only be expected to increase.

The mild, mostly snow and ice-free winters make the California climate ideal for the development of retirement communities. Thousands of older people, many with respiratory problems, have relocated into these communities. Many of these retirees have little or no experience with forestry practices and therefore may not be receptive to frequent incursions of smoke into their communities.

Federal agencies can face litigation for damages implicated by smoke or face costly stop-action injunctions that waste resources and lose favorable weather opportunities for prescribed burning. Furthermore, it may be easy to motivate a public to take precautions in the face of smoke from a monster fire. Public cooperation might be difficult during smaller, seemingly insignificant, and more frequent prescribed burns that can produce locally serious smoke incidents.

Land managers face a dilemma. They must either treat forests more frequently with prescribed fire to reduce wildfire threat to nearby dwellings while increasing the threat to air quality, or they may preserve air quality by not burning and increase the threat of destructive wildfire. Thus, once prescribed burning becomes a widespread practice in California, the wildland/urban interface problem will become one of both fire and smoke.

Remote Sensing of Smoke at Night

Existing information on smoke, particularly the behavior of smoke at night, is largely anecdotal. The body of scientific information necessary to serve as a base for wise management decisions and sound regulatory guidelines is lacking. Mistakes made at one location can lead to unnecessary penalties imposed on prescribed burning at other locations.

Although smoke in the daytime can be a nuisance when it moves into sensitive areas and a hazard to transportation when it drifts across roadways, the most severe impacts of smoke near the ground occur at night. Small amounts of smoke from smoldering heavy fuels can become trapped near the ground and carried several miles in slow moving air without much dispersion. In addition, smoke entrapped within moist shallow valleys can initiate or enhance local fog. Visibility impairment by smoke or smoke/fog over roadways can create serious hazards to transportation.

The most efficient way to observe a smoke plume moving near the ground at night is from the air. It was hypothesized that the smoke that scatters headlights from vehicles to create visibility hazards would also scatter moonlight and thus be visible from the air.

During January-March 1997, a project was conducted to test if smoke could be observed from an aircraft equipped with a light-enhanced night vision video imaging system. The project included representatives from three USDA Forest Service groups: the Remote Sensing Applications Center (RSAC), Southern Region Fire and Aviation, and the Southern Research Station Smoke Management Team. The project was conducted at the Oakmulgee Wildlife Management Area located on the Talladega National Forest in western Alabama. The site was selected to account for typical terrain in the South, safety, and the absence of light sources. The Oakmulgee Wildlife Management Area has the following characteristics:

- Valley to ridge elevation differences typical of the Piedmont (60-100 m: 200-300ft).
- Major stream valleys that extend 16 km (10 mi) without crossing important roadways.
- A major highway located 13 km (8 mi) from the site separated from all drainage by a system of ridges.
- Few alien light sources (yard lights, lights from homes or automobiles) that would interfere with the light-sensitive equipment.

The field operations were restricted to clear skies and near calm winds during three eight-night windows timed to coincide with the full moon in January, February, and March 1997. This approach insured data collection during maximum moonlight. However, only four nights, one in January, one in February, and two in March, met the meteorological criteria.

A Xybion intensified multispectral video camera³ was mounted in a Beech Craft King Air aircraft (figs. 1, 2). The Xybion camera combines both intensified and multispectral video camera technologies to provide uniform multispectral imaging over a wide range of ambient light levels. The two key features of this device are the capacity to boost ambient light energy up to 15,000 times and the filtering ability that allows viewing of objects over several spectral bands.

³ Mention of trade names or products is for information only and does not imply endorsement by the U.S. Department of Agriculture.



Figure 1--Beechcraft King Air Aircraft used for the smoke detection project.

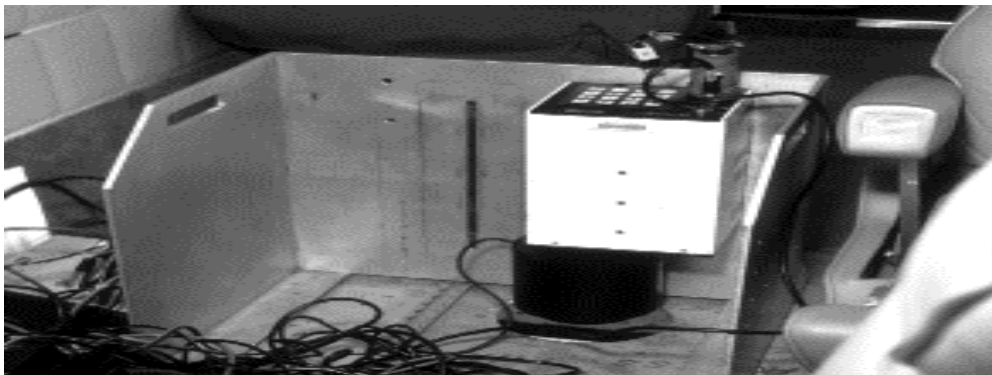


Figure 2--Xybian multispectral video camera installed in the aircraft.

In addition, since the Xybian camera provides for a standard video signal output, an RS-170 compatible monitor was used on the aircraft so "real time" imaging could be examined and adjusted while storing to S-VHS tape. This feature allowed the operator on board the aircraft to make video signal gain adjustments when possible to achieve the highest contrast settings for video recording.

Video imagery was stored via a super VHS data recorder. Global Positioning System (GPS) information for the aircraft was superimposed on each frame of the recording tape.

Only one night during the January window was suitable for operations. The mission was

flown at about 1,500 m (5,000 ft). A 40-acre night burn was started at about 21:00 Central Standard Time (CST). The heat column generated by this fire-lofted smoke above the surrounding ridges and it was carried off by prevailing winds.

Although unsuccessful at remote sensing of smoke trapped near the ground, the January mission provided some useful lessons. First, The Xybion camera was operated without filters at 100 percent gain to detect the smoke in moonlight. Near infrared radiation coming from ground material and passing through the smoke exceeded moonlight reflected from the smoke. Smoke was rendered nearly invisible. As the Xybion did not have an infrared cut-off filter to reduce reflected infrared that was penetrating the smoke, one was purchased, mounted to a 12 mm lens, and installed with the filter wheel set to an open aperture where no filter was in place. It was expected that this modification would cutoff near infrared light and improve relative contrast between smoke and background terrain features.

Second, the prescribed fire generated too much heat and lofted the smoke above the valley inversion. Alternative methods to generate much smoke without inversion-penetrating heat would have to be found. A new smoke-generating method was designed using smoke bombs and hay bales soaked with diesel fuel.

During the February operations window, the equipment was mounted and tested in a 30 m (100 ft) tower located on the Oconee National Forest in central Georgia (fig. 3). The smoke source was a single bale of hay soaked with diesel fuel and ignited. Once burning vigorously, the fire was extinguished. The smoldering hay produced copious amounts of smoke with minimal heat production. This test showed improved contrast between smoke and background.



Figure 3--Tower used for equipment verification.

During March 20-21, 1997, the project returned to the Oakmulgee National Wildlife Refuge near Centerville, Alabama. Forest Service ground personnel burned 50 bales of hay soaked in diesel fuel. In addition, they detonated 60 smoke bombs that had a burn lifetime of about 2 minutes

each. The fire was started at 21:45 CST along a road that followed a northeast-southwest oriented stream basin (fig. 4).

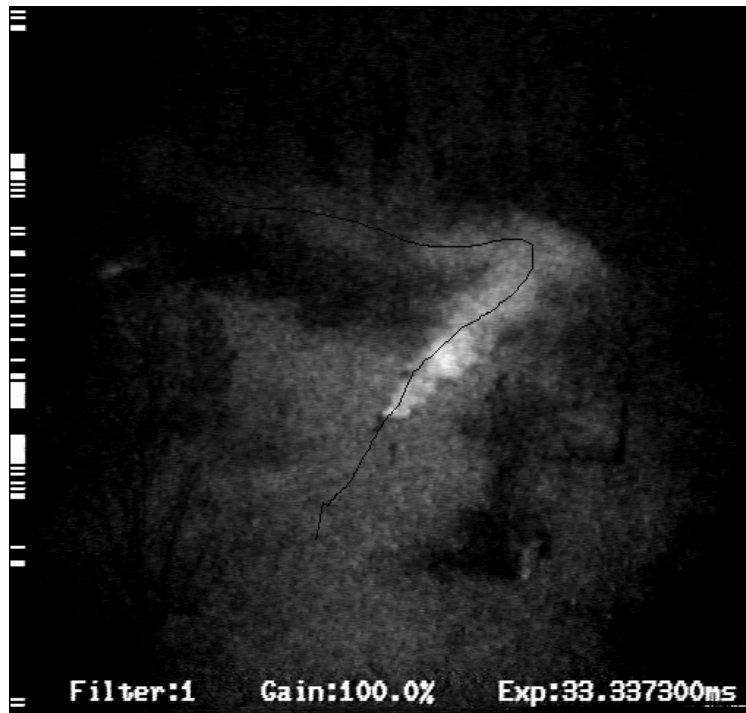


Figure 4. Intensified infrared imagery

Aircraft overflights at about 1,500 m (5,000 ft) commenced at 21:48 CST and continued at 7 minute intervals for 2 hours. Video images from the Xybian intensified multispectral camera equipped with the hot mirror were stored in S-VHS format.

Images from the S-VHS tape were captured by using a TARGA-Plus frame grabber. These images were stored as TIFF image files in a OPTIMAS image analysis system. It was necessary to enhance the contrast of the images. The contrast was stretched by using an output lookup table.

Results

Enhanced images of the first successful remote imaging of smoke near the ground at night were taken on March 20, 1997 (fig. 5). The field of view is 1,400 m from left to right and is compressed to 1,050 m from top to bottom with an aspect ratio for analog video of 1.335.

The burn site is identified by the bright area near the top of figure 5a. The bright area was smoke illuminated by a combination of scattered moonlight and diffused light from flaming material. The valley road leading from the lower left of the image to the burn site is clearly visible. Other roads follow ridge lines; one to the west of the burn site and the other barely visible to the southeast near the right edge of the image. These roads connect south of the burn site, enclosing the drainage area. The drainage area exits past the burn site toward the top of the figure.

The origin of the secondary sources of light surrounding the burn site and extending toward the bottom right of the figure are not known for certain. The sources could be bare ground beneath hardwood trees that had not yet leafed-out. Roads are strips of bare ground. In addition, dogwood

trees were in full bloom. Dogwood blossoms reflect in visible light. Ground observers reported that flowering dogwoods could be easily seen in moonlight.

By 22:02 CST (figure 5b), the smoke plume has moved up the valley along the valley road. Although the brightest areas extended from the burn site toward the center of the image, dense smoke was observed all along the road to where it ascended the southern ridge of the valley near the bottom of the image.

After 22:15 CST, the smoke turned up a side valley and crossed the southern perimeter road. An example is the image for 22:58 CST (fig. 5c). Elevations surrounding the drainage basin were above 150 m (480 ft) except at one location where they were 130 m (430 ft). It was at this location where smoke exited the valley.

The pattern of smoke movement continued through 23:00 CST. Figure 5d (23:51 CST) shows smoke shortly after the burn was concluded. The bright areas at the burn site were vehicle headlights. The dissipating smoke plume continued to flow up the side valley. The image shows no evidence of smoke along the lower half of the valley road. However, ground crews reported dense smoke along that stretch of road.

Discussion

The Talladega Smoke Study has proven a technology that uses an intensified video camera for airborne remote sensing of smoke moving near ground at night. This technology is critical for smoke management because airborne observations are the only means by which the movement of the entire smoke plume can be observed, understood, and the only source of observations adequate to validate numerical models for ground-level nocturnal smoke movement and dispersal.

The windfield near the ground at night is extremely complex in both space and time. Winds are channeled by small variations in elevation. Therefore, smoke within such windfields can be carried to unexpected places. This complexity points to a need for a smoke sensing technology that can be used routinely under starlight as well as moonlight to monitor smoke movement at night.

A comparison of ground observations with smoke images collected from the airborne remote sensing part of the Talladega project revealed that some shallow layers of dense smoke escaped detection. Some smoke was hidden beneath partially closed vegetation canopies. However, we noted the apparent absence of smoke over the southern half of the valley road in the imagery. Furthermore, smoke that turned up the side valley and crossed the gap in the ridge vanished from the imagery toward the end of the project. It was passing over a clear-cut field and should have been clearly visible.

In order to detect dense smoke confined to shallow layers, it is necessary to increase the gain of the intensifier from 15,000 to 80,000. Furthermore, the Xybion camera was red-extended. An improved camera should have extended blue sensitivity in the ultraviolet (400-500 nm) portion of the spectrum. These are the wavelengths that are scattered mostly by smoke.

As California land managers shift from fire prevention strategies to the use of prescribed fire for restoring and preserving the health of ecosystems, the wildland/urban interface problem will shift from fire to fire and smoke. As judicious application of prescribed fire reduces the threat of catastrophic wildfire, smoke will become the primary obstacle to fire-base land management which is the current situation facing forest managers in the southern United States.

Successful widespread application of prescribed fire will require knowledge of smoke concentration, location, and movement so that appropriate reaction strategies can be implemented if

necessary. The Talladega experiment shows that smoke moving near the ground at night can be remotely imaged from an aircraft. Thus, it may be possible to monitor nocturnal smoke events operationally. Such data will be useful for implementing reaction strategies and for validation of numerical smoke movement and dispersion models.

Acknowledgements

Loan of the Xybion intensified multispectral camera by the USDA Forest Service Remote Sensing Applications Center and training of Smoke Management Team personnel by Paul Maus is gratefully acknowledged.

Ken Forbus and Tim Giddens of the Southern Research Station Smoke Management Team are acknowledged for technical and electronic contributions to the project.

Ground crews at the Talladega National Forest in Alabama, Oakmulgee Ranger District, under the leadership of Syd Coleman made success possible.

Implementing Prescribed Fire in Non-Attainment Areas Through a Memorandum of Understanding

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Introduction

The San Joaquin Valley Unified Air Pollution Control District (Air District) along with Federal and State natural resource protection agencies (NRFPA) are in the process of developing a memorandum of understanding (MOU) for implementing a prescribed fire program that satisfies U. S. Environmental Protection Agency (USEPA) required Best Available Control Measures (BACM). The Air District committed to an MOU development. In its 1994 Serious Area PM-10 Plan and 1997 PM-10 Attainment Demonstration Plan (PM-10 ADP), the Air District is required to implement BACM to reduce PM-10 emissions from a variety of open burning sources and an MOU is listed as one of the recommended strategies for prescribed burning by the USEPA Prescribed Burning Guidance document.

The Air District is designated as a serious non-attainment area for PM10 and prescribed burning is currently regulated through District Rule 4103 "Open Burning". The PM-10 ADP commits the Air District to developing a BACM level prescribed burning rule scheduled for implementation before the end of 1998. The prescribed burn rule will be applicable to all burns; however, it is anticipated that "routine" burn permits will be secured for small acreage, light fuel loading, simple burns anticipated to release low to moderate levels of emissions. The MOU is intended to address air quality concerns and coordination from large acreage, "high" fuel loading, and complex burn projects with the potential to release moderate to large amounts of emissions.

The MOU is being developed to encourage voluntary use of BACM level practices rather than waiting for adoption of a prescribed burn rule. Given the planned increase in prescribed burning, the NRFPA suggested development of an MOU with BACM level controls. The MOU will re-enforce BACM methods for emission reduction, serve as a burn activity timing and coordination tool between federal and state NRFPA, provide emission inventory estimates, improve coordination and communication between NRFPA and Air District staff, and enhance public education and awareness. The responsibilities agreed to in the MOU provide mutual assurances that each signatory party will make every effort to meet the obligations contained in the MOU. Development of an MOU as an alternative approach to the existing "command and control" burn permit issuance process will allow a better chance for users of prescribed fire to meet their resource objectives while still meeting Federal Clean Air Act mandates.

Purpose

The draft MOU has been designed to establish a formal working relationship between the Air District and NRFPA. In addition, it will provide the mechanism for NRFPA involvement in air quality improvement efforts that can incorporate research efforts of the participating agencies.

An MOU can also provide compliance with State Implementation Plan (SIP) commitments and Federal Clean Air Act Amendment mandates including the possibility of General Conformity compliance.

MOU Background

The Interagency Air and Smoke Counsel (IASC) is an informal gathering of air regulators and resource agencies that serves as a statewide clearinghouse for attempts to resolve issues related to prescribed fire and air quality. It is within this setting that the idea of an MOU first developed. The San Joaquin Valley Unified Air Pollution Control District offered to lead an effort to develop a "model MOU" with interested NRPAs within their jurisdiction. The Air District realized early that active involvement of the NRPAs would be crucial in providing true opportunities for emission reductions given the wildfire potential in California. The NRPAs have professional and research staff with significant expertise in fire science and subsequent knowledge that can provide techniques to reduce emissions.

Summary of the Draft MOU

General Provisions

- The NRPAs continue to assist the Air District in the development and implementation of measures concerning prescribed burning in future mandated air quality plans.
- The NRPAs and the Air District communicate and provide each other with the data and/or information necessary to complete the objectives of the MOU and the Workplan.
- The Air District and the ARB have the ultimate responsibility for adoption of the SIP, including the component pertaining to prescribed burning.
- The MOU does not supercede, alter, or modify the intent or applicability of any statute, rule, regulation, or ordinance of the Air District or the NRPAs.
- The MOU may be amended, modified, or supplemented by mutual agreement by the signatories or their successors. Also, allow termination of participation in the MOU by any party (ies) by giving 30 days notice in writing to each party (ies) to the MOU.

Joint Undertakings by the NRPAs and Air District

- Develop visible smoke and PM-10 controls and emission reduction techniques in a Workplan to satisfy Federal BACM requirements.
- Participate in the development of methodologies to estimate criteria pollutant emission factors, emission inventories, and emission budgets.
- Identify, evaluate, and incorporate the use of smoke emission and dispersion models to predict, to the extent possible, prescribed fire behavior.
- Evaluate the effectiveness of visible smoke and PM-10 reduction techniques to ensure public health and safety, and to prevent exceedances of the national ambient air quality standards.

- Participate in the development and utilization of standard methodologies to reduce wildfire emissions through prescribed burning in order to remain within emissions budgets and satisfy General Conformity requirements.
- Establish parameters which will permit prescribed burning on ARE announced "No Burn Days" or allow ignited prescribed burns, whether management or naturally ignited, to continue during ARB announced "No Burn Days".
- Participate in the Prescribed Fire Incident Reporting System (PFIRS) program to coordinate and report prescribed burning activity within the San Joaquin Valley Air Basin.
- Pursue enforcement actions for any violation of applicable burning regulations.

NRFPA Responsibilities

- Best Available Management Practices (BAMPS) - Utilize NRFPA expertise to develop and submit BAMPS to the Air District for incorporation into the BACM SIP. It is hoped that BAMPS can be developed and implemented which demonstrate emission reductions that equal or exceed BACM to be used to prevent, reduce, and/or minimize adverse air quality.
- Burn Plans - Prepare and submit burn plans with supporting documentation to the Air District for prescribed burning in a timely manner in advance of the prescribed burn. To ensure compliance with the conditions of the MOU and to assist the District in its record keeping requirement, NRFPAs should forward a post-burn report upon completing a prescribed burn project to the Air District.
- Communication - Notify the Air District as soon as possible in the event of unforeseen meteorological occurrences resulting in impacts on populated and other sensitive areas. If these types of impacts occur, the NRFPAs should be allowed to take appropriate actions to minimize and reduce the impacts. Documentation describing the effectiveness of actions should be forwarded to the District as expeditiously as possible.
- ARE Meteorological Forecasts - Observe all ARB announced 72/48/24 hour meteorological advisories and restrict prescribed burning to designated periods unless an exemption has been approved by the Air Pollution Control Officer (APCO). Per State law, exemptions can be allowed when denial of burning would threaten imminent and substantial economic loss.
- Burn Permits - Conduct prescribed burning and issue permits within areas of their jurisdiction as described in the MOU. Observe the requirements of the California Public Resources Code section 4291.
- Enforcement - The NRFPAs should refer enforcement actions to the Air District for any violation of applicable burning regulations.

Air District Responsibilities

- Control Measures - Coordinate the development of BACM for inclusion in the SIP. There are 8 minimum BACM components: 1) smoke dispersion evaluation, 2) public education and awareness, 3) burn planning, administration and authorization, 4) ensuring

burner qualifications, 5) surveillance and monitoring, 6) emission inventory, 7) emission reduction techniques, and 8) state oversight. Review and adopt the list of approved BACM measures.

- Burn Plans - Assist in development of the air pollutant emission reduction component of burn and smoke management plans to meet BACM requirements. Receive, review and approve burn and smoke management plans in timely manner. Where appropriate, require revisions to minimize the potential of adverse air quality impacts on populated or sensitive areas. Require timely Air District response with failure to respond to burn and smoke management plans resulting in automatic District approval as submitted.
- Reporting Requirements - Prepare annual reports using ARB and Air District air monitoring stations data and reports provided by the NRPAs prescribed burning to estimate air quality improvements.
- Enforcement - Provide all enforcement needed to meet EPA and SIP requirements and incorporate technical assistance provided by the NRFPAs. Provide appropriate enforcement of the adopted measures.

Signatories

At this point in the process the following agencies have participated in the development of the Draft MOU and are expected to be signatories to the final.

- San Joaquin Valley Unified Air Pollution Control District.
- U.S. Department of Agriculture, U.S. Forest Service (Sequoia, Sierra, and Los Padres National Forests).
- U.S. Department of Interior, National Park Service (Sequoia and Kings Canyon National Parks).
- U.S. Department of Interior, Bureau of Land Management (Bakersfield, Hollister, and Folsom Resource Areas).
- U.S. Department of Interior, U.S. Fish and Wildlife Service.
- U. S Department of Interior, Bureau of Indian Affairs
- California Department of Forestry and Fire Protection (Ranger Units in the Air Districts jurisdiction).
- California Department of Parks and Recreation (Park and Recreation areas in the Air Districts jurisdiction).
- California Air Resources Board.

Draft Work Plan

While the MOU outlines the general agreements necessary to develop a cooperative effort, a work plan will add the level of detail necessary to spell out expected procedures within BACM requirements. The BACM requirements are: 1) Smoke Dispersion Evaluation; 2) Burn Planning, Administration, and Authorization; 3) Burner Qualifications; 4) Public Education and Awareness; 5) Surveillance and Enforcement; 6)Emission Inventory; 7) Emission Reduction Techniques; 8) State Oversight and; 9)Economic Assessment. The Work Plan is expected to develop an agreement for the procedures and technical methodologies for each of the BACM

components and due to the technical nature of the document it will require frequent amendments. Some of the technical components being considered for implementation are; 1) Prescribed Fire Incident Reporting System (PFIRS) to enhance communication and scheduling, 2) NFSPUFF as a possible transport modeling technique, 3) Monitoring methods and techniques, 4) Analysis methods, 5) Cooperative public awareness strategy and, 6) Emissions tracking via PFIRS

Summary

The interested parties to the MOU are undertaking this effort to develop procedures for increasing the use of prescribed fire in a way that will not exacerbate the Air Districts ability to attain compliance with air quality standards. As a serious PM-10 non-attainment area the Air District is required by the Federal Clean Air Act Amendments of 1990 to implement BACM to achieve the National Ambient Air Quality Standards. The MOU provides the mechanism to implement BACM with opportunities for NRFPA input and expertise in the process.

Broad-Scale Fire Severity in the Dynamic Global Vegetation Model

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Abstract

Because ecosystem structure and function are often constrained by disturbance, it is critical to include disturbance processes in Dynamic Global Vegetation Models (DGVMs) used to assess the potential broad-scale impact of global change. The ability to simulate the impact of changes in fire severity on vegetation and the atmosphere has been a central focus in the development of our MC1 DGVM. MCFIRE, a broad-scale fire severity model we are currently developing as part of our DGVM, simulates the occurrence and impacts (i.e., vegetation mortality and fuel consumption) of relatively infrequent and extreme events historically responsible for the majority of fire disturbance to ecosystems. In our MCFIRE model, the occurrence of severe fire is strongly related to climatic conditions producing extended drought as indicated by the low moisture content of large dead fuels. Because of constraints posed by currently available datasets, we have been developing our DGVM on a relatively fine-scale data grid at a landscape-scale, but we soon will implement the model at regional to global scales on much coarser data grids. Constraints on the broad-scale impact of severe fire imposed by the fine-scale heterogeneity of fuel properties will be represented in our coarse-scale simulations by sub-grid parameterizations of the fire behavior and effects algorithms for distinct land surface types. In preliminary tests of the MC1 DGVM on the fine-scale data grid, the accurate simulation of ecosystem structure and function under current climatic conditions is dependent upon fire effects in the model simulations, especially at the interface between forest and grassland.

Introduction

Simulating broad-scale disturbance is the *terra incognita* of fire modeling (Simard 1991). Nevertheless, there is an increasingly critical need to relate wildland fire to broad-scale issues such as the potential impact of global climate change on terrestrial ecosystems (Gardner and others 1996, Ryan 1991). The composition and function of ecosystems are constrained by disturbance, and ecosystem change often occurs as abrupt transitions caused by changes in disturbance regimes (Davis and Botkin 1985). Global climatic change is predicted to significantly alter disturbance patterns (Overpeck and others 1990) and thus ecosystem change could be sudden and extensive. Fire regimes may be especially sensitive to climatic change (Clark 1990), and changes in the frequency and severity of fire could have greater impacts on the rates of ecosystem change than more direct effects of global warming. In addition to the impact on terrestrial ecosystems, more severe fire regimes could also result in a greater transfer of carbon to the atmosphere, thus contributing even further to global warming and ecosystem instability (Neilson and King 1992, Neilson and others

1994). The ability to simulate vegetation change and feedbacks to the atmosphere due to changes in fire severity is a key requirement for the broad-scale Dynamic Global Vegetation Models (DGVM) currently under development for use in global change impact assessments (McKenzie and others 1996).

In this paper we describe the MCFIRE model, a broad-scale fire severity model we are developing for use in our MC1 DGVM. MCFIRE contains four requirements for simulating changes in broad-scale fire severity under a changing climate. The first is the dynamic simulation of fuel constraints on fire behavior, that is, changes in fuel moisture and fuel loading with changes in climate. Fuel moisture is directly tied to climate, but controls on the dynamics of fuel loading are more indirectly related through climatic effects on vegetation productivity and decomposition (Agee 1993).

The second requirement is to dynamically simulate the various impacts of fire that determine fire severity (Simard 1991). Unlike physically-based measures of fire behavior (e.g., rate of spread, fireline intensity, etc.) and the various indices of fire danger, measures of broad-scale fire severity are necessarily system-specific. For example, the impact of fire severity on ecosystems includes the portion of the vegetation killed, the amount of biomass consumed, and the loss of soil nutrients. Emissions of different gaseous and particulate species are an appropriate measure of the impact on the atmosphere.

The third requirement of MCFIRE is the ability to predict the timing and location of severe fire events. For the purposes of global change impact assessment, it was critical not to impose fire frequencies on our model, but rather let them be an emergent property of the simulations. In order to simulate the broad-scale impact of fire, it may not be necessary to model fire behavior and effects across the entire range of fire intensity and extent that occur on a landscape. The vast majority of fires, while important in the maintenance of ecosystem properties and the spatial heterogeneity of landscapes, may nevertheless be insignificant from the standpoint of broad-scale fire severity. Only a very low percentage of fires are, in fact, responsible for a very high percentage of the fire-caused damage to ecosystems, the atmosphere, and society (Strauss and others 1989). These infrequent, high-intensity fires of large extent are commonly associated with a specific, synoptic-scale sequence of weather events that greatly reduces the spatial heterogeneity in fuel flammability and further increases the burn connectivity of the landscape through wind-driven enhancement of fire spread (Bessie and Johnson 1995, Huff and Agee 1980, Johnson 1992, Pickford and others 1980, Swetnam and Betancourt 1990).

Finally, since our DGVM will eventually be implemented at grid cell resolutions of 10 km or greater, spatial heterogeneity at the sub-grid level in factors like fuel moisture and loading had to be included in our coarse scale simulations of fire behavior and effects. Because the relative heterogeneity of fuels and weather in space and time is a fundamental determinant of fire severity, simplifying assumptions of homogeneity characteristic of fire modeling systems at finer levels of scale (McKenzie and others 1996) are not appropriate in a broad-scale fire severity model.

MC1 DGVM Overview

We are developing the MC1 DGVM to assess the potential impact of global climate change on ecosystem structure and function at wide range of spatial scales from the landscape to the globe. The DGVM consists of three linked models ([fig 1](#)): a biogeographical rule-base model based on concepts developed for MAPSS, the mapped atmosphere-plant-soil system (Neilson 1995); the

Century biogeochemical model (Parton and others 1992); and the new MCFIRE model.

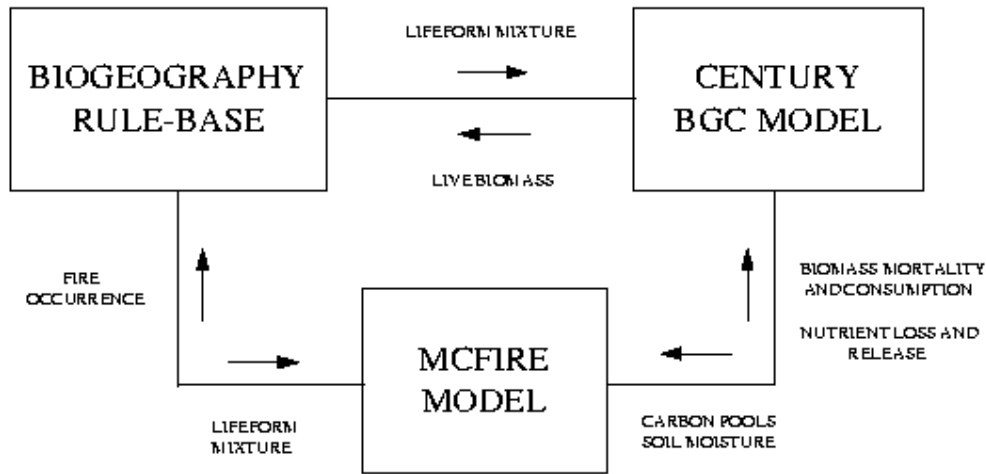


Figure 1 -- Linkages and feedbacks among the three modules comprising the MCI Dynamic Global Vegetation Model

The rule-base distinguishes 21 different vegetation formations according to climatic zone, woody and grass life-form dominance, and vegetation density. Thresholds of thermal and effective moisture indices are used in the rule-base to predict climatic zone and lifeform dominance (e.g., temperate evergreen needleleaf conifer with C3 grass, or subtropical deciduous shrub with C4 grass) at a pixel. Threshold values of the aboveground plant biomass simulated by the Century biogeochemical model are used to position the vegetation type along a gradient of vegetation density from desert grassland to shrub or tree savanna to closed forest. Vegetation succession in the DGVM is modeled as shifts in the relative dominance of individual lifeforms. Succession is driven by both fire disturbance and long-term trends in the climatic input data relative to the climatic thresholds in the rule-base model.

Century is a biogeochemical model that simulates production, carbon and nutrient dynamics, and hydrology for grassland, savanna, and forest ecosystems. The primary feedback from the MCI biogeographical rule-base to the Century model is the specification of lifeform mixture for the purpose of parameterizing the biogeochemical model.

The MCFIRE model simulates the occurrence, behavior, and effects of severe fire in the DGVM. The occurrence of a simulated fire in the model triggers a re-evaluation of the vegetation class by the MCI biogeographical rule-base. Fire effects (i.e., plant mortality and live and dead biomass consumption) are estimated by MCFIRE as a function of simulated fire behavior and vegetation structure. Fire effects feed back to the Century model as adjustments to levels of the different live and dead carbon and nutrient pools.

The MCFIRE Model

Model Inputs

Data inputs to the MCFIRE model (fig. 2) are the same long-term time-series data used by the entire DGVM. These data include average monthly temperature, total monthly precipitation, average monthly relative humidity, and average monthly wind speed. In addition to climatic data, MCFIRE requires the lifeform mixture provided by the MC1 biogeographical rule-base, and the aboveground live and dead biomass and soil moisture provided by Century.

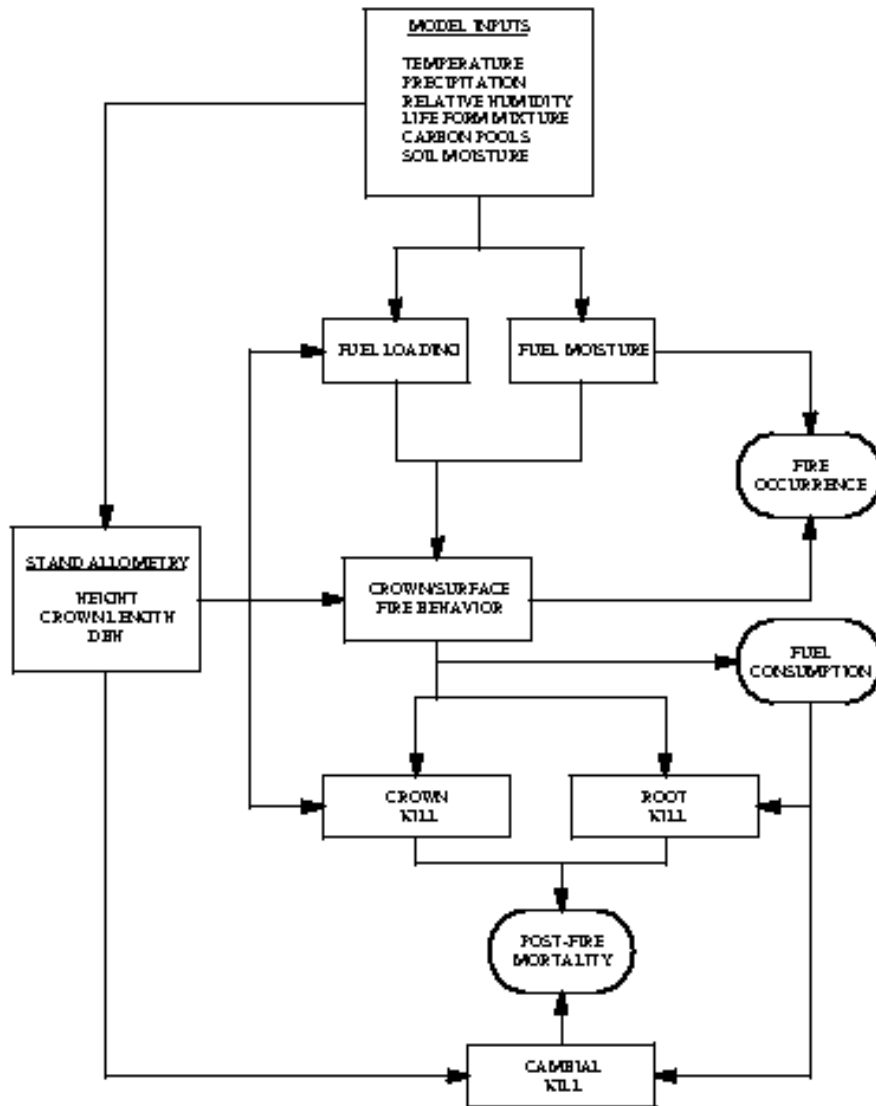


Figure 2 -- Flow diagram for the MCFIRE module.

Fuel Moisture and Loading

The percent moisture and weight per unit area of fuels are estimated for four dead fuel classes (i.e., 1-, 10-, 100-, and 1000-hr fuels) and three live fuel classes (i.e., overstory leaves and understory woody and herbaceous vegetation). We use a combination of the Canadian Fine Fuel Moisture Code (Van Wagner 1987) and the National Fire Danger Rating System (Bradshaw and others 1983) equations to estimate the moisture content of the four dead fuel classes. Live fuel moisture is estimated from an index of plant water stress (Howard 1978). The index is a function of the percent soil moisture simulated by the Century hydrology submodule.

The MCFIRE model obtains estimates of live and dead biomass in a few aboveground pools from the Century model. The biomass is partitioned into fuel classes using life-form specific allometric functions that first estimate average plant dimensions (e.g., bole diameter and canopy height) from biomass, and then the allocation of biomass into different structural components (e.g., leaves, small and large branches, and boles) that correspond to the different fuel size classes.

Potential Fire Behavior and Effects

Both surface and crown fire behavior are simulated in MCFIRE. Surface fire behavior is modeled using the Rothermel (1972) fire spread equations as implemented in the National Fire Danger Rating System (Bradshaw and others 1983). Crown fire initiation is simulated using Van Wagner's (1993) formulation. Indices of fire behavior (e.g., fireline intensity, rate of spread, and the residence time of flaming and smoldering combustion) are used in the simulation of fire effects in terms of plant mortality and fuel consumption.

Crown mortality is a combined effect of crown scorch and cambial kill simulated in MCFIRE. Crown scorch is a function (Peterson and Ryan 1986) of lethal scorch height (Van Wagner 1973) and the average crown height and length as determined by the allometric functions of biomass. Cambial kill is a function (Peterson and Ryan 1986) of the duration of lethal heat and the bark thickness estimated from average bole diameter. A function of crown scorch and cambial kill (Peterson and Ryan 1986) is used to estimate the percentage mortality of the crown biomass.

The mortality of live roots due to a simulated fire is estimated from the depth of lethal heating in the soil. The depth of lethal heating is modeled as a function of the duration of flaming and glowing combustion at the surface (Peterson and Ryan 1986). We derived the depth vs. duration relationship from empirical data presented by Steward and others (1990).

In the case of a simulated crown fire, we assume live leaves and fine branches are completely consumed. Otherwise, live leaves are consumed and live fine branches are transferred from live to dead carbon pools in Century in proportion to the percentage mortality of the crown. The large branch and bole biomass of killed trees or shrubs and the biomass of killed roots are also transferred to dead carbon pools. The consumption of dead biomass is modeled as functions of the moisture content of the different fuel size classes (Peterson and Ryan 1986). Dead fuel consumption feeds back to Century as reductions in the dead carbon and nutrient pools.

Fire Occurrence

The potential fire effects simulated in the model do not feedback to the Century model unless MCFIRE determines that a fire has occurred. The occurrence of fire in the model is triggered by threshold values of extended drought and a joint probability of fire ignition and spread ([fig. 3](#)). We

use the moisture content of the dead 1,000-hr fuel class as an indicator of extended drought. Large dead fuels are very slow to absorb and release moisture (Fosberg and others 1981), so their percent moisture content is a good index of extended periods of either dry or wet conditions.

When the 1,000-hr fuel moisture drops below a calibrated drought threshold in the model, a simulated fire will occur if there is also a greater than 50 percent probability of fire ignition and spread. To calculate a joint probability of ignition and spread, we use an estimate of fine fuel flammability and a ratio of the simulated rate of spread to a critical rate of spread for reportable fires (Bradshaw and others, 1983). Lightning as the ignition source is another constraint on fire occurrence. Currently we are using a logistic function of monthly temperature and precipitation to determine the presence or absence of lightning.

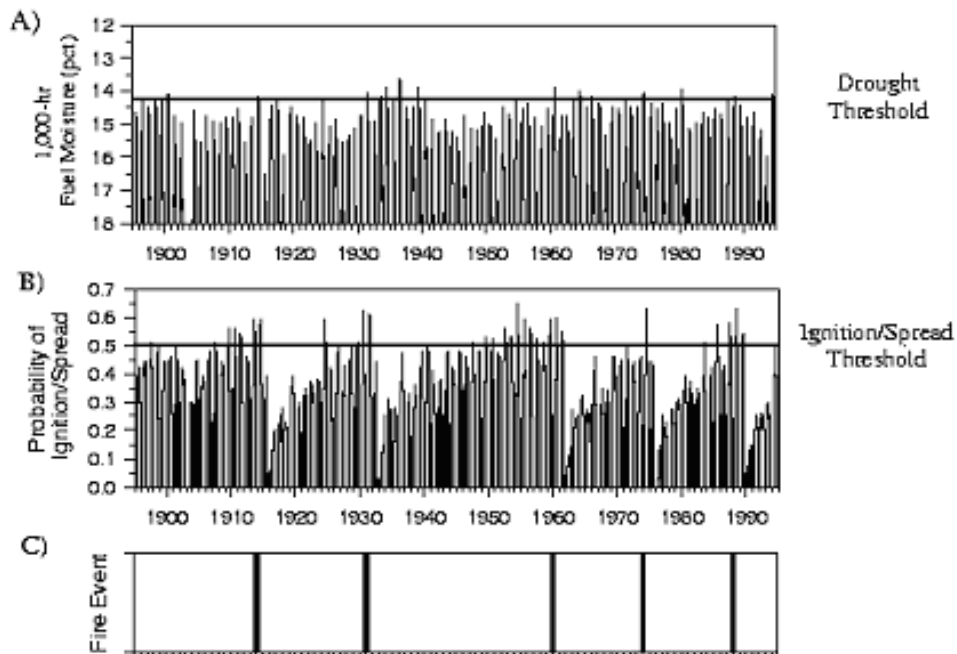


Figure 3 -- Determination of severe fire occurrence during a 100-year simulation with MCFIRE: the drought threshold relative to 1000-hr fuel moisture (A), the ignition/spread threshold relative to probability of ignition and spread (B), the five severe fire events triggered when both thresholds were simultaneously exceeded (C).

Development and Preliminary Testing of the DGVM

Much of the development and initial testing of MCFIRE and the rest of our MC1 DGVM is taking place within a 12.5 square kilometer study area that is part of Wind Cave National Park (WCNP) in the Black Hills of South Dakota. The implementation of the DGVM at WCNP is one part of a larger study to assess the impact of global change on the Central Grasslands Region at landscape to regional scales (Neilson and others 1996). The primary advantage of first implementing the model at the landscape-scale is the availability of model input data. We were able to generate a 100-yr monthly climatic dataset for the study area that is distributed on a 50 meter grid and includes all the necessary inputs to the DGVM. Long-term, distributed climate datasets at broader scales are

not currently available, although a historical gridded climate dataset for the conterminous United States at a 60 km resolution will be produced by the Vegetation Ecosystem Model Assessment Project (VEMAP) in 1998 (Kittel and others 1997).

As a model test area, WCNP offers the additional advantage of including a broad range of the vegetation types simulated by the DGVM, including temperate evergreen conifer and mixed forests, temperate evergreen savanna, both C3 and C4 grasslands, and deciduous hardwoods in riparian/wetter areas.

For example, some results of a 100-yr simulation for a data cell representing the evergreen conifer savanna (fig. 4) demonstrate the effect of including the impact of fire in the DGVM. With fire turned off in the model (fig. 4A), tree leaf biomass reaches a level interpreted by the biogeographical rule-base as characteristic of forest, not savanna. With fire turned on (fig. 4B), the potential tree leaf biomass is reduced to savanna levels by simulated fires that return every 20 years on average. Live grass biomass exhibits a repetitive cycle, with fast regrowth in the absence of competition from woody vegetation and then a gradual decline with increasing competition until consumption by the next fire event.

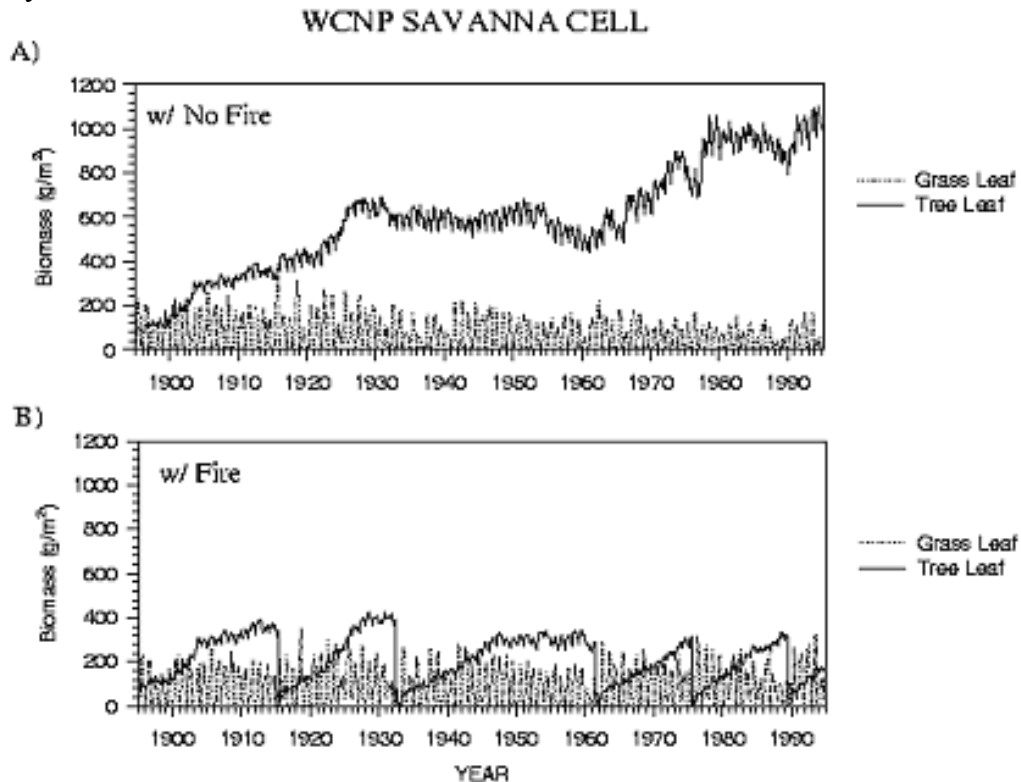


Figure 4 -- Tree and live grass biomass simulated by the MCI DVGM in a Wind Cave National Park (WCNP) data grid cell representing evergreen conifer savanna: without fire (A), and with fire (B).

Vegetation type succession on the entire modeling grid for year 40 to year 60 of the 100-yr simulation (fig. 5) also demonstrates the importance of fire in shaping the forest-grassland mosaic that is characteristic of WCNP. Here the six vegetation types represented in the original simulation have been aggregated into three for graphical purposes, and two of the panels in the figure show the distribution of burned area (shown in grey) for two especially intense and extensive fire events simulated in years 41 and 59. These two simulation years correspond to two years in the historical

drought periods of the mid-1930's and early 1950's, respectively. Before the first severe fire event, savanna surrounds the upland forest areas. The simulated fire event converts almost all the savanna to grassland. Then there is a period without severe fire during which grasslands gradually turn back to savanna and forest. The next severe fire converts the much of the area back to grassland, producing a vegetation type distribution that is very similar to the actual distribution of vegetation currently observed in the park.

Incorporating Sub-Grid Heterogeneity into Broad-Scale Simulations

When running our model on the WCNP data grid, we can safely assume that the spatial distribution of factors like fuel moisture and fuel loading are relatively homogeneous with each of the 50 m grid cells. This is a critical assumption because the algorithms used to model fire behavior were developed at a stand level under the assumption of homogeneity in fuel properties (Rothermel 1972; McKenzie 1996).

However, once we obtain the VEMAP historical gridded climate dataset, we will be implementing our DGVM on a coarser 60 km grid across the entire conterminous United States. Eventually, we also expect to implement our DGVM globally at even coarser resolutions. For these

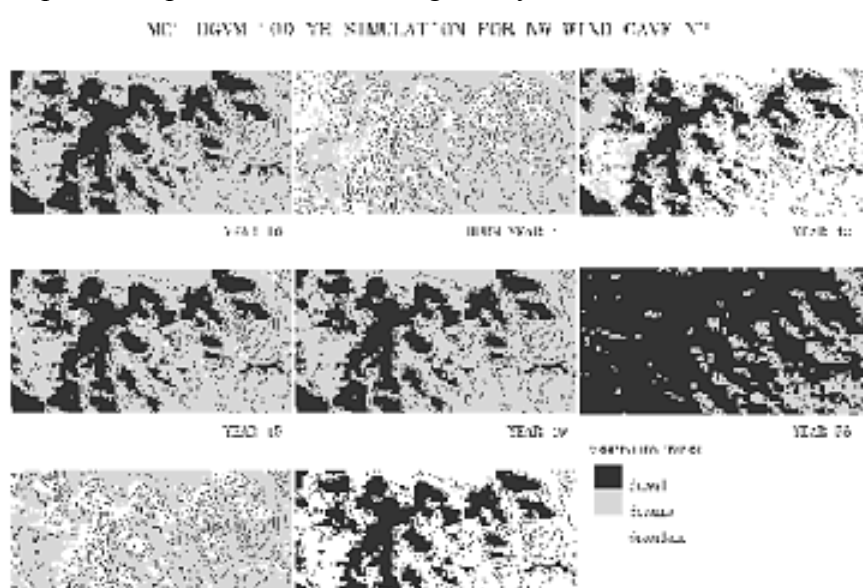


Figure 5 -- Distribution of vegetation types and the extent of severe fire in the modeling study area for selected simulation years in a 100-yr simulation generated by the MCI DGVM. All panels show the distribution of vegetation types, except for the two panels labeled "burn year" which show the extent of simulated fire in grey. Contour interval is 10 m.

simulations, our assumption of within-cell homogeneity will no longer be tenable. There will be considerable patchiness in the occurrence and intensity of severe fire in any area the size of one of these coarse grid cells. Much of this patchiness will be related to variation in topographically-controlled factors like slope steepness, aspect, and vegetation characteristics that determine fuel properties. Thus, to adequately represent fire behavior and effects for coarse grid

cells as a whole, we must account for the spatial heterogeneity within grid cells.

Land surface type (LST) parameterization has emerged as one means of modeling sub-grid cell heterogeneity in regional climate models (Avisar and Pielke 1989, Pielke and Avisar 1990). An LST is a portion of the grid cell that is physiographically distinct. For example, all north-facing slopes within a specified elevational band can be represented in a regional model as a single LST with a specified area, although in reality north-facing slopes may be scattered throughout the cell. Within the grid-cell, spatial patterns of the different LSTs are not explicitly modeled. Grid cell output to the atmosphere equals the area-weighted mean of the LST outputs.

For example, we used a 90 m digital elevation model (DEM) and a topographic shading algorithm (Frew 1990) to distinguish six different LSTs in a 10 km cell centered over the H.J. Andrews Experimental Forest in the southern Oregon Cascades (fig. 6). Exposure to radiation and slope steepness, characteristics likely to influence fuel moisture and fire behavior, were selected to distinguish the LSTs in this example.

Once LSTs have been distinguished within a coarse grid cell, our DGVM will be parameterized for each LST via a downscaling of the grid-cell level input data. Of key importance in formulating the downscaling methods will be relationships between climate and elevation, slope, and aspect (Daly and others 1994). We will derive these relationships by modeling the climate in select regions across the United States at both fine and coarse resolutions. Once the DGVM is parameterized, we will run the model once for each LST, calculating the results for the entire grid-cell as an area-weighted average of the results for each LST. For example, the amount of gaseous and particulate emissions emitted to the atmosphere by a fire simulated within a coarse grid cell would be calculated as the average of the emissions emitted from each LST weighted by the total cell area occupied by each LST.

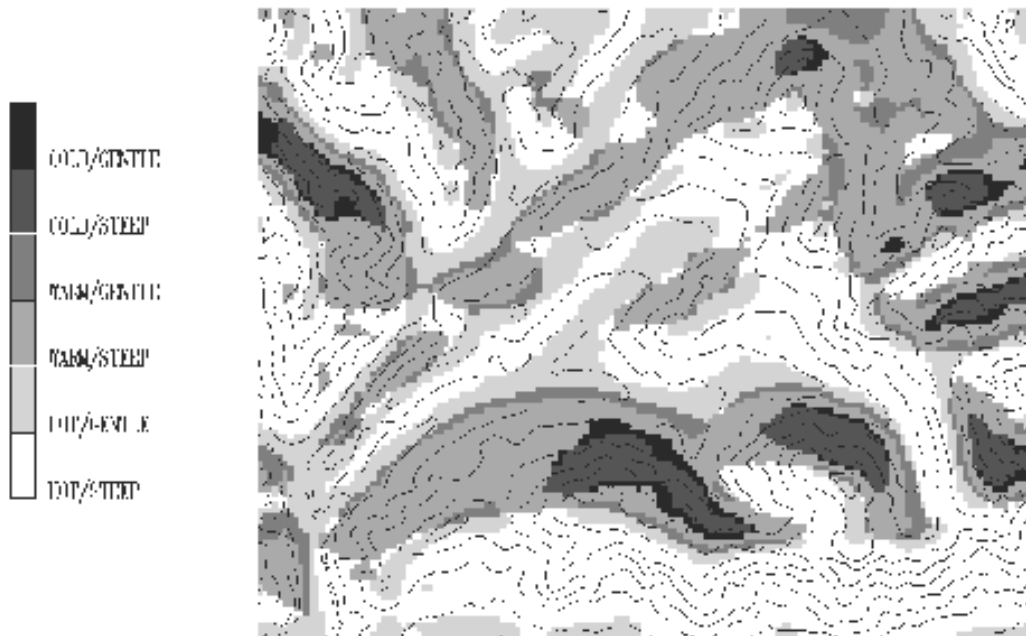


Figure 6 -- Land surface types distinguished by exposure to solar radiation (cold, warm, or hot) and slope steepness (gentle or steep) in a 10 km cell centered over the H.J. Andrews LTER in the Oregon Cascade Mountains. Contour interval is 100 m

Conclusions

Terrestrial ecosystems are often constrained by disturbance, and changes in disturbance regimes can lead to abrupt changes in ecosystem structure and function. Fire is the primary natural disturbance in many different ecosystems, and fire regimes may be especially sensitive to climate change. A lack of understanding regarding the reponse of broad-scale fire severity to climate change limits our ability to predict potential changes in ecosystem structure and function and feedbacks to the atmosphere (McKenzie and others 1996). It is critical to account for the role of fire in dynamic vegetation models used to assess the potential impacts of climate change. In preliminary tests of the MCFIRE module in the MC1 DGVM, the accurate simulation of ecosystem structure and function under current climatic conditions is dependent upon fire effects in the model simulations, especially at the interface between forest and grassland.

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PEGASUS: Toward an Integrated Weather/Wildfire Modeling and Decision Support System

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Southern California has a well-earned reputation for multiple major wildfire incidents. Strategic fire planning is a shared responsibility among Federal, State and local firefighting agencies, the result of necessity, and a research and development program called FIRESCOPE. FIRESCOPE gave the firefighting community the Incident Command System (ICS), an organizational and administrative paradigm for rapid mobilization and deployment of firefighting resources. It also gave southern and central California a command center staffed by Federal, State and local agency personnel. The Operations Coordination Center (OCC) provides interagency coordination and support for fire suppression operations in the southern part of the state. Located in Riverside, California, the Center combines the firefighting resources of the USDA Forest Service, the California Department of Forestry, the Counties of Los Angeles, Ventura, and Orange, the Los Angeles City Fire Department, and the California Office of Emergency Services. In fire season, usually June through November, OCC examines daily the potential of fire in southern and central California, using a model to analyze and predict the weather and its anticipated effect within the operations area. A fire weather index dependent on wind speed, relative humidity, and temperature indicates the potential for fire ignition and spread as weather changes through the course of the day. The index does not describe specific fire behavior characteristics, but it gives the fire planners a sense of where and when fire problems may occur. The spatial and temporal variations of the index are generated from a regional weather model. The tactical level of fire planning considers a smaller area and more focused objectives. However, the modeling and simulation activities at that scale are more complex. This paper describes a prototype geographical analysis and support system (PEGASUS), designed to integrate high resolution weather and fire behavior modeling systems that provide a useful simulation tool for fire managers.

Fire Behavior Modeling

A spatially and temporally descriptive fire behavior forecast can be overwhelming, without modeling. For more than 20 years, fire behavior specialists have been using the Rothermel fire spread model (Rothermel 1972). In addition to a spread rate estimate, the model estimates ignition potential and heat energy released, all of which dictate how the fire is fought. The fire model accounts for the combined influences of fuel, terrain and weather. It tracks the moisture exchange between vegetation and the air.

The Rothermel model was designed to estimate, for fire-danger rating purposes, the “average worst conditions.” The estimates are average worst conditions in the sense that they

key on mid-slope conditions, and the time of day when weather would yield the worst fire danger on average. Rothermel (1972) cited two management applications for his model:

1. The “hypothetical fire” situation in which operations’ [sic] research techniques are utilized for fire planning, fire training, and fuel appraisal.
2. The “possible fire” situation for which advance planning is needed, such as fire-danger rating and presuppression planning. Predictions of potential fire severity for possible management practices (i.e., methods of thinning, slash treatment, and prescribed burning) have the potential for being the most valuable contribution that fire modeling can perform.

Rothermel excluded fire behavior forecasting as an application of the model, citing fuel and weather variations as factors that would cause departures from predicted behavior and pose unacceptable risks in fire suppression activities. He predicted that a more sophisticated model to predict the behavior of a specific fire would be developed in time. Twenty-five years after he made that prediction, the Forest Service and other Federal agencies are using only modified forms of the Rothermel model.

For a fire suppression operation, a purpose of the fire model is to estimate the actual burning conditions as closely as possible. The Rothermel model simulates spread only in one dimension. Other fire spread models, e.g. Pagni and Peterson (1973) are more sophisticated, but these require data and computational resources unavailable to the fire agencies, and they are complex beyond the comfort level of practitioners. The Rothermel model is a practical formulation that integrates the effects of fuel, weather, and topography. Later versions of the Rothermel model modified the treatment of wind and slope effects (Albini 1976, Rothermel 1983). A breakthrough that would give the fire model length *and* breadth. was accomplished with the notion, derived empirically, that fire shape is often elliptic.

Anderson (1983) cited several studies reporting that fires describe a circular shape immediately after ignition, but then burn elliptically as a preferred spread direction becomes apparent, due to wind, slope, or a combination of environmental factors. He compared laboratory and case study fires with an elliptic parameterization of fire shape, and found that a double ellipse formulation was useful for describing fire size and shape. The double ellipse consists of two semiellipses whose major axes are collinear, one major axis representing distance burned in the direction of maximum spread (the heading fire), the other major axis representing distance burned in the opposite direction (the backing fire). More recently, Richards (1995) proposed an elegant general mathematical framework, consisting of partial differential equations that describe two-dimensional fire growth over time. The solutions include the double ellipse as a special case. The rate of spread at each point on the perimeter, as a function of environmental conditions, must be specified; hence, Richards’ formulation still requires a spread model like Rothermel’s. The advantage of Richards’ method is that it provides a basis for describing very complex burning scenarios, even in the presence of barriers. The simulations require an iteration algorithm, which Richards and Bryce (1995) used on a 486 microcomputer. Long computing times are a problem, but they state that the procedure can run 40 times faster on a workstation, and the computational algorithm can also be improved.

FARSITE (Finney 1995) is the most recent addition to fire modeling systems in the U.S. It simulates and displays two-dimensional fire spread and runs on a laptop. FARSITE employs a

version of the Richards algorithm reported in 1990 (Richards 1990). Given the initial fire location, the algorithm solves the forward spread rate at designated points on the perimeter (the spacing between points is an input parameter), using the Rothermel model. An elliptic wavelet is constructed at each point, with major axis oriented in the direction of and proportional to the local forward spread rate. In the manner of Huygens' principle (a wave theory of the propagation of light, in which a point on the wave front can be considered as the source of a new wave), the curve that is tangent to the ellipses thus generated describes the new position of the fire perimeter (fig. 1). The end result gives remarkably complex fire simulations (fig. 2).

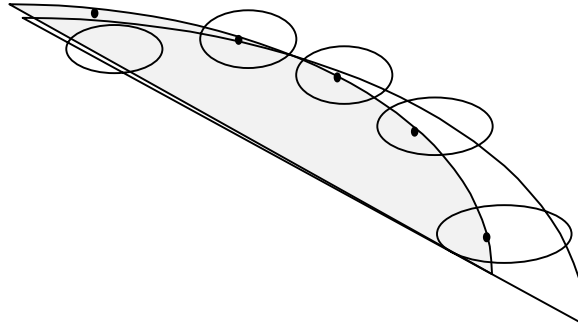


Figure 1--Huygens' principle applied to fire spread simulation. At each chosen point on the perimeter, the fire is advanced by an elliptic model with data at that point.

FARSITE introduced a complexity that is typical of computer simulations: that of specifying simulation parameters. The parameters have nothing to do with the phenomenon of fire, but they control the outcome of the simulation. One parameter has already been mentioned: the spacing between points on the fire perimeter. Another is the maximum distance parameter, which sets the upper limit that the simulation will propagate the fire in a given time step. Without this parameter, the algorithm may spread the fire without recognizing the fine details of the fire environment. For example, too large a distance parameter could miss obstacles such as a small stream.

A good fire weather forecast must accurately describe spatial and temporal variations of the weather elements--primarily wind speed and direction, relative humidity, and temperature. Currently, the fire behavior analyst typically relies on a spot forecast from the incident meteorologist, or a few well-chosen weather observations, but meteorological support for FARSITE requires a significantly different service that is best facilitated by weather modeling.

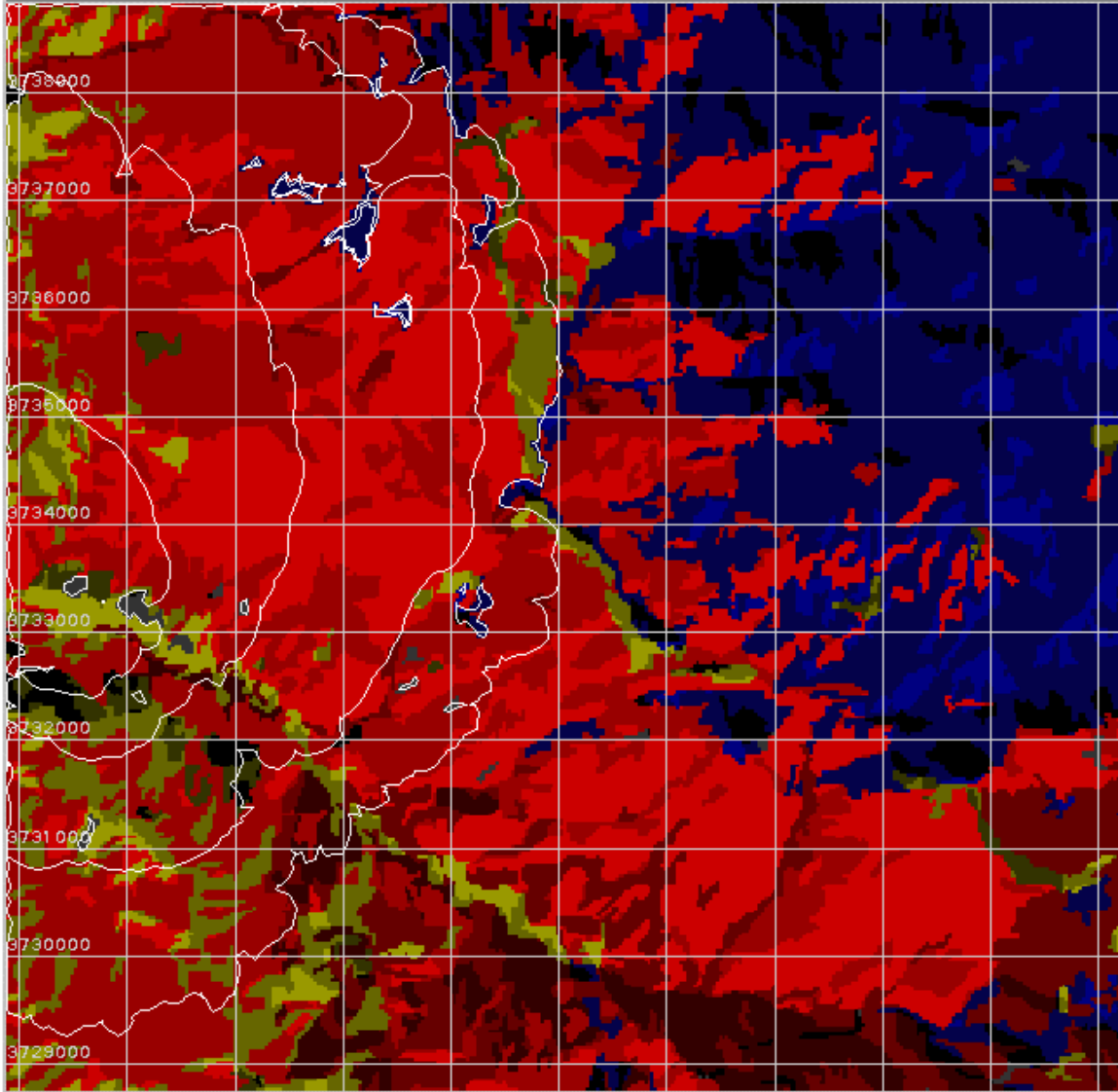


Figure 2--A simulation of fire spread in the area of the Bee Fire, which burned nearly 10,000 acres near Idyllwild, California, in the summer of 1996. The different shades represent different fuel types. The grid lines are spaced 1 km apart. The white lines are simulated perimeters at 1-hour intervals.

Fire Weather Modeling

Fire is essentially a local spatial phenomenon, but fire weather modeling starts at a global scale, for several reasons. First, larger scale atmospheric systems influence the character of local weather. Second, larger scales of weather patterns must be considered in forecasts that extend over more than a few days. Third, global weather models are routinely used to produce weather forecasts at large operational centers, such as the National Weather Service's (NWS) National Centers for Environmental Predictions (NCEP). The global model output is therefore a starting point for local weather modeling. The grid spacing in the global model domain is typically 100 - 250 km.

A high resolution weather model is necessary to describe features that influence weather on a fine scale, especially terrain, which is often complex in areas prone to wildland fire. Hence,

where a grid spacing of 100 km might be sufficient to analyze the regional threat of fire, incident weather modeling might require a spacing of 30 m, to depict sharp topographic gradients and narrow canyons and passes that are likely to divert and channel wind flows and influence fire behavior. Moreover, the weather model must include different physics at finer scales. A more sophisticated model accounts for fine scale processes, at the expense of more computation time.

Figure 3 illustrates a simulation of weather conditions in the area of a fire in southern California in the summer of 1996. The graphic actually was generated from multiple models, beginning with the global scale. A higher resolution regional grid of the area was superimposed within the global grid (fig. 3). The regional grid depicts terrain features better than the global grid. The global weather field provides a boundary condition for further simulations on the regional grid. The regional model adds spatial detail to the global forecast, in the area of the regional grid. In turn, the regional simulation provides boundary conditions for an even higher resolution weather model with a grid spacing of 2 km (fig. 4). This hierarchical approach is called *nested grid* modeling. A hydrostatic model is used for the global and regional simulations, but the fine grid uses a nonhydrostatic model. This strategy provides high resolution only over the area of interest, thus reducing computation time.

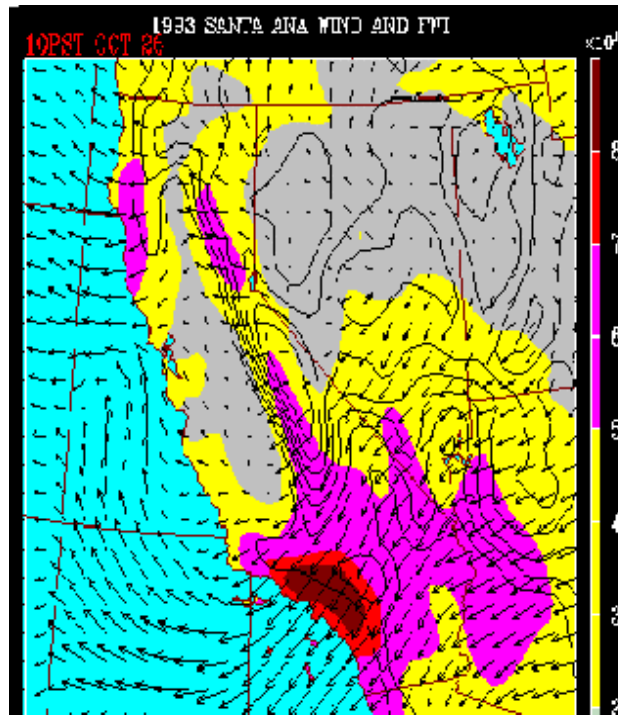


Figure 3--A regional fire weather graphic of the weather-induced fire potential across a portion of the western US on 26 Oct 93. The scale at right corresponds to values of the fire weather index. Higher values indicate higher fire potential. The arrows represent wind flow at 10 m. This particular graphic shows a wind condition known as Santa Ana in southern California, an especially dry and windy pattern.

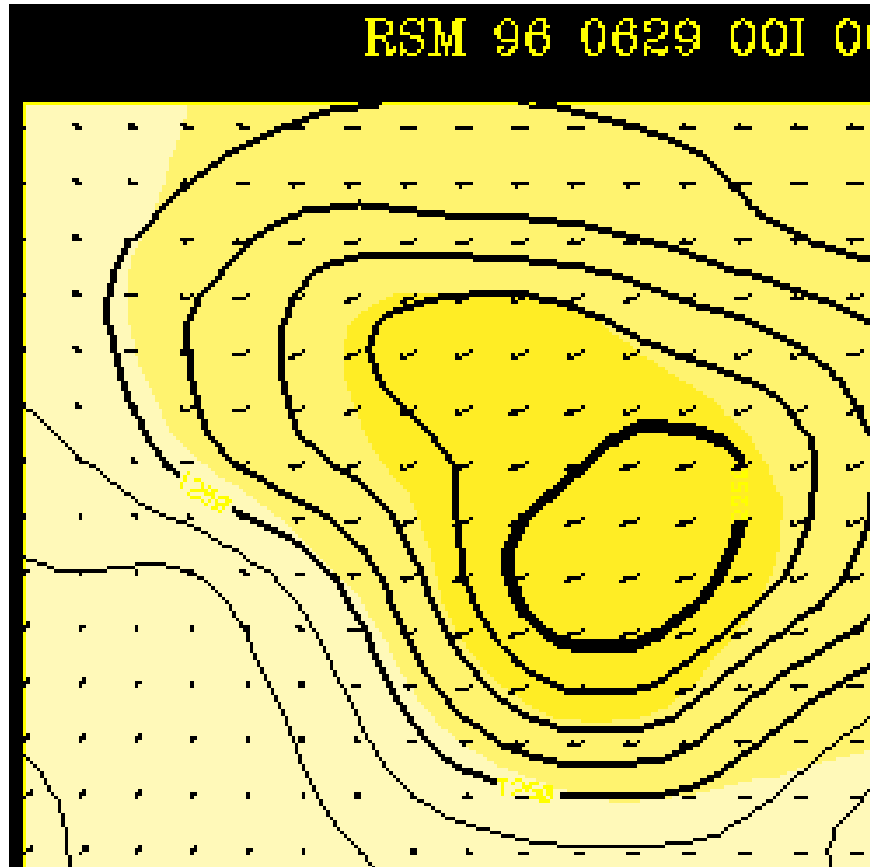


Figure 4--High resolution simulation of weather conditions on 29 June 1996, Mt. San Jacinto, California. The vectors depict the wind field at 10 m above the surface, and the shading represents fire weather index intervals. Terrain contours are shown by the solid black lines.

A Prototype Fire Modeling System

Currently, the Forest Service's Pacific Southwest Research Station and cooperators are developing a prototype modeling and simulation system to support tactical wildland firefighting (Fujioka 1998). The system, called PEGASUS (prototype emergency geographical analysis and support system), will enhance the quality and quantity of information in the planning section of the incident command and the multiple incident coordination center. Under the current prototype design, weather modeling support is provided routinely at a regional scale, to evaluate the potential for fires in an area covering multiple jurisdictions, and requiring coordination between several agencies. If a fire occurs and escapes initial attack, more weather simulations at higher spatial resolution may be generated, to provide input to a fire behavior model. The fire behavior model simulates the spread and intensity of the fire, providing fire planners with an indication of the suppression resources required for the planning period.

A variety of models has been described for the support of wildland fire management. In spite of their sophistication, it is still prudent to expect errors in the modeling process. The PEGASUS design contains a built-in fire spread model validation step, to routinely examine the quality of the model predictions. There are several sources of prediction error, arising from the observing system, the modeling system, and input values. Assuming that data on the spread of a fire is available at regular intervals, we can calculate the prediction error from a designated point on the perimeter as

$$\text{prediction error} = \text{predicted position} - \text{observed position}$$

$$e(s) = p(s) - o(s)$$

in which s denotes a point on the initial fire perimeter. Then we construct the linear model

$$e(s) = \mu + \sum_{i=1}^p \beta_i x_i(s) + \varepsilon(s)$$

in which μ is the mean error, $\{\beta_i\}$ are unknown constants to be estimated statistically, $\{x_i\}$ are independent variables to be tested for error associations, and $\varepsilon(s)$ is a spatial random variable.

An error analysis of this type will help decision-makers to determine the reliability of the fire spread simulations. It will highlight the variables in the modeling process that are statistically correlated with the errors, and thus provide diagnostics for model improvement. A reasonable probability model for the errors will allow simulated fire perimeters to be bounded spatially by confidence bands that indicate the region where the actual perimeter will occur, with given probability (fig. 5). Moreover, when the errors are consistent, a statistical adjustment can correct the bias, and reduce the error variance. But this requires sufficient data to conduct an analysis and determine a reasonable probability model.

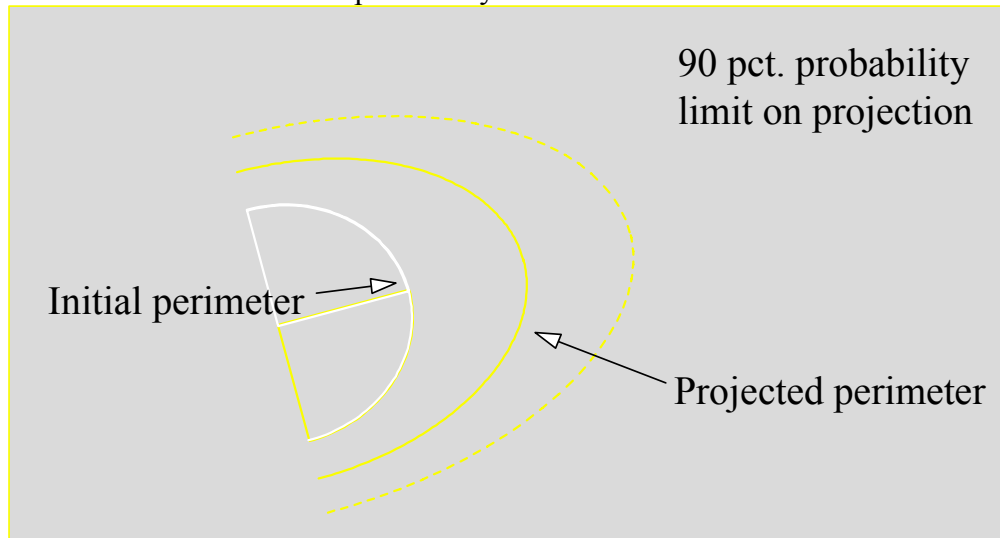


Figure 5. Conceptual example of a perimeter projected by simulation, and bounded within a spatial interval that determines where the actual perimeter might occur, according to some probability law.

Problems and Prospects

In summary, the PEGASUS project combines weather modeling and fire behavior modeling in support of tactical wildland fire management. We have seen that the simulations, particularly the weather models, require substantial data and computing resources. Under PEGASUS, the NWS National Centers for Environmental Predictions provide the data assimilation and global forecast of weather conditions out to 72 hours. These are produced routinely as part of everyday operations for a variety of uses. Currently, however, the regional weather simulations are prepared in California for research purposes, at the Scripps Institution of Oceanography. This step adds another 6 hours to the total processing time, including approximately 4 hours of computing on a high-end workstation.

Currently, the high resolution weather model is not operational. Weather simulations tested so far have taken too much time to run operationally. One workstation simulation by PEGASUS cooperators at the Los Alamos National Laboratory took 35 hours of central processing unit (CPU) time to produce one hour of simulated high resolution weather. The same simulation was subsequently run with a parallelized version of the model code; with 32 nodes, the CPU time was reduced to 1.5 hours. Under PEGASUS, this component of the modeling suite will be run on a supercomputer, an extraordinary requirement for wildland fire managers, given current practices.

In fact, the land management agencies are not yet fully prepared to implement a PEGASUS type operation. In the Forest Service, geographic information systems are only now coming on line. Much work still remains to prepare fuels databases, without which a FARSITE type system is unusable. Even terrain data poses some challenges. That data will come from the U.S. Geological Survey, but the nationwide database is too massive to get the portion of data of interest to the computing site in a timely manner.

The plan to validate model simulations against observed fire spread provides a necessary reality check, but it needs the support of remote sensing systems that are only now finding their way out of research and into operations. We will need high resolution imaging systems that can see the edge of a fire through smoke, at a resolution on the order of 10 m. The perimeter location data must be digital for the error analysis, and sufficiently time-resolved to track the growth of the actual fire. To be useful for incident management, the information must also be timely.

The PEGASUS prototype draws heavily on expertise outside the fire management agencies. Even the FARSITE fire behavior system is relatively new. Much training needs to take place before the modeling technologies can be implemented, and perhaps other specialists, e.g., supercomputing experts, are needed for the high speed computing requirements. One of the early potentials envisioned for PEGASUS was in fact its training value. Computer simulations provide useful and illustrative wildfire scenarios.

Finally, connectivity must be established, between data centers and computing centers (these are not necessarily the same), between computing centers and operation centers, and between operation centers and the incident. There is presently no complete network with all of these links in place.

The PEGASUS concept described to this point leads almost, but not completely, to a decision-making model. One remaining prospect is to add a modeling component with an explicit decision context, such as an optimal resource allocation model. Mees and others (1994).

considered the cost plus net value change of deploying different mixes of firefighting resources under both success and failure scenarios: success means the fire is contained with the given mix of resources, and failure means the fire escapes in spite of the firefighting effort. The model realistically assumes that success or failure is subject to random fire behavior and random fire line effectiveness. The Mees and others model (1994) considered random flame length as a measure of random fire behavior. Flame length dictates how wide a fire line must be constructed in order to contain the fire. Given a firefighting force and a choice of fire line width, they optimized the firefighting strategy by choosing the line width that minimized the expected cost plus net value change (this criterion differs from the traditional cost plus loss, because fire may also have beneficial effects which must be considered). For fire line i , the expected cost plus loss is K_i :

$$K_i = \sum_j C_{ij} + (1 - P_{ij})L_{ij} + (1 - P_i)L_i$$

in which C_{ij} is the cost of firefighting on segment j of line i ,
 P_{ij} is the probability of containing the fire at noncritical segment j of line i ,
 L_{ij} is the net value change associated with failure of containment at segment j of line i ,
 P_i is the probability of containing the fire at critical segments of line i , and
 L_i is the net value change associated with failure of containment at critical segments of line i .

Critical segments were defined as those at which failure of containment would result in total failure of containment. Noncritical segments were less threatening, such as the flank and rear of a fire. The optimum resource allocation is defined as the one that minimizes K_i .

The Mees and others model (1994) can use the modeling information of the PEGASUS system to predict future fire location and intensity, including flame length. Further work would be required to predict future fire line positions when fire suppression is applied, and to express the probability of containment for the predicted fire behavior and firefighting resource mix. In principle, the optimization problem remains the same, but the probability functions would be reparameterized to take advantage of the information in the PEGASUS system. The planning objective is still to choose the firefighting resource mix that minimizes cost plus net value change, K_i , for the given fire line i . With more sophisticated optimization algorithms, it is possible to also optimize the fire line position, i.e., make the fire line width a decision variable.

Although much has been done to advance weather and fire behavior modeling, the PEGASUS models can be enhanced by future research and applications.

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Characterizing a Shrub Fuel Complex for Fire Behavior Modeling

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Introduction

Chaparral vegetation in southern California and pocosin vegetation on the coastal plain of North Carolina are similar fuel complexes. Both are “live” shrub fuel complexes composed of a heavy load of highly flammable vegetation often represented by fire behavior fuel model 4 (chaparral). Both have a high dead fuel fraction. Fires in both types can have high spread rate and intensity, and can exhibit extreme fire behavior. Shrub species in both types are well-adapted to a regime of stand-regenerating fire and usually recover quickly after fire.

Yet chaparral and pocosin vegetation types are also quite different. Chaparral grows on steep terrain over mineral soils, whereas pocosin is found on flat terrain over organic soils several feet deep. Chaparral occurs in a warm, dry climate; pocosin in a hot, humid climate. Severe fires in chaparral occur during warm, dry foehn winds (Santa Ana or East winds) with high temperatures, low humidities, and low dead fuel moisture contents. In pocosins, severe fires such as the 1971 Bomb Range fire (Wade and Ward 1971) are often associated with cold front passage, which brings relatively cool temperatures and moderate humidity, resulting in moderate fuel moistures. Because of the deep organic soils in pocosins, residential and commercial development is difficult, so the “wildland-urban interface” fire problem is much less extensive than in southern California chaparral. However, road building is difficult in pocosins, so road density is low and vehicle access is poor. In the organic soils will not support the weight of conventional firefighting equipment, so special high flotation flexible-track vehicles must be used.

Significant efforts have been made to describe chaparral fuels (Conard and Regelbrugge 1994, Countryman and Philpot 1970, Paysen and Cohen 1990, Rothermel and Philpot 1973, Wakimoto 1977), but less so for pocosin (Wendel and others 1962, Blackmarr and Flanner 1975). A recent chaparral fuel modeling workshop (March 11-12, 1997 at the Pacific Southwest Research Station, Forest Fire Laboratory, Riverside, California) led to the development of several preliminary custom chaparral fuel models for use with the BEHAVE fire behavior prediction system (Andrews 1986).

This paper describes the preliminary results of a study that examined the structure of pocosin fuels to create custom fuel models for use in fire behavior modeling.

Sampling Method

We sampled 59 1-meter-square plots in pocosin vegetation in three study areas on the coastal plain of North Carolina. Twenty-five plots were in high (or “tall”) pocosin averaging about 2 meters in height, 24 plots were in low (or “short”) pocosin about 1 meter in height, and 10 plots in low pocosin that was burned under prescription just 2 years prior to sampling. Height of the shrub canopy at each plot ranged from less than 1 meter in the burned low pocosin to more than 3 meters in the high pocosin. This paper focuses on 10 high pocosin and 10 low pocosin plots sampled on or near the Dare County Bombing Range (DCBR), North Carolina. These sites last burned in the 1971 Air Force Bomb Range Fire (Wade and Ward 1973).

We clipped and bagged all living and dead vegetation within each plot in layers 0.5 m deep, using a plot frame made of 13-mm (1/2-inch) EMT (metal) electrical conduit as a guide. The vertical poles of the frame were connected with 1 m lengths of conduit with structural pipe fittings to keep the poles properly aligned. Marks on the vertical poles divided the plot into 0.5-m vertical layers. In the lab, the samples were sorted into six categories: three “size” classes (foliage, 0 to 6 mm [0 to 1/4 inch] diameter, and 6 to 25 mm [1/4 to 1 inch] diameter), and two components (live and dead). Surface litter, composed mainly of leaf litter and fine twigs, was collected in two 1/4-m² quadrats. All samples were then oven-dried and weighed.

Analysis

The essential characteristics of a fuel complex for fire behavior modeling include the load (kg/m²) and bulk density (kg/m³) of fuel by particle-size class. Bulk density is load divided by fuelbed depth (m). For any fuel complex, these characteristics can be displayed in a bulk density diagram with depth of fuelbed on the y-axis and bulk density on the x-axis. We compared fuelbed characteristics at both the individual-plot and stand levels (average of 10 plots). At a representative plot in each fuel type, the high pocosin exhibited higher bulk density and load than the low pocosin. The high pocosin was also a deeper fuel bed. Both high and low pocosin plots exhibited a characteristic decrease in bulk density with increasing height within the fuelbed. This general pattern was observed for nearly all individual plots sampled. However, most of the bulk density of the lower layer consists of live stems greater than 6-mm (1/4-inch) diameter, which do not contribute significantly to frontal fire behavior and are therefore not usually considered in fire behavior modeling.

This decrease in bulk density with increasing height within the fuel complex is even more pronounced at the stand level. This is because the shorter plots in the stand do not contribute to bulk density in the higher layers.

Anderson (1982) recommends using fire behavior fuel model (FM) 4 to represent high pocosin, and FM 6 for low pocosin. Compared to FM 4, the DCBR high pocosin is a slightly deeper fuel bed, but is less tightly packed (if, as in the standard models, the coarse live fuels are not considered), and has a similar loading of fuels that can potentially carry a fire. The DCBR high pocosin has less fine dead fuel than FM 4, and no live or dead fuels greater than 25 mm diameter at all. In subsequent fuel models built from the same data (table 1), the litter load (2 tons/acre) was included as dead 10-hr fuels rather than as 1-hr fuels as might be done based on the surface-area-to-volume ratio (SAV) of the individual litter particles. If the litter load were included as a 1-hr timelag fuel, the fire model would assume this load to be evenly distributed throughout the fuelbed,

resulting in a lowering of the characteristic SAV and leading to an overprediction of spread rate. Because litter is quite compact relative to the rest of the fuel bed, we opted to treat the litter as an effectively coarse fuel with relatively low SAV. As such, the litter does not have a significant effect on predicted spread rates. In pocosin fuels, litter characteristics determine whether a fire will be able to spread and probably has little influence on ultimate fire behavior.

Likewise, we compare the low pocosin with FM 6. Like the high pocosin, the low pocosin has no 100-hr timelag component, only live and dead fuels less than 25 mm diameter. Fuel model 6 has a significant load of 100-hr timelag fuel, but no live fuels (it nominally represents dormant shrubs and hardwood slash). The low pocosin is a deeper, more compact fuel bed than FM 6; therefore, it also has a higher fuel load.

We used the inventory data to develop first approximations for fuel models of low and high pocosin at the DCBR site. These preliminary models are based on the actual measured load and depth, with broad assumptions concerning other fuel model values. These models are for comparison with standard models and for future calibration with actual fires. The models are not yet ready for operational use.

Fuel model characteristics of standard and custom fuel models were compared (table 1), as were values for other inputs needed to use Rothermel’s (1972) fire spread model (tables 2, 3).

Table 1. Summary of fuel load and surface-area-to-volume ratios (SAV) by size class and component for the high and low pocosin custom models, as well as fire behavior fuel models 4 and 6. In the pocosin models, litter was included in the dead 10-hr timelag class. The “total” row for the SAV column indicates the surface-area weighted SAV, also called the characteristic SAV.

Inputs		High pocosin		Fuel Model 4		Low Pocosin		Fuel Model 6	
		load	SAV ¹	load	SAV ¹	load	SAV ¹	load	SAV ¹
Dead	1-hr	4.2	2000	5.0	2000	6.1	2000	1.5	1750
	10-hr ²	4.5	109	4.0	109	4.0	109	2.5	109
	100-hr	0.0	30	2.0	30	0.0	30	2.0	30
Live	foliage	5.0	1500	5.0	1500	4.8	1500	N/A	
	twigs	3.0	1500			2.6	1500	N/A	
Total		16.7	1667	16.0	1739	17.5	1730	6.0	1564

¹ Characteristic surface-area-to-volume ratio
² Litter fuel in the high and low pocosins was included in this class.

Table 2. Additional fuel model parameters for the high and low pocosin custom models, as well as as fire behavior fuel models 4 and 6. For the custom models, depth is average depth of the 10 plots, while extinction moisture and heat content are first approximations based on experience.

Variable	High pocosin	Fuel Model 4	Low pocosin	Fuel Model 6
Depth (ft)	6.7 ¹	6	3.1 ¹	2.5
Extinction moisture(pct)	30	20	30	25
Heat content (BTU/lb)	9000	8000	9000	8000

Table 3. Site characteristics and fuel moistures representing wildfire conditions in pocosin vegetation.

Input factor			Value
Fuel moisture content (pct)	Dead	1-hr	10
		10-hr	15
		100-hr	20
	Live	foliage	120
		twigs	120
Wind reduction factor			0.4
Slope (pct)			0

Predicted spread rate and fireline intensity were compared over a range of 20-ft windspeeds. Fire managers have observed that fuel model 4 does not adequately predict rate of spread in pocosin fuels. When dead fuel moistures are 15-20 percent, as they often are during both wildfire and prescribed fire conditions, fuel model 4 underpredicts actual spread rates. This is due to the relatively low extinction moisture in fuel model 4 (20 percent) relative to the typical pocosin burning conditions. At lower fuel moistures, FM 4 may overpredict spread rate due to the abundance of fine dead fuel in the model.

The preliminary DCBR high pocosin model predicts slower spread rates than FM 4 at the fuel moistures often encountered in pocosin wildfires (table 3). The model also predicts slightly lower spread rates for the low pocosin than the high pocosin, despite a slightly higher fuel load in the low pocosin. This is due to a lower packing ratio (bulk density) in the high pocosin, which leads to higher spread rates, especially in windy conditions. Rothermel's model predicts the spread rates for FM 6 will be slower than the other fuel models.

Similar to spread rates, the highest intensities occur with FM 4. The high pocosin has lower intensities than low pocosin, although its spread rates were higher. This is because the low pocosin model has a higher heat yield per unit area, mainly resulting from its slightly higher load and higher SAV (finer fuels). The intensity for FM 6 is quite low compared to the other models.

Discussion

The fuel inventory procedures we used were designed to provide estimates of fuel model parameters from a relatively uniform shrub fuel complex. The technique also provides information on the vertical distribution of fuel within the fuel complex. Although the Rothermel fire model cannot use this information, several other fire models under development can use this vertical fuel distribution information. Examination of chaparral and other live fuel complexes in this manner may provide useful insight into its structure and composition. Similar methods may also prove useful in examining the structure of conifer canopy fuels to better determine canopy fuel characteristics for crown fire behavior modeling.

The preliminary fuel models for high and low pocosin at the Dare County Bomb Range appear to be reasonable starting points for future refinements. The fire behavior they predict falls between that predicted by fuel models 4 and 6, the standard models used in pocosins with fuel moisture conditions typically found during wildfires.

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A Method for Examining Patterns in Mapped Fire Histories: Identification of Homogeneous Fire Landscapes

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Abstract

In examining the mapped fire history of a large region, one may need to separate a study area into sub-regions that are homogeneous in terms of fire regime (i.e., to identify homogeneous "fire landscapes"). Because a fire regime is the result of complex interactions between fuel distributions, weather, and the cause and spatio-temporal patterns of ignitions, identification of fire landscapes may not be an easy task. Simplification of a fire regime (e.g., to fire frequency) or the use of surrogates (e.g., climatic regions or fuel maps) is often used, but this approach may ignore important aspects of how a fire regime manifests itself in a particular area. Inclusion of all available information, such as the fire size range, seasonality, and unusual intervals between fires, can provide a much better view of how fire landscapes differ from each other in significant ways. We propose an objective and repeatable method using variables generated from a mapped fire history, and we apply it to Los Padres National Forest in central coastal California. Fire variables were calculated on a regular grid spacing and incorporate the following: seasonality and cause of fire starts, number of times burned, longest and shortest interval between fires, and largest and smallest fires to pass over a site. Results indicate that this method captures the vast majority of variation in fire variables and their spatial pattern, providing mapped fire landscapes for use in fire planning or for further statistical analysis.

Fire is the primary ecological disturbance structuring many of the world's terrestrial ecosystems, and spatio-temporal patterns of fires can provide insights into how these systems have developed and how we should manage them. In analyzing the fire history of a specific region, one is concerned that the fire regime be stationary (i.e., not containing mixed distributions) over space and time, but the scale and timing of dominant mechanisms are often poorly understood. Temporal shifts in fire regime can be caused by changes in climate or fire suppression, and different methods have been developed for dealing with mixed distributions over time (Clark 1989, Johnson and Gutsell 1994).

Identification of areas that are spatially homogeneous in terms of fire history has received some attention, but many studies are performed using the spatial unit for which data were collected (e.g., at the scale of a specific county or forest). This scale may be appropriate, particularly if the goal is to characterize a process at a regional scale. Conversely, one may need to separate a study area into spatial units that are homogeneous in terms of fire history to examine the importance of local factors. A notable example of this is Baker (1989), in which homogeneous regions were sought by fitting fire-interval distributions to fire history data. Although characterization of fire frequency is a well established approach (Heinselman 1973, Johnson and Gutsell 1994, Johnson and Van Wagner 1985), the focus on fire intervals can omit important aspects of a fire regime that many mapped fire histories contain. Chou and others (1990) used a fire history to examine the distribution of fires and their spatial neighborhood effects, but the study area had been simplified to a binary variable (i.e., burned versus unburned). Inclusion of all available information, such as the fire size range, seasonality, and unusual

intervals between fires, can provide a more complete view of how regions differ from each other in important ways.

We propose here a methodology that is flexible, yet quantitative and repeatable, for identifying "fire landscapes" that are homogeneous in terms of several fire-related attributes. As a demonstration of its usefulness, we quantify and compare the vegetation composition of resulting fire landscapes on Los Padres National Forest (LPNF) in central coastal California to test whether analysis of fuel dependency at the scale of the entire study area is appropriate.

Study Area and Data

LPNF is located along the central Coast Ranges and Transverse Ranges of California (fig. 1) and is divided into the Main and Monterey Divisions, covering about 585,000 and 125,000 ha, respectively. Annual precipitation in the Main Division ranges from 250 to 1,000 mm, and the Monterey Division is slightly wetter, ranging from 500 to 1,500 mm per year (Davis and Michaelsen 1995). The vegetation is predominantly chaparral and coastal sage scrub, both of which are fire adapted. Although the area has a history of fire suppression, recent research on sediment cores from the Santa Barbara Channel indicates that large fires have been occurring for centuries (Mensing 1993), suggesting that they are a natural part of chaparral ecology and not the result of fire suppression. Moritz (1997) analyzed the distribution of large fires in the modern LPNF fire regime and found that suppression has probably not altered the likelihood of large fires over time. Although Santa Ana winds are clearly one of the dominant forcing mechanisms of this fire regime at a regional scale (Moritz 1997), the degree of local fuel dependency is an important issue and has yet to be addressed.

To begin examining the role of fuels in LPNF, we focus on the fire regime and vegetation distribution of the Main Division. By using methods described in Johnson and Gutsell (1994), preliminary work to estimate how the hazard of burning changes over time showed neither a strong dependency on fuel age nor complete independence, indicating possible mixed distributions. Given the size of the study area, it is likely that the Main Division contains sub-regions that should be examined separately, due to differences in vegetation that impact fire ignition and spread. It is also likely that sub-regions dominated by different fire sizes should be analyzed separately, as fuel-dependency can change under small- versus large-fire dynamics (Moritz 1997).

A digital fire history of LPNF is currently maintained in a geographic information system (GIS), spanning the period 1911-1995. One coverage contains fire start locations, which are points with several fire-related attributes (e.g., start date, fire name, and cause), regardless of the fire's eventual size. Another coverage contains mapped fire areas greater than about 125 ha, which are polygons covering the areas burned. From this polygon dataset, several additional fire-related attributes can be derived and mapped, such as the range of intervals between burning and sizes of past fires at a site. Historically, fires outside the LPNF boundary were not mapped in a consistent way, unless they threatened Forest lands (Cahil, personal communication). Visual inspection showed that burned areas within a 3200 m buffer of the LPNF boundary were mapped consistently, and this was chosen as the limit of the study area. Although this is a somewhat arbitrary distance, it is a reasonable balance between losing a great deal of valuable information (i.e., by stopping analyses at the LPNF boundary) and including areas exhibiting mapping bias (i.e., by including the area of all mapped fires in the dataset).

The Main Division of LPNF contains portions of the central-western and southwestern ecological regions of California (fig. 1; Hickman 1993). Our analysis uses a recently completed GIS database of vegetation data that was originally prepared for the California Gap Analysis Project (Davis and others 1995). For each vegetation polygon, up to three primary species comprising the dominant overstory of vegetation have been classified into the hierarchical system defined by Holland (1986), and we have aggregated these types to the community level in the Main Division (table 1).

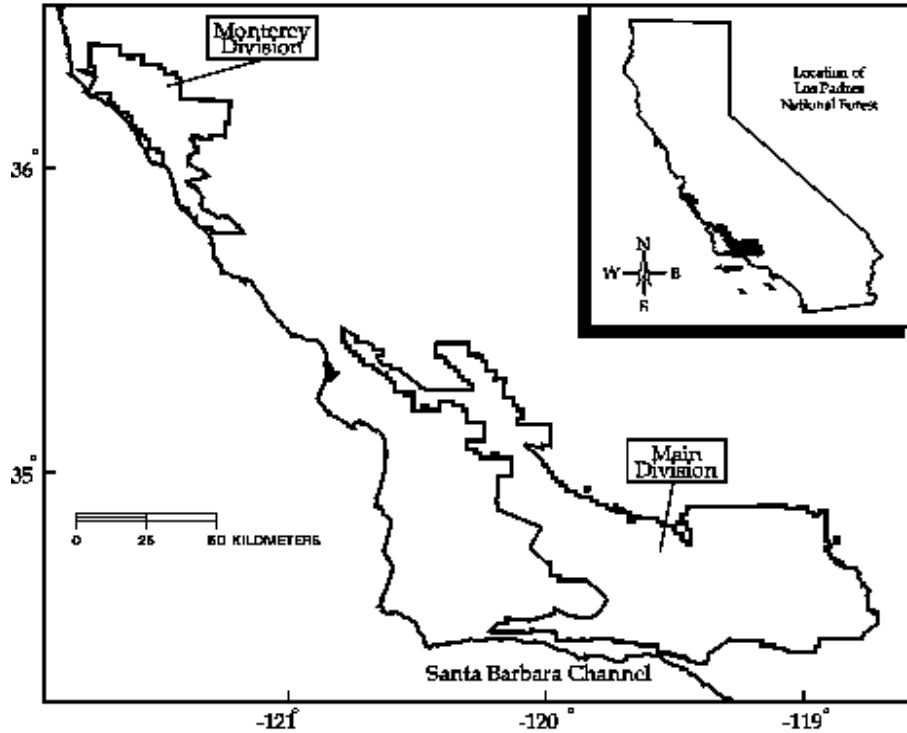


Figure 1. Location of map for Los Padres National Forest

Table 1. Holland community types in the Main Division of LPNF. Code "Rip" represents an aggregation of various riparian and wetland types.

Holland code	Community	Area (ha)	Proportion
32000	Coastal Scrub	57828	0.062
35000	Great Basin Scrub	8676	0.009
37000	Chaparral	499863	0.532
39000	Upper Sonoran Subshrub Scrub	2108	0.002
42000	Valley and Foothill Grassland	50917	0.054
Rip	Riparian/Wetland Mix	6652	0.007
71000	Cismontane Woodland	78223	0.083
72000	Pinon and Juniper Woodlands	114440	0.122
81000	Broadleaved Upland Forest	34148	0.036
83000	Closed-cone Coniferous Forest	234	0.000
84000	Lower Montane Coniferous Forest	23562	0.025
85000	Upper Montane Coniferous Forest	17773	0.019

Methods

Our methodology for identifying homogeneous fire landscapes consists of the following three steps: create fire history attribute variables and eliminate redundant information; perform statistical clustering into the desired number of classes; and examine spatial clusters for interpretation and coherence as fire landscapes. Although this process is quantitative and repeatable, it includes case-specific decisions (e.g., number and definition of attribute variables, size of grid cells, number of fire landscape classes, and clustering algorithm), depending on the data available and the research objective.

The nine fire history attribute variables used in this study (table 2) incorporate the frequency of burning, the range of fire sizes and intervals between burning, and the seasonality and cause of fire starts. For individual spatial units or "observations" for clustering, the study area was gridded into cells that are 2 k on a side, resulting in nine grid coverages in a GIS. This cell size reflects the approximate spatial accuracy of fire start data, and the resulting number of cells is appropriate for most statistical clustering exercises. Cells contained summed number of occurrences for each point-related attribute, while polygon-related attributes were calculated by weighted spatial averages across cells. Data were then exported from the GIS as ASCII text files for non-spatial statistical analysis, which was performed using the Splus software package. Although incorporating as many fire-related attributes as possible can lead to important insights, it also greatly increases the complexity of the clustering exercise and can include redundant variables. For these reasons, principal components analysis (PCA) was used to reduce the dimensionality of the dataset and eliminate redundant information (Joliffe 1986). This reduction is achieved by a transformation to a new set of variables, the principal components (PCs), which are uncorrelated and defined as linear combinations of the original variables. We then evaluated the importance of each principal component (PC) factor, based on the proportion of total variance explained and correlations to original fire history attribute variables. Using a minimal number of PCs, while still accounting for a specific level of total variance (e.g., often a 90 or 95 percent cutoff), resulted in "observations" for clustering.

Table 2. Fire history attribute variables. The biggest and smallest fires are measured in ha; the fire season is defined as the months May through October.

Name	Description	Type
burned	Number of times burned	Polygon
longest	Longest interval between burns	Polygon
shortest	Shortest interval between burns	Polygon
biggest	Biggest fire	Polygon
smallest	Smallest fire	Polygon
inseason	Number of ignitions during fire season	Point
outseason	Number of ignitions outside fire season	Point
lightning	Number of lightning ignitions	Point
nonlightning	Number of non-lightning ignitions	Point

As clustering is primarily an exploratory technique for identifying patterns or groups in data, there is no correct or incorrect approach that will work in all cases. There are a wide variety of statistical clustering algorithms available, and it is largely up to the user to determine

which to use and how many classes to specify. We used several of the model-based hierarchical clustering methods (Banfield and Raftery 1993, Gordon 1981) that are available through Splus, varying the number of PCs to retain, the algorithm to use, and the number of output classes to specify. Spatial relationships were not factored into the clustering process (i.e., cell location is not used in clustering algorithms), although geographic coordinates for each cell are retained for later use.

Resulting data clusters were then related back to the original nine fire attribute variables for interpretation. Because the number of "observations" or data units being clustered is dependent on cell size, statistical significance of differences between clusters (e.g., difference in mean number of times burned between fire landscape classes) is somewhat artificial. Clusters become less unique as more are specified; thus, a large number of classes is preferable to address the question at hand, but not so many that interpretation is meaningless. In addition, clusters should be mapped out to examine their spatial characteristics, as some algorithms produce clusters that greatly fragment the landscape, while others produce coherent units that make sense as fire landscapes. To accomplish this, clustered data units with their fire landscape class and geographic locations were exported from Splus and imported back into the GIS. After evaluating the spatial coherence of various clustering scenarios, we chose one for this study and derived vegetation distributions for select fire landscape classes.

Results

In performing PCA, we used the correlation matrix between the nine original fire history attribute variables (table 3). This produced nine new factors, each of which explains a successively smaller portion of total variance in the original dataset (fig. 2). We decided to retain PC1 through PC5, reducing the dimensionality of the dataset to be clustered from nine to five variables and retaining 95 percent of variance explained. Figure 3 shows PC loading scores (i.e., the linear combinations) for original fire history attribute variables.

Of the many clustering scenarios, we chose the results from the Ward's method algorithm (Ward 1963) with six fire landscape classes for use in analyzing vegetation distributions in the Main Division of LPNF. For the six fire landscape classes, boxplots in figure 4 show their relationship to original fire history variables. Mapping this set of results (fig. 5) indicates that they form relatively discreet spatial units at the landscape scale, instead of greatly fragmenting the study area, as some of the other six-class clustering algorithms produced.

Table 3. Correlation matrix for fire history attribute variables

Variable	BN	LO	SH	BG	SL	IS	OS	LI	NL
Burned (BN)	1.00	-	-	-	-	-	-	-	-
longest (LO)	-0.62	1.00	-	-	-	-	-	-	-
shortest (SH)	-0.84	0.92	1.00	-	-	-	-	-	-
biggest (BG)	0.64	-0.45	-0.56	1.00	-	-	-	-	-
smallest (SL)	0.34	-0.45	-0.43	0.82	1.00	-	-	-	-
inseason (IS)	0.05	0.06	0.01	-0.06	-0.11	1.00	-	-	-
outseason (OS)	0.10	-0.01	-0.05	0.00	-0.05	0.65	1.00	-	-
lightning (LI)	-0.20	0.18	0.21	-0.14	-0.11	0.44	0.18	1.00	-
nonlightning (NL)	0.13	-0.00	-0.06	-0.01	-0.08	0.94	0.79	0.16	1.00

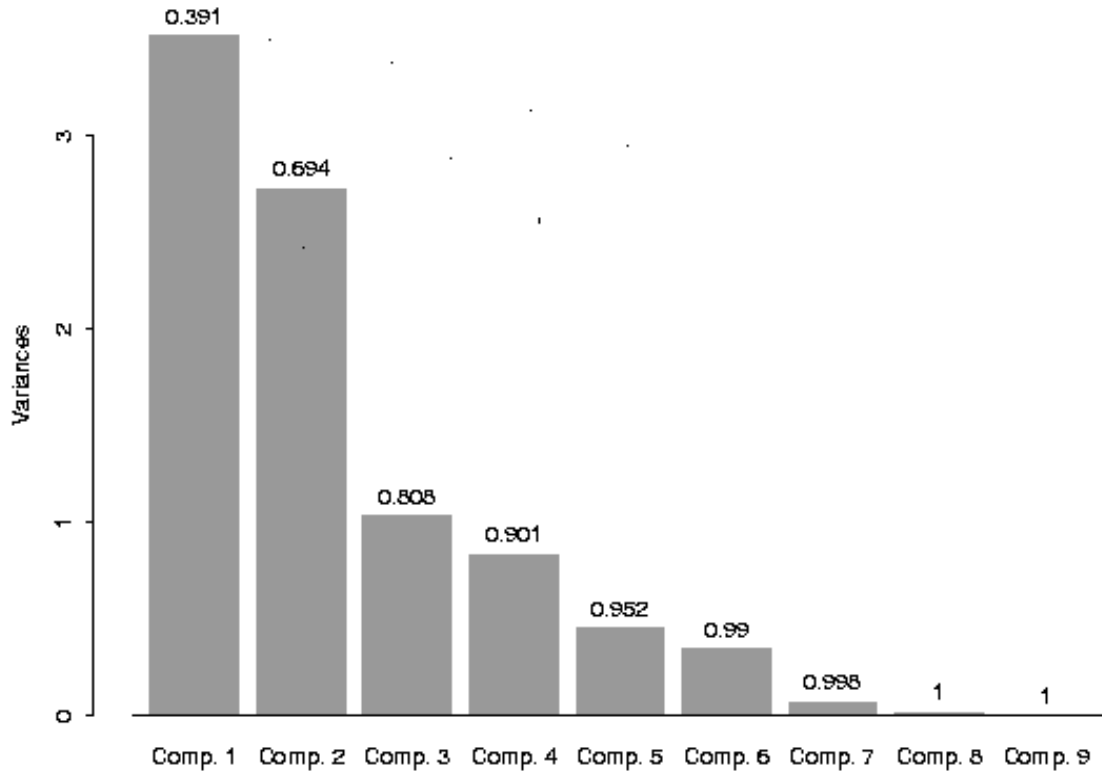


Figure 2. Proportion of total variance accounted for by each principal component.

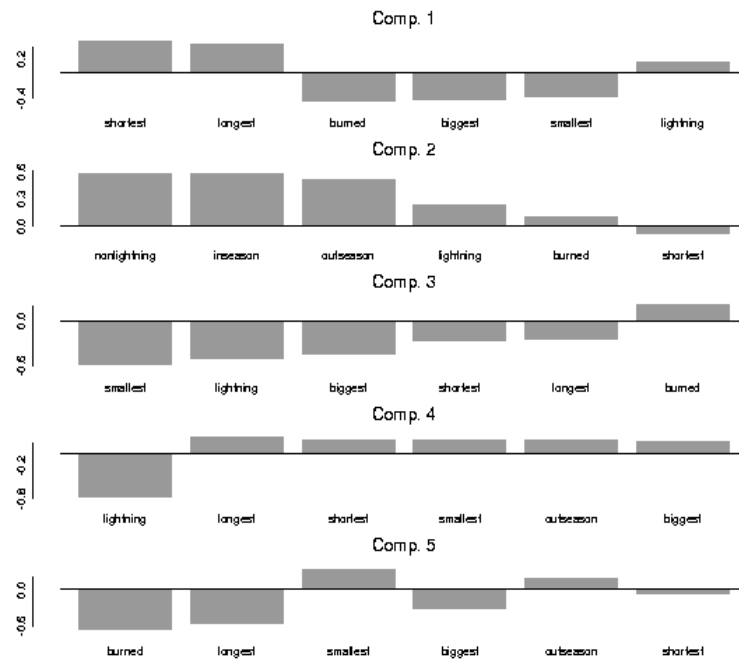


Figure 3. Loadings of fire history attribute variables for each principal component. Of the nine variables, the six largest loadings are shown here.

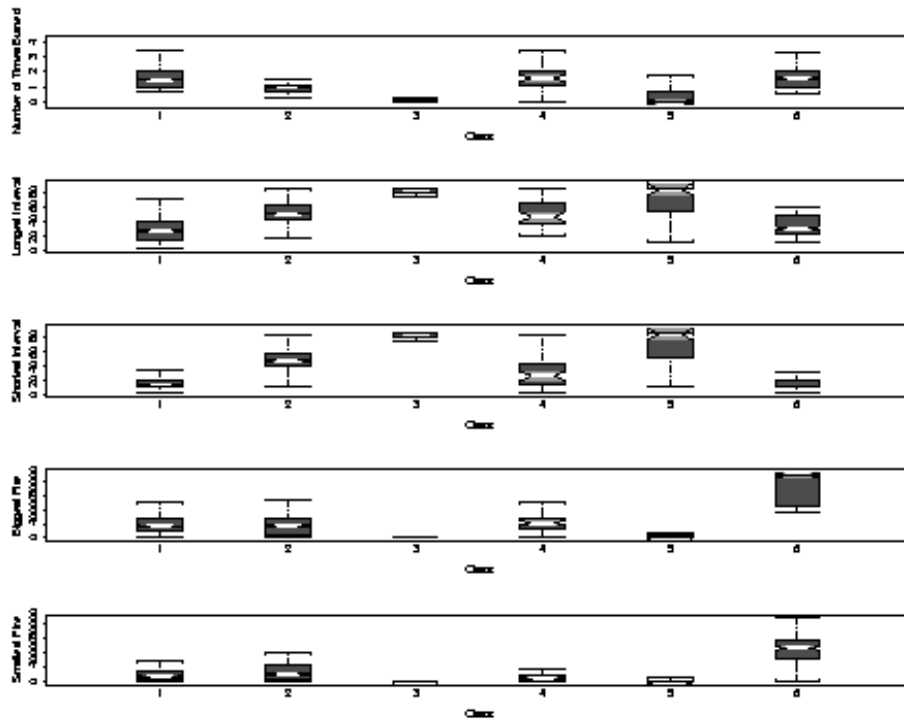


Figure 4A. Boxplots showing distributions of fire history attribute variables by fire landscape class; polygon-related variables only. Notches about mean values would represent 95 percent confidence intervals, given cells with 2k on a side; the size of boxes indicates the quartiles, and the outermost whiskers indicate 1.5 times the interquartile range.

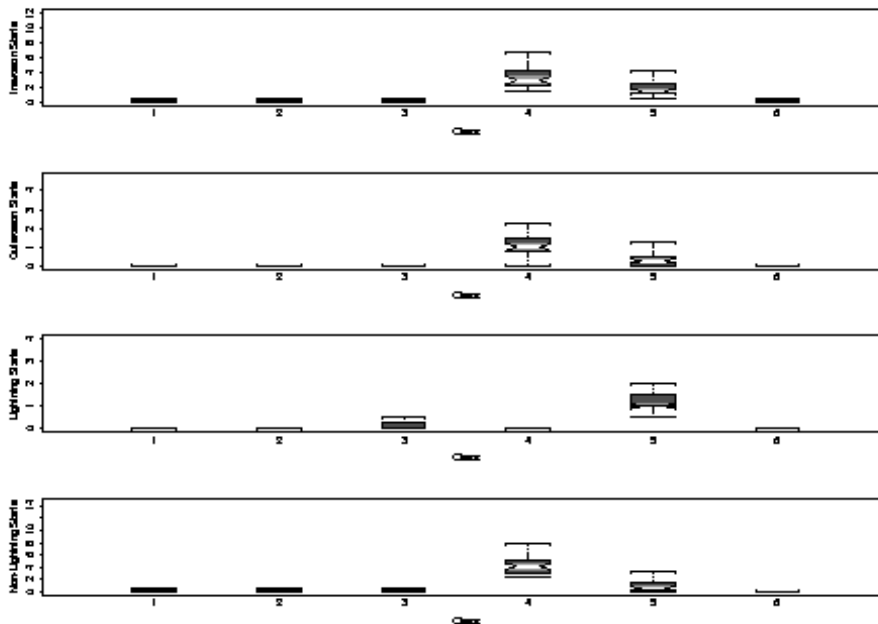


Figure 4B Boxplots showing distributions for point-related variables .

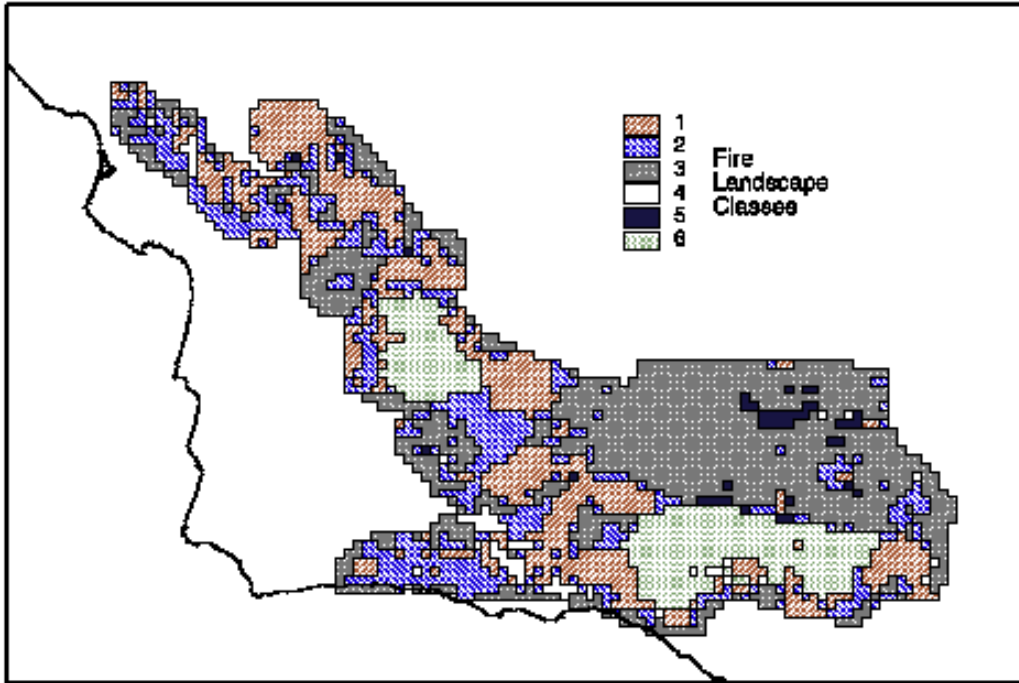


Figure 5. Mapped fire landscape classes, six-class results. Ward's clustering method. Spatial patterns reflect both fire polygon and point data

Discussion

The type of clustering exercise in this study is exploratory and allows the user several opportunities for case-specific decisions. For example, choosing different cell sizes might lead to insights about how scale interacts with various fire history attributes and the patterns of fire landscapes that result. On a more practical level, sampling from available "observations" or clustering with fewer PCs might make the problem more tractable, given software or computer memory limitations. Choosing a smaller number of fire landscape classes or a simpler statistical clustering algorithm can also lower processing requirements, but it can result in fire landscapes that are not interpretable or useful.

Our experience with many of these decisions and this dataset has highlighted important aspects of using point (i.e., fire start location) and polygon (i.e., fire area) data together in this type of analysis. With small numbers of fire landscape classes, it appears that some clustering algorithms emphasize variation in point data, while others emphasize variation in polygon data, and this may depend on the nature and number of PCs used. Spatial characteristics of the original fire history and numerical aspects of the digital dataset itself must also play a factor, and this is an area for future work. Classes generally became associated with only one fire history attribute, or a few highly correlated ones, as increasing numbers of classes were specified. Consequently, some users of this approach may want to cluster point- and polygon-related attributes as separate datasets (e.g., to examine fire ignition landscapes versus fire spread landscapes).

Clustering for intermediate numbers of classes can lead to fire landscapes that differ in terms of both fire ignitions and fire spread (fig. 4). All six fire landscape classes differentiate

themselves in their polygon-related attributes, while Classes 3-5 also vary in terms of the timing and cause of fire starts, which are point-related attributes. The spatial characteristics of these classes (fig. 5) also provide interesting insights. Class 3 areas rarely burn, experience some lightning starts in the fire season, and cover a large area of the map; in contrast, Class 5 areas burn occasionally but cover a much smaller area and experience a higher number of ignitions, regardless of timing and cause. Class 4 areas, which cover the least area of the six classes and tend not to show any spatial grouping, actually burn more often than Classes 3 or 5 and experience high numbers of human-caused starts, regardless of timing.

Acknowledging that fuel dependency must play an important role at some scale, we hypothesize that this fire landscape classification is appropriate for examining vegetation distributions, and we focus on three of the widespread classes (Classes 1, 3, and 6). Therefore, the null hypothesis would be that analysis of fuel dependency is appropriate at the scale of the entire study, making these fire landscapes artificial subdivisions of a homogeneous area. Differences in fire history would therefore simply be manifestations of a stochastic process in space and time, and vegetation composition in any given fire landscape should be roughly the same. Using the actual vegetation distribution of Holland types (table 1), one can use the proportion of each type across the entire Main Division as the expected proportion one should find in any given sub-region. Although the statistical significance of testing the null hypothesis is not meaningful in this spatial context, examining expected versus observed vegetation distributions in sub-regions is one way to address the scale of analysis issue.

Class 3 contains approximately half as much chaparral and over twice as much pinon-juniper woodlands (fig. 6) as would be expected under the null hypothesis, providing evidence

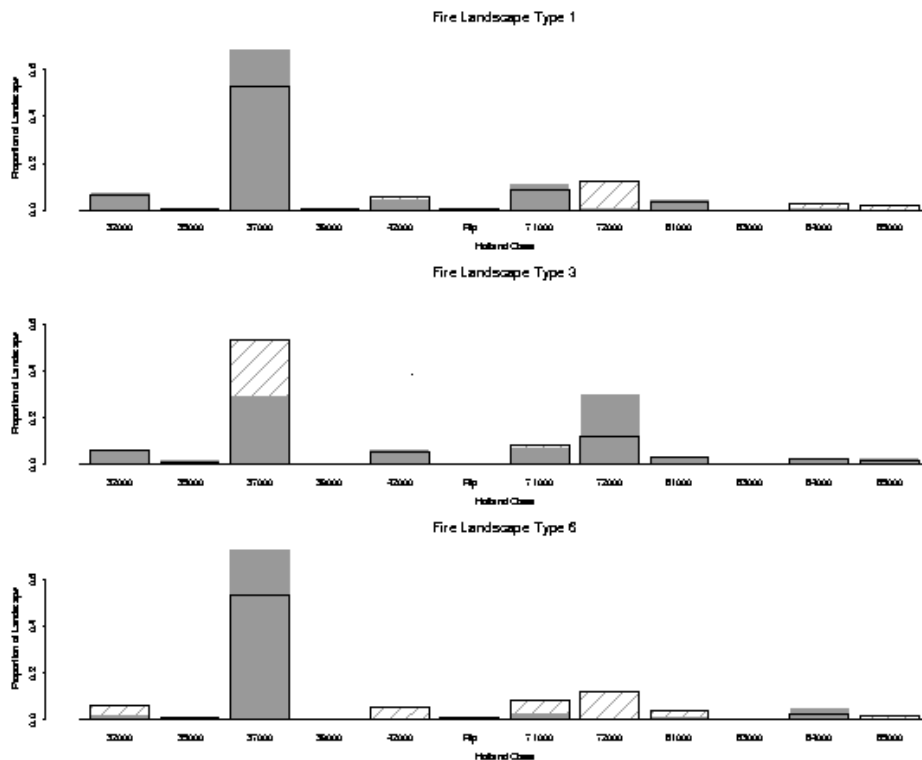


Figure 6. Expected (hatched bars) versus observed (solid bars) vegetation distributions for select fire landscapes.

for its rejection. This makes sense, as Class 3 is extensive and contains over 90 percent of the pinon-juniper woodlands, which rarely burn, that exist in the study area. Classes 1 and 6 exhibit a very similar vegetation composition to each other, but they have substantially more chaparral and far less pinon-juniper woodlands than would be expected under the null hypothesis. This provides further evidence for rejecting the null hypothesis, supporting the assertion that these fire landscapes are meaningful sub-regions which capture some degree of fuel dependency at a finer scale than the entire study area. However, it is interesting to note how different Classes 1 and 6 are in terms of fire size characteristics (fig. 4A), given their many other similarities and their spatial proximity (fig. 5). Local factors other than fuels, such as topography or road access for fire suppression, must be included for a more complete understanding. Spatial neighborhood effects, such as those identified by Chou and others (1990), must also be investigated.

The methodology we propose here shows promise for future work in understanding the dominant factors that control fire regimes and the scales at which they operate. Results will only be as good as data used in the analysis, and clusters identified may sometimes be the meaningless outcome of stochastic processes. Nonetheless, it is general enough to incorporate a wide variety of fire history information, and its flexibility will accommodate a number of research goals.

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Fire Management and GIS: A Framework for Identifying and Prioritizing Fire Planning Needs

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Abstract

With more funding becoming available for prescribed fire, it will be increasingly important to optimize selection of critical areas most in need of burning, on the basis of value, hazard, and risk criteria. A process under development by Sequoia and Kings Canyon National Parks integrates these criteria within a geographic information system (GIS) framework. Our goal is to identify high priority areas for prescribed burn treatment to optimize use of funding and resources. This use of GIS merges natural resource data with fire management planning information. We developed three major models that were integrated within a GIS: **Value**, **Hazard**, and **Risk**. The **Value** model consisted of two major parts: ecological need and infrastructure and human life/safety. For ecological need, we considered burn rotations on the basis of historic fire-return intervals (pre-1860) within major plant communities. The longer that the current time interval without a fire exceeded the maximum historic fire return interval, the greater the priority rating for returning fire to an area. For infrastructure and human life and safety, we gave greater weight to areas of high visitation and areas with buildings or other facilities when developing the GIS data. The **Hazard** model considered key factors (fuel model, slope, aspect, elevation) that affected management's ability to control fires, or a fire's resistance to control once ignited. Finally, the **Risk** model considered historic wildfire occurrence from both human and lightning causes. We aggregated these models in various ways depending on the specific questions we were attempting to answer, although each model could be output as a separate analysis. As severe wildfires continue to increase in North America due to continuing fuel accumulation, the use of fire as an option for fuel reduction and ecosystem management will become more important. In addition, the use of GIS will be an essential tool for planning and implementing such landscape-scale management programs.

Introduction

Project Area

Sequoia and Kings Canyon National Parks (SEKI), located in the southern Sierra Nevada, are topographically rugged with elevations ranging from 1,600 to 14,495 feet. Major drainages are the Kern, Kaweah, Kings, and San Joaquin Rivers. The Parks encompass about 864,383 acres. Three broad vegetation zones dominate the Parks: the *foothills* (1,600 to 5,000 ft) composed of annual grasslands, oak and evergreen woodlands, and chaparral shrubland; the *mixed-conifer forest* (5,000 to 10,000 ft) with ponderosa pine and white and red fir forests, and

the *high country* (10,000 to 14,000 ft) composed of subalpine and alpine vegetation, and unvegetated landscapes. Within the mixed-conifer zone, well-defined groves of giant sequoia are found.

The climate is distinctly Mediterranean with cool moist winters and warm summers with little rainfall (seasonal summer thunderstorms occur sporadically at higher elevations). Precipitation increases as elevation increases, to about 40 inches annually from 5,000 to 8,000 feet on the west slope of the Sierra, and then decreases as one moves higher and to the east. Substantial snow accumulations are common above 5,000 feet during the winter.

European settlement of the area began in the 1860's with extensive grazing, logging, and mineral exploration. The Parks were founded in 1890, originally with the intent of protecting sequoia groves from logging, but were expanded to include much of the surrounding rugged, high mountains.

Historic Fire Regimes

Historically, fire played a key ecological role in most Sierra Nevada plant communities. At the landscape level, fire history research shows an inverse relationship between fire frequency and elevation in areas of conifer forest (Caprio and Swetnam 1995). Currently, fire history information is lacking for the foothills area of the park. The cause of fires prior to European settlement is usually attributed to ignitions by lightning or Native-Americans. However, since the actual source of these fires cannot be determined, the specific cause(s) remain largely unknown. The seasonal occurrence of pre-settlement fires was similar to the contemporary late summer-early fall fire season (Caprio and Swetnam 1995). Historic fire size ranged from large fires burning across multiple watersheds, to fires restricted to a few or a single trees. Fire intensity was variable both spatially and temporally (Caprio and others 1994, Stephenson and others 1991). In much of the mixed-conifer zone, fires were primarily non-stand replacing surface fires, although many exceptions exist (Caprio and others 1994). Specific regional fire years have also been identified (years in which fires have been recorded at sites from throughout the southern Sierra Nevada where pre-European fire history has been reconstructed), usually occurring during dry years (Swetnam and others 1992), along with long-term variation (1,000-2,000 years) in the fire regime associated with climatic fluctuations (Swetnam 1993).

Fire regimes in the Sierra Nevada changed dramatically beginning with European settlement around 1850-1870 (Caprio and Swetnam 1995, Kilgore and Taylor 1979, Warner 1980). Factors that contributed to this decline in fires during the latter portion of the 19th century include the loss of Native-American populations that used fire and heavy livestock grazing that reduced herbaceous fuels available for fire spread (Caprio and Swetnam 1995). The occurrence of fires of large size decreased dramatically during the 20th century because of active fire suppression. This change in fire regime has led to unprecedented fuel accumulations in many plant communities, structural and composition changes, and has resulted in an increased probability of widespread severe fires (Kilgore 1973).

Fire as a Tool

Most land management agencies classify fires as either “suppression fire” or “prescribed fire”. The prescribed fire category is further broken down into prescribed natural fires (PNF), ignited naturally by lightning (unplanned ignitions), or management ignited prescribed fires (MIPF; planned ignitions). This paper focuses on the use of planned ignitions to achieve land management goals.

Land management agencies use fire for a variety of reasons, including: fuel reduction for protection of human safety and developments, resource protection, site preparation, thinning, elimination of undesirable species, protection of desirable species, and reintroduction of fire as a natural process. Agencies with large land areas are interested in restoration of fire as a natural process. In recent years, Federal land management agencies have begun to re-emphasize the return of fire to the ecosystem. Reintroducing fire as a natural process after nearly a century of fuel accumulation will not be easy for many reasons. Some issues include difficulties in fire control and associated costs, unnatural or unwanted fire effects, and social acceptance of fire, including smoke impacts on neighboring communities. Despite these issues, planned ignitions will be a key tool for putting fire back into the ecosystem (Federal Wildland Fire Management Policy and Program Review 1995).

Results and Discussion

Value Model

The **Value Model** was divided into two components: ecological need and human life safety/infrastructure. The motivation for an ecological need component was based on the National Park Service’s mission statement to “protect and preserve” natural resources. Fire is an important process and component for working towards this goal.

The ecological need component provided a rating index to rank areas on the need for fire. All areas within the Parks’ 11 broad vegetation classes were rated based on *fire return interval departures* (FRID). This rating permitted us to assign priorities based on ranks for all areas in our model. A specific value for each area’s FRID was based on the *time since the last fire* (TSLF), relative to the maximum average fire return interval (RI_{max}) prior to European settlement for each vegetation type. The historic fire regime return interval values (**table 1**) were based on reconstructed fire history chronologies derived from tree-ring samples obtained from fire-scarred trees in the vicinity of Sequoia and Kings Canyon National Parks. If information for a vegetation type did not exist from within or near the Parks, the information was obtained from the literature (Caprio and Lineback in prep.). To provide a conservative estimate, we used the RI_{max} for each vegetation class. The TSLF was derived from historic fire records (started in 1921) or was based on the last widespread fire date recorded by the fire history reconstructions. On the basis of history chronologies, the year 1899 was chosen as a conservative base year for the occurrence of the last fire for all areas where no recent historic fires (since 1921) have occurred (**fig. 1**).

Table 1. Maximum average fire return intervals (RI_{max}) for vegetation classes (Caprio and Lineback in prep.).

Vegetation classification	RI_{max}
1 - Ponderosa mixed conifer	6
2 - White fir mixed conifer	16
3 - Red fir mixed conifer	50
4 - Lodgepole pine forest	163
5 - Xeric conifer forest	50
6 - Subalpine conifer	508
7 - Foothills hardwood and grassland	17
8 - Foothills chaparral	60
9 - Mid-elevation hardwood	23
10 - Montane chaparral	75
11 - Meadow	65

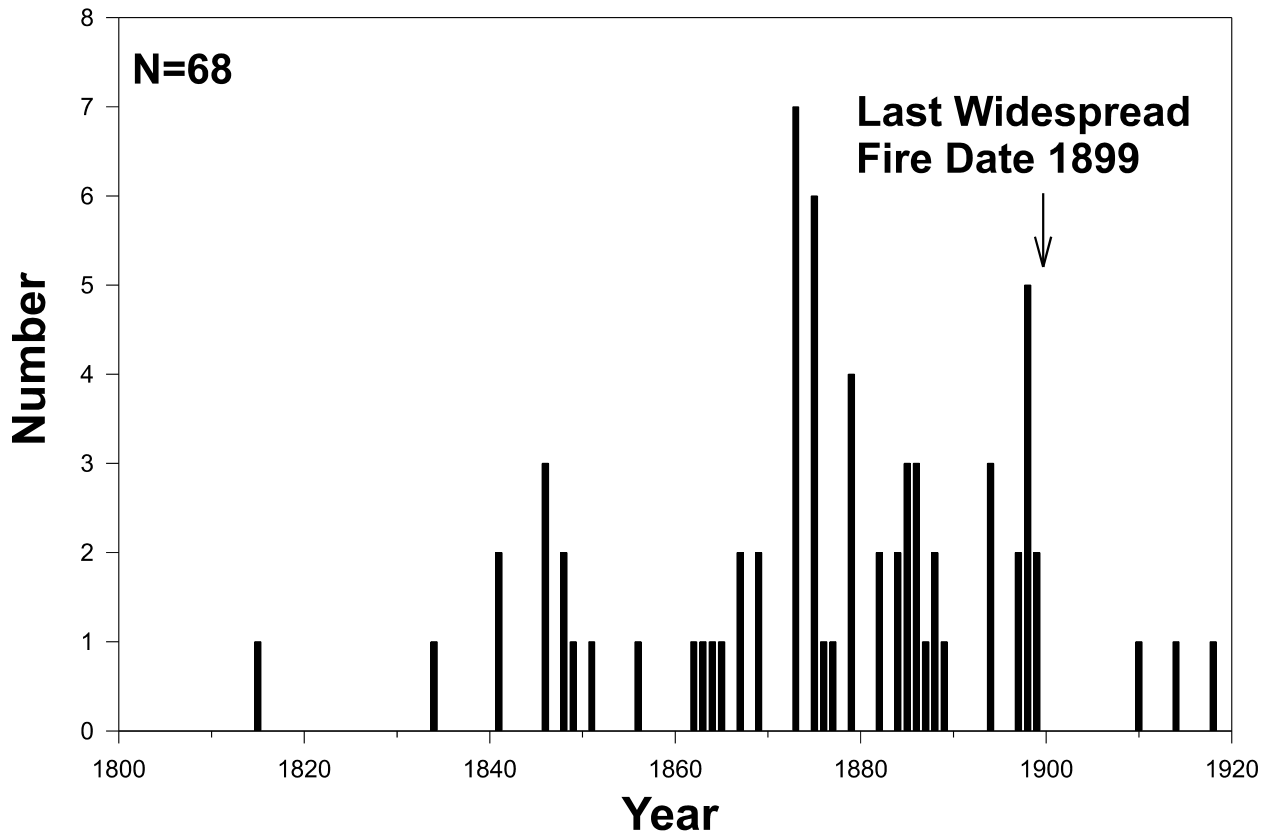


Figure 1. Fire history dates (before 1920) for sites in or near Sequoia and Kings Canyon National Parks.

By using these inputs, a derived index was calculated to quantify the departure of the vegetation type from its pre-European settlement fire return interval. The equation for the index is:

$$\text{Fire Return Interval Departure (FRID)} = \frac{\text{RI}_{\text{max}} - \text{TSLF}}{\text{RI}_{\text{max}}}$$

in which,

RI_{max} = maximum average return interval for the vegetation class,

and,

TSLF (time since last fire) = time that has passed since the most recent fire from historic fire records or using the baseline date of 1899 derived from the fire history chronologies.

The departure index ranged from -16 to 1 given our data set with a beginning TSLF of 1899 and a minimum RI_{max} value of 6. We reclassified the index values into four rating categories that were likely to capture current forest conditions and the need for burning based on historical fire intervals (**table 2**).

Table 2. Fire return interval departure index for each ecological need category.

Extreme	High	Moderate	Low
≤ 5	> -5 and ≤ -2	> -2 and ≤ 0	> 0

By using this component of the model, these categories were mapped spatially across the Parks by using a geographic information system (GIS) (**fig. 2**). While the dominant ecological need category was “moderate” (**fig. 3**), the “extreme” and “high” categories were most important in the lower and mid-elevation conifer forests. These areas have the highest visitor use and are consequently the greatest human safety concern to park managers.

In the infrastructure and life/ safety component of the **Value Model**, we addressed the anthropogenic and natural resources on the landscape that could potentially be impacted by fire. Each factor was divided into three categories: high, moderate, or low, based on a number of criteria (**table 3, 4**).

Table 3. Infrastructure values: criteria as they relate to replacement costs or disruption of services caused by fire.

High	Moderate	Low
developed sites, power/phone lines, electronic sites, pipelines	campgrounds, picnic areas, maintained roads	trails, vistas, overlooks, fences, backcountry camp sites

Table 4. Life/safety values: categories for developed areas as they relate to the potential threat to human life from fire.

High	Moderate	Low
Bearpaw High Sierra Camp, Oriole Lake, Atwell Area, Cabin Cove Area, Silver City Area, Giant Forest Area, Ash Mountain Area, Crystal Cave Area, Crystal Cave Road, Mineral King Road, General Hwy from Hospital Rock to Eleven Range	Grant Grove Area, Red Fir Area, Lodgepole Area, Wuksachi Area, Dorst Campground, Faculty Flat Area, Generals Hwy from Eleven Range to Grant Grove	Cedar Grove Area, Mineral King Valley Area

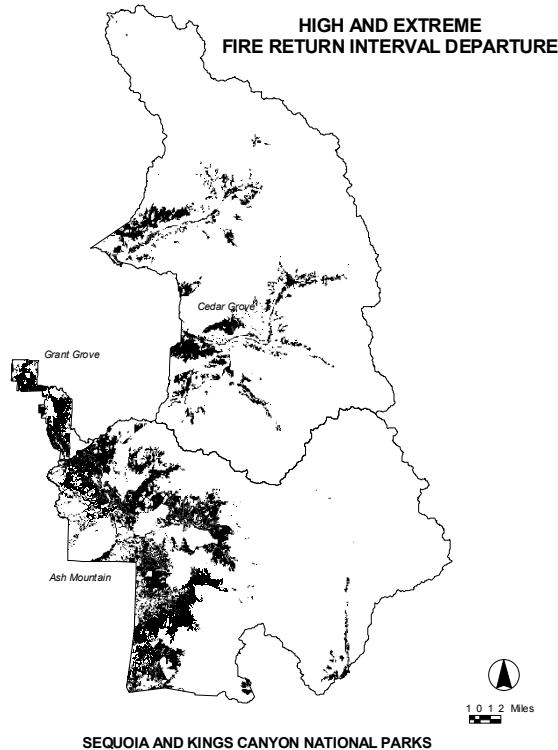


Figure 2. Spatial extent of extreme and high categories derived of the fire return interval departure (FRID) analysis from the ecological need component of the *Value Model* for Sequoia and Kings Canyon National Parks.

Hazard Model

In the **Hazard Model** we examined key parameters that affect a manager’s ability to control a fire (i.e., resistance to control). The four parameters were fuel model, slope, elevation, and aspect. Slope, aspect, and elevation were derived from a digital elevation model (DEM). The fuel models used were the 13 standard fuel models for fire behavior estimation (Albini 1976)

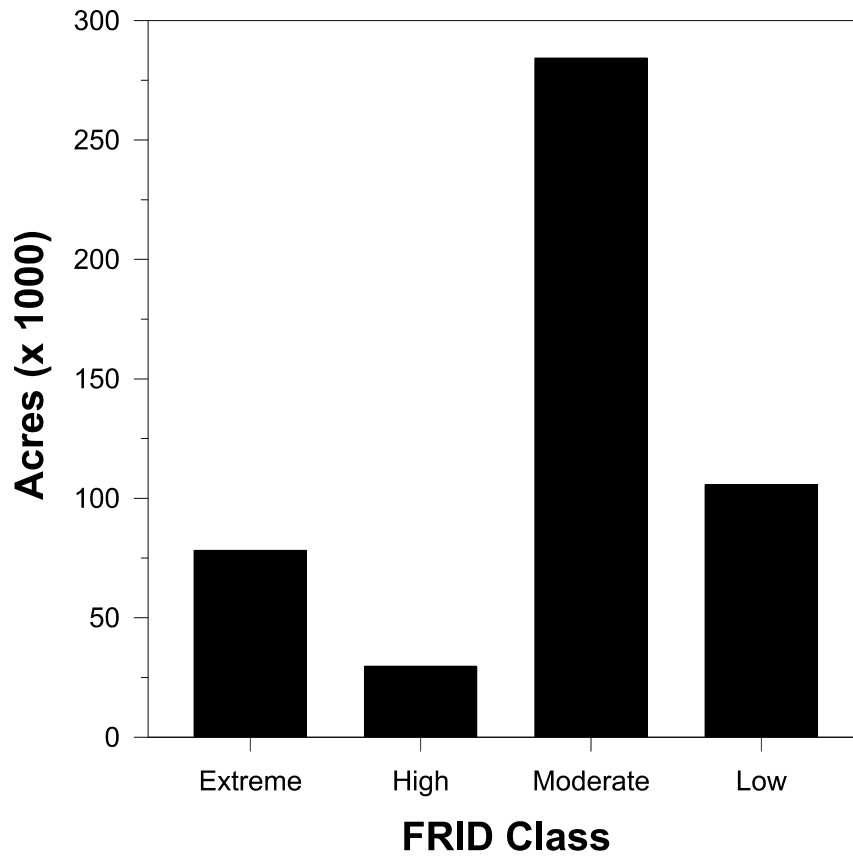


Figure 3. Acreage within each of the fire return interval departure (FRID) classes for the total vegetated area in Sequoia and Kings Canyon National Parks.

and "custom models" (Burgan and Rothermel 1984) developed from Park fuels surveys by the Park's fuels specialist (**table 5**). Custom models were developed because standard fuel models were not representative of the actual fuel conditions found within some vegetation types within the Parks.

Table 5. Custom fuel model descriptions ("low elevation" $\leq 6,500$ ft, "mid elevation" = 6,500-8,000 ft, and "high elevation" $\geq 8,000$ ft).

Custom model description	Custom model number
Low elevation short needle conifer	14
Low elevation pine	15
Mid-elevation short needle conifer	16
Mid-elevation pine	17
High elevation short needle conifer	18

Each of the four parameters was divided into three categories: high, moderate, or low hazard, based on specific elements within each parameter (**table 6**). Applying this model using GIS (**fig. 4**) indicated that the largest portion of the Parks was in the low hazard category and the smallest portion was in the high category (**fig. 5**).

Table 6. Hazard Model parameters, ratings, and individual elements within each parameter.

Parameter	High	Moderate	Low
Fuels	4, 9,10,15	1, 2, 3, 5, 6, 14,16,17	8, 18
Slope	40 pct.+	11-39 pct.	0-10 pct.
Elevation	0-5000 ft.	5001-8000 ft.	8000+ ft.
Aspect	S, SW	SE, E, W	N, NE, NW

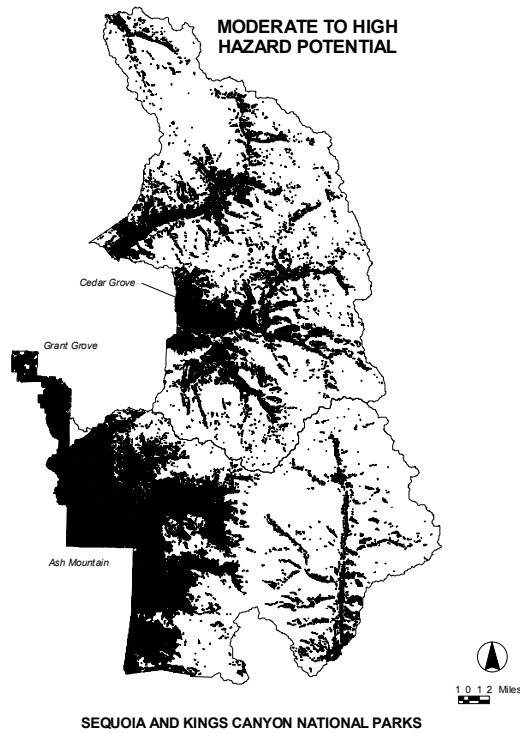


Figure 4. Spatial extent of the two Hazard Model categories of Sequoia and Kings Canyon National Parks

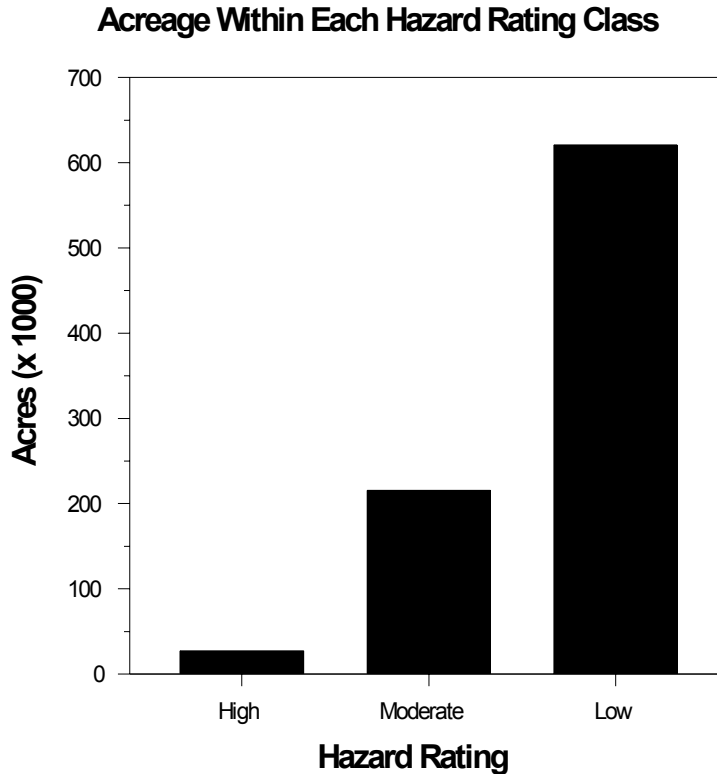


Figure 5. Acreage within each of the **Hazard Model** classes for the total vegetated area of Sequoia and Kings Canyon National Parks

Risk Model

In the **Risk Model**, we identified the risk of potential ignitions by examining the historic occurrence of both human and naturally (lightning) caused fires. We divided the Parks into watersheds and plotted the occurrence of reportable fires over the past 10 years of record (**fig. 6**). We compared the number of fires with the ratio of fires per 1,000 acres for the 13 watersheds within the Parks. The watershed with the greatest risk of a non-management ignition (an ignition due to lightning or human-caused wildfire) was the South Fork of the Kings (135 unplanned fires). The watershed with the largest number of human caused wildfires was the Marble Fork of the Kaweah, followed by the South Fork of the Kings and the Middle Fork of the Kaweah (**fig. 7**). All three of these watersheds are areas of high visitor use. The ratio data showed that the watershed with the greatest risk per acre was Kings Tributaries (Grant Grove), followed by the Marble Fork of the Kaweah, with most of the risk attributable to human-caused fires. The risk from natural lightning fires varied to a lesser degree among watersheds and appeared to be related to the proportion of a watershed that was vegetated. The ratio data for the Kings Tributaries watershed was somewhat misleading because of the small size of the area (3701 ac). These two analyses indicate that the greatest risks were located in the Marble Fork of the Kaweah watershed, followed by the Kings Tributaries. A key assumption in the **Risk Model** was that locations where fire ignitions have historically occurred will continue to be sources of ignition.

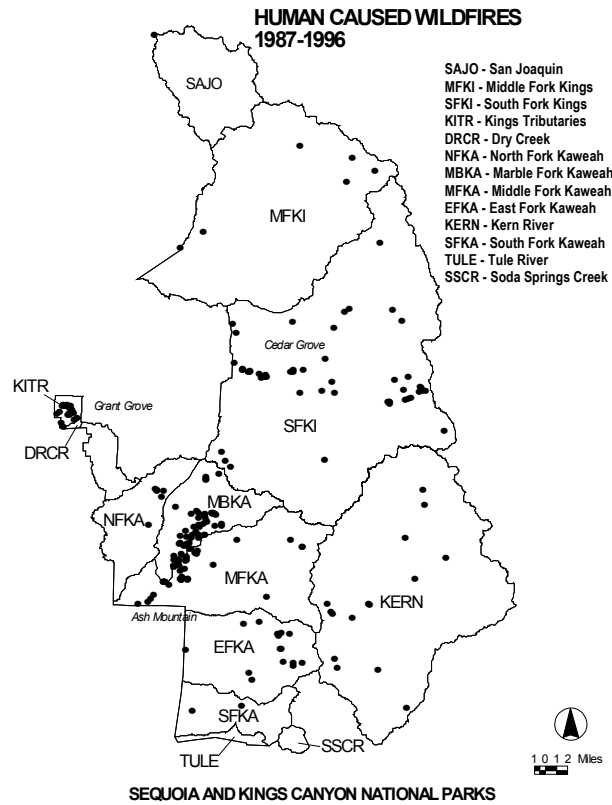


Figure 6. Human caused fire ignition points for the period from 1987 to 1996 used in part for developing the Risk Model

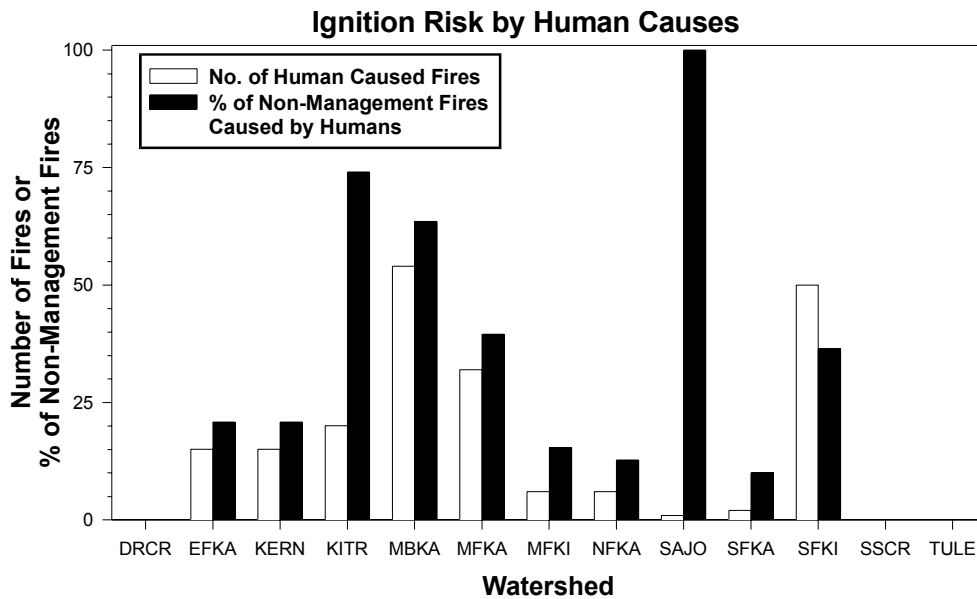


Figure 7. Ignition risk by watershed for human caused wildfires. The figure gives total number of human caused fires and proportion of these relative to all unplanned fires within each watershed of Sequoia and Kings Canyon National Parks. Watershed abbreviations are: DRCR – Dry Creek; EFKA- East Fork of the Kaweah; KERN – kern River; KTR – Kings Tributaries; MBKA – Marble Fork of the Kaweah; MFKA - Middle Fork of the Kaweah; MFKI - Middle Fork of the Kings; NFKA – North Fork of the Kaweah; SAJO – San Joaquin River; SFKA – South Fork of Kaweah; SFKI – South Fork of the Kings; SSCR – Soda Springs Creek; TULE – Tule River

Model Summary

The framework presented for the development of GIS models for prioritizing fire planning needs produce simple, color-coded ratings on park maps for each of the model components. The areas with the highest priority ratings based on either **Value**, **Hazard**, or **Risk** can be viewed spatially when determining which areas to focus planned ignition efforts. Depending on the program goals and questions asked, the models can be used separately or merged, by using either overlays or by combining model algorithms to produce integrated maps of a combination of models. Other applications for this framework include: fire prevention planning, fire preparedness planning, and use in National Environmental Policy Act (NEPA) compliance documents.

Future Model Considerations

As these models evolved and developed, potential improvements were identified in the form of model validation, improved source data, and model refinement. Some of the planned changes include:

- The fuels and vegetation data will be improved. Some modification and customization of these themes will occur as we add to our information base.
- The ecological need component of the **Value Model** should incorporate the importance of repeated burns in areas that have been burned for fuel reduction. These areas will then have a higher priority than similar unburned areas since there is value in not letting fuel conditions deteriorate into the severe classes again. The secondary or re-burns are also usually less costly than the primary fuel reduction burn.
- The ecological need component should also incorporate vegetation fire return intervals that are more sensitive to local landscapes. This refinement will result in historic fire return intervals that more fully consider landscape differences such as aspect, elevation, slope, and watershed.
- Additional inputs into the ecological need component could include a weighting for our confidence about the input data. For example, vegetation types for which we have a poor understanding of pre-European fire history might be given a weighting that would reflect the uncertainty of our knowledge. Another potential input into this component could be the identification of critical areas or habitats that would either be a target for fire or protected from fire because of specific ecological reasons.

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The Bee Fire: A Case Study Validation of BEHAVE in Chaparral Fuels

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Abstract

The Bee Fire burned 9,620 acres of grass and chaparral in the San Bernardino National Forest in southern California from June 29 to July 2, 1996. Rate of spread data were determined from successive fire perimeters and compared with rate of spread predicted by the Rothermel rate of spread model using fuel model 4 (heavy brush) and a custom fuel model for chamise chaparral. A linear relationship between observed and predicted rate of spread was found ($R^2 = 0.60$). The two fuel models performed similarly with only a difference in scale. Observed spread rates were approximately 80 percent of the spread rates predicted with fuel model 4 and 380 percent of the spread rates predicted with the custom model. The regression models did not fit 4 of the 28 observations, but no apparent cause for the lack of fit was found.

Introduction

Fire is a common occurrence in the Mediterranean climate of California. In any given year, thousands of acres of chaparral and other shrub types are burned by wildfires. Much effort has focused on attempting to describe the manner in which fire spreads through the chaparral fuels; however, some fire managers believe that existing fire spread models do not work well in chaparral and that additional work should be conducted to develop a fire spread model for chaparral that can be used to assist in tactical decisions associated with suppression and prescribed burning as well as in strategic decisions such as fire budget planning. Other fire managers have adapted existing models or created other decision tools to aid in these decisions (Raybould and Roberts 1983).

To our knowledge, existing fire spread models have not been systematically validated for the chaparral fuel types or for other shrubby fuel types in the western United States. Limited validation of the Rothermel model has occurred (Albini and Anderson 1981, Stevenson et al. 1974). We are currently conducting a validation study of fire spread models in chaparral and other shrub type fuels by using information from chaparral wildfires that have occurred in California. The purpose of the study is to identify the set of conditions where current operational models perform well and to identify the set of conditions where improvements need to be made.

This paper describes results of a comparison of fire spread rates predicted by the Rothermel fire spread model (Albini 1976, Rothermel 1972) with fire spread rates derived from a fire perimeter growth map.

Methods

The Bee Fire was accidentally ignited at 1647 hours, June 29, 1996 on a southern aspect in a chaparral fuel type dominated by chamise (*Adenostoma fasciculatum* H&A) at an elevation of 2,200 ft (677 m) on the San Jacinto Ranger District of the San Bernardino National Forest in southern California. This fire can best be described as a “heat wave” fire as opposed to a Santa Ana fire. Local suppression forces initially battled the fire; by the morning of July 1, a Type I Incident Command Team assumed control of the fire due to its complex nature and the multiple resources that were at risk. A Fire Behavior team consisting of a Fire Behavior Analyst, two Fire Behavior Analyst trainees, and two Field Observers was assigned to support the Incident Command Team. During the next week, the Fire Behavior team reconstructed fire perimeter growth from June 29 to July 1 through interviews and documented fire perimeter growth from July 1 to July 2, 1996 at which point the fire was declared contained at 9620 acres (3848 ha). The team worked with a Geographic Information System Specialist and a Meteorologist to digitize the fire perimeter maps, gather and modify weather data from the Keenwild Remote Automated Weather Station (RAWS), and generate fuel, slope, and aspect maps for use with FARSITE™.

The fire perimeter map produced by the Fire Behavior team (fig. 1) consisted of 28 polygons representing the perimeter location at different times. For each polygon, an “effective”

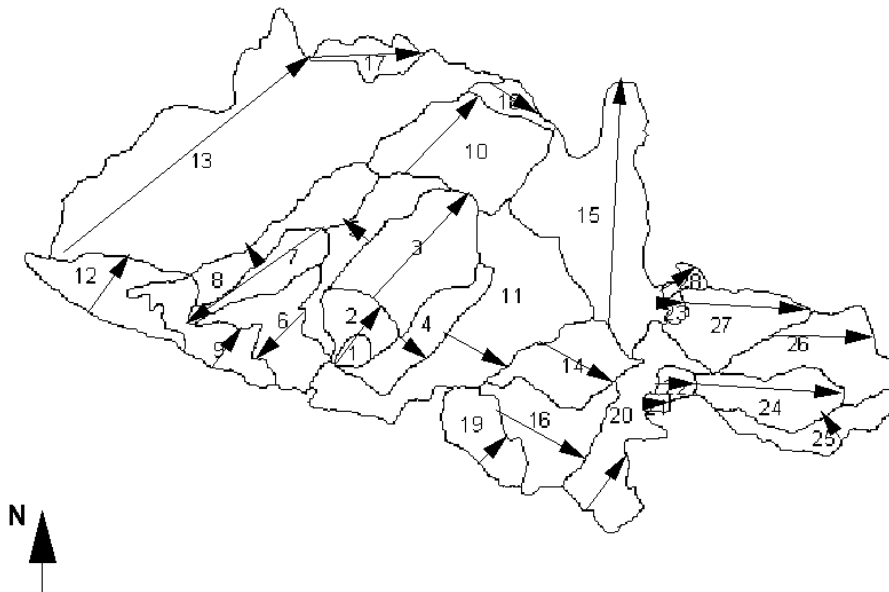


Figure 1. Fire perimeter map for the Bee Fire, San Bernardino National Forest, California, which occurred June 30 to July 3, 1996 and burned 9620 acres of chaparral vegetation. Each numbered polygon indicates a separate spread episode.

rate of spread was estimated by drawing a vector from one perimeter to the next successive perimeter, determining the elapsed time between these perimeters, and calculating the rate of spread by using $R_e = L/T$, where R_e is “effective” rate of spread, L is the distance between successive perimeters, and T is the elapsed time between successive perimeters (Fujioka 1985). Real-time rate of spread measurements are more detailed than rates of spread derived from fire perimeters reconstructed after the fact. However, for the purposes of this paper, the level of detail is sufficient. Fire behavior prediction input variables were estimated along each of the vectors assuming uniform conditions and established techniques used by fire behavior analysts. The DIRECT module of BEHAVE (Andrews 1986) was used to calculate the “predicted” rate of spread for each set of input variables for the Fire Behavior Prediction System fuel model 4 (FBPS4) and for a custom fuel model CHAMISE2 (Weise 1997). If one of the input variables changed along the vector within the polygon (such as a change in slope or fuel type), an additional “predicted” rate of spread was derived. Thus, more than one predicted rate of spread may exist for a polygon. In the case of multiple predicted spread rates, the harmonic mean, H , (eq. 1) spread rate was calculated (Fujioka 1985) where a_i is a weighting coefficient and R_i is the predicted rate of spread for a uniform set of conditions. For this analysis, $a_i = l_i / L$, where l_i is the distance the fire spread at rate R_i .

$$H = \frac{1}{\sum_{i=1}^n a_i / R_i} \quad (1)$$

We estimated coefficients for a regression model of the form $OROS = a + bH$ where H and $OROS$ are predicted and observed spread rates, respectively. Coefficients were estimated separately for the FBPS4 and CHAMISE2 fuel models. In addition to providing a measure of the relationship between predicted (by BEHAVE) and observed spread rates, this regression model may also provide a mechanism to correct BEHAVE predictions. Analysis of residuals was performed to identify any systematic error in prediction that can be attributed to BEHAVE input variables.

Results and Discussion

Rate of spread was predicted using environmental and fuel input values (Table 1). Relative humidity ranged from afternoon lows of 18 percent to highs of 38 percent in the early morning (0200 hours). Similarly, temperatures ranged from night time lows of 60 °F to low 90's in the afternoon. Live fuel moistures were somewhat lower than normal for this time of the year for chamise and an average value of 60 percent for live woody moisture was used for FBPS4. CHAMISE2 has two live fuel components. We assumed live fuel moistures for foliage and fine branchwood were 80 percent and 60 percent, respectively. Dell and Philpot (1965) found that only chamise foliage moisture content varied appreciably annually and that fine branch moisture content ranged from 40 to 60 percent throughout the year.

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Table 1. Input variables used to predict rate of spread with the DIRECT module of BEHAVE on the Bee Fire, San Bernardino National Forest, San Bernardino, California.

Date	Polygon	Time	Elapsed Elevation (hr)	Slope (ft)	Temp. (pct)	RH (°F)	1 (%)	Fuel Moistures(pct) ¹				Wind Direction		Wind Direction (mph)	Spread
								10	100	Live	Actual	Relative ² (°)	Speed (°)		
6/29/96		1	0.2	2200	28	84	19	3	4	5	60	293	243	5	Max
		2*	0.8	2600	30	84	19	3	4	5	60	293	243	5	Max
		3	0.3	3000	34	75	24	3	4	5	60	345	282	4	Max
		3	0.3	3200	34	75	24	3	4	5	60	345	34	4	Max
		3	0.1	3400	53	75	24	3	4	5	60	345	302	4	Max
6/30/96		4	4.5	2800	48	61	28	5	5	6	60	99	55	0	94
		5	7.5	2800	17	60	28	7	6	6	60	83	155	2	Max
		6	0.5	2200	23	60	38	7	6	6	60	83	220	2	Max
		7*	0.5	2400	34	60	28	7	6	6	60	83	144	2	Max
		8	0.8	2200	26	70	34	7	6	6	60	100	280	0	320
		9	1.0	2000	33	70	34	7	6	6	60	100	241	0	360
		10	0.3	4000	42	93	14	3	4	5	60	302	352	8	Max
		11	4.4	3000	54	93	14	3	4	5	60	302	280	0	98
		12	0.3	2000	15	90	16	3	4	5	60	257	220	4	Max
		12	0.3	2000	34	90	16	3	4	5	60	257	220	4	Max
		13	0.7	2000	14	93	14	3	4	5	60	303	316	7	Max.
		13	0.1	2200	17	93	14	3	4	5	60	303	250	7	Max.
		13	0.2	2400	30	93	14	3	4	5	60	303	250	7	Max.
		14	3.0	3000	76	93	14	3	4	5	60	303	270	7	90
		14	2.5	3400	50	93	14	3	4	5	60	303	270	7	90
		15	0.8	3800	33	85	17	5	5	6	60	293	255	7	328
		15	0.7	4600	33	85	17	5	5	6	60	293	287	7	Max.
		16	0.3	2400	13	85	17	5	5	6	60	293	170	7	Max.
16	0.1	2400	25	85	17	5	5	6	60	293	240	7	Max.		
17	0.5	3000	40	85	17	5	5	6	60	293	205	7	Max.		
18*	1.1	4600	25	85	17	5	5	6	60	293	172	7	Max.		
7/1/96		19	0.5	2400	33	74	27	7	6	6	60	70	25	2	Max.
		20	0.8	3200	40	74	27	7	6	6	60	70	5	2	Max
		21	0.1	3600	33	97	15	3	4	5	60	264	175	8	Max.
		22*	0.1	3800	33	97	14	3	4	5	60	289	210	7	Max.
		23	0.1	3600	50	97	14	3	4	5	60	289	200	7	Max.
		24	0.5	4600	17	97	14	3	4	5	60	289	289	7	Max.
		25	0.1	4800	14	92	15	3	4	5	60	305	247	6	Max.
		26	0.6	4800	33	92	15	3	4	5	60	305	233	6	Max.
		27	0.3	4400	29	92	15	3	4	5	60	305	215	6	Max.
7/2/96		27	0.2	4800	20	92	15	3	4	5	60	305	215	6	Max.
		28	0.3	3800	50	96	23	7	6	6	60	198	300	3	Max.

¹ The fuel moistures are for 1-hour, 10-hour, and 100-hour timelag dead fuels and live woody fuels.

² Wind direction relative to uphill direction; 0° indicates upslope wind, 180° indicates downslope wind.

* denotes polygon for which observed rate of spread was classified as an outlier.

Observed spread rates ranged from 3 to 265 chains/hr (1 to 89 meter/min) (table 2). Reported average forward spread rate (for 6 hours or longer time intervals) in chaparral for large historical fires was 10 ch/hr and 95 percentile rate was 40 ch/hr (Chandler and others 1963). Predicted forward spread rates ranged from 9 to 274 chains/hr for FBPS4 and from 2 to 57 chains/hr for CHAMISE2. A linear relationship between predicted and observed spread rates was noted for both fuel models (fig. 2). Plots of predicted spread rates for FBPS4 and CHAMISE2 versus observed spread rates were very similar--the primary difference between the fuel models was the range of predicted spread.

Table 2. Observed and predicted rates of spread for 28 spread events in chaparral on the Bee Fire, June 30 to July 3, 1996 on the San Bernardino National Forest, San Bernardino, California.

Polygon	Observed		Predicted ¹			
	(ch/hr)	(m/min)	FBPS4		CHAMISE2	
	(ch/hr)	(m/min)	(ch/hr)	(m/min)	(ch/hr)	(m/min)
1	152	51	120	40	26	9
2*	28	10	120	40	26	9
3	138	46	110	37	24	8
4	5	2	9	3	2	0.7
5	3	1	28	9	4	1.3
6	106	36	27	9	4	1.3
7*	189	64	22	7	3	1
8	17	6	24	8	2	0.7
9	32	11	16	5	3	1
10	259	87	274	92	57	19
11	11	4	10	3	2	0.7
12	73	24	84	28	18	6
13	208	70	199	67	42	14
14	10	3	7	2	2	0.7
15	110	37	88	29	18	6
16	166	56	175	59	35	12
17	163	55	154	52	31	10
18*	29	10	168	56	33	11
19	57	19	49	16	7	2.3
20	57	19	58	19	8	2.6
21	189	64	219	73	46	15
22*	265	89	182	61	39	13
23	170	57	155	52	33	11
24	201	67	201	67	43	14
25	189	64	160	54	34	11
26	126	42	150	50	32	11
27	167	56	152	51	33	11
28	101	34	82	28	11	4

¹ Rate of spread predicted using DIRECT module of BEHAVE program. FBPS4 is fuel model 4 (heavy brush) for the Fire Behavior Prediction System (formerly NFFL fuel model 4) and CHAMISE2 is a custom fuel model developed specifically for chamise fuels (*Adenostoma fasciculatum*).

* denotes polygon for which observed rate of spread was classified as an outlier.

Results of the regression analyses further supported the similarity in performance of the two fuel models. Both regression equations accounted for 60 percent of the variation in OROS. Neither intercept (*a*) estimate was significantly different from 0 at the $\alpha = 0.05$ level. Both slope (*b*) estimates were significantly different from 0 at $\alpha = 0.05$ (eq. 2, 3). The same 4 observations (polygons 2, 7, 18, and 22) had influential residuals (defined here as studentized residual > 1.5 where studentized residual is the residual divided by its standard error) for both regression equations. Wind direction for all four observations was generally downslope (144° to 243°).

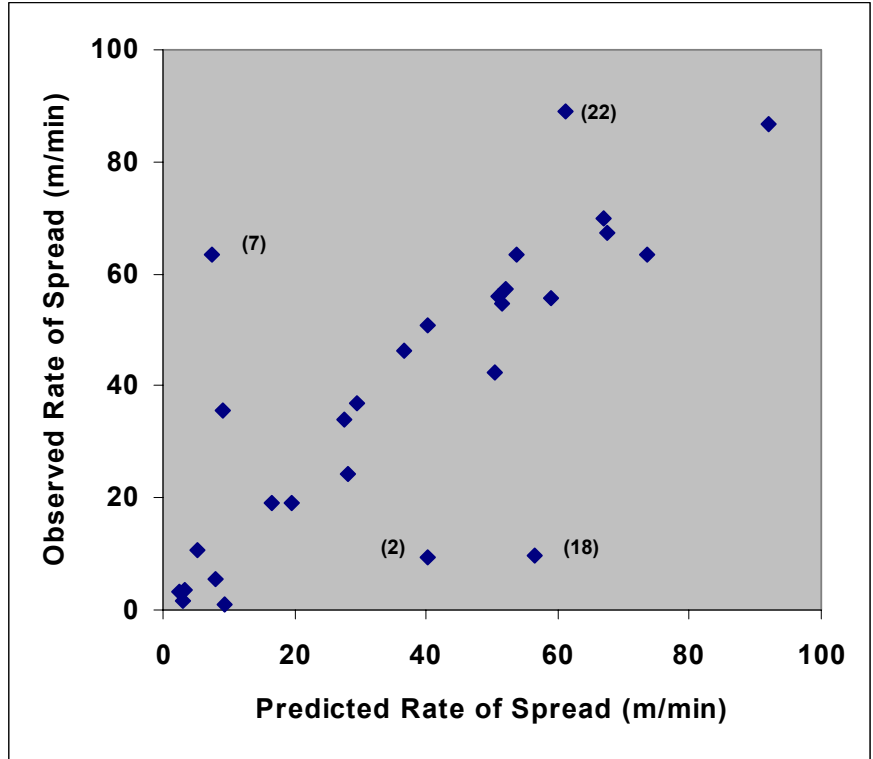


Figure 2. Observed and predicted fire spread rates in chaparral fuels from the Bee Fire, June 29-July 3, 1996. Spread rates predicted using the BEHAVE implementation of the Rothermel rate of spread model and FBPS fuel model 4 (heavy brush). A plot of predicted spread rates using a custom fuel model for chamise was similar to this figure except the range in predicted rate of spread was 0 to 19 m/min.

where 0° or 360° indicates wind blowing directly upslope). Wind direction was generally downslope for several other observations also. Plots of residuals against all possible independent variables did not reveal any discernable trends in the residuals. As a result, no additional attempts to improve the regression models were made.

$$OROS = 31.5 + 3.79(CHAMISE2) \quad (2)$$

$$OROS = 25.4 + 0.82(FBPS4) \quad (3)$$

From this analysis, there is some evidence of correlation between predicted and observed rate of spread in chaparral fuels. For the Bee Fire, observed spread rates were about 80 percent of those predicted using FBPS fuel model 4 and about 380 percent of those predicted using the custom fuel model CHAMISE2. As mentioned previously, the only difference between rate of spread predictions for the two fuel models appears to be a matter of scale, even though the fuel model parameters were quite different. Perhaps the manner in which the individual components of the fuel models are averaged greatly reduced the perceived differences between the two fuel models. Limitations in the formulation of the Rothermel model as applied to live fuels have been identified (Albini and Anderson 1981, Cohen et al. 1995, Martin and Sapsis 1987, Weise and Biging 1997). Further analysis is needed to understand fuel model performance.

With the exception of the four “outliers”, the Rothermel model predictions correlated well with observed spread rates for the Bee Fire. Under similar fuel and weather conditions, it may be possible to use either of the equations to correct BEHAVE outputs to predict spread rates in chamise chaparral. Additional validation work with other spread data is necessary to identify the conditions under which the Rothermel model works best in chaparral fuels.

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Use of *FARSITE* for Simulating Fire Suppression and Analyzing Fuel Treatment Economics

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Abstract

A module was developed to simulate the effects of suppression on fire growth in *FARSITE*. This capability provides one component of a simulation system that could ultimately be used for analyzing fire management operations and planning alternatives. Both ground and air attack have been incorporated. An example application is described for the Camp Creek Watershed in the foothills of the Sierra Nevada, California. This area is typical of the wildland-urban intermix, a situation with the greatest potential financial consequences of wildland fire. The effectiveness of suppression attack on a wildfire was simulated for two management scenarios: one with the current fuel conditions and one with a modest 15-year program of fuel treatments on public lands. Costs to both scenarios associated with fuel management and fire suppression were estimated. Crew availability and arrival times were estimated from experience in this area. The simulation showed that fuel treatments with the specified effects on fuel structure did slow fire growth and thereby allowed attack resources to contain the fire more quickly. The economic analysis supports the idea that a fuel management program can reduce costs of suppressing wildfires and damages in adjacent lands.

Introduction

The *FARSITE* fire growth model (Finney 1994, 1998) is increasingly used as a planning tool for exploring effects of fuel management options on fire growth (Stephens 1995). It has also been used to demonstrate consequences to fire behavior of specific fuel treatments (Van Wagendonk 1996). The value of using *FARSITE* is its ability to mechanistically model fire growth with complex fuels, weather, and topography. *FARSITE* uses the same fire behavior models most fire managers are familiar with in the BEHAVE program (Andrews 1986) and displays color maps of fire behavior across a landscape. The deterministic nature of *FARSITE* simulations allows the results to be directly related to the causative factors.

A natural progression of these simulations is to attempt to address their broader implications to fire suppression effectiveness and fuel management economics. Large fires (e.g. ones that escape initial attack) are of primary concern because of their expense and damage but are difficult to model in a generic way or to predict in terms of economic implications (Dimitrakopolous and Martin 1988). Efforts to do this have required computerized tools such as FOCUS (Bratten and others 1981), FEES (Mills and Bratten 1982), CFES (Fried and others 1988), NFMAS (USDA Forest Service 1987). None of these models, or other approaches to fire

and fuel management economics (Maxwell and others 1983, Murphy 1972, Omi 1977) are spatially explicit or consider directly the effects of a heterogeneous fire environment on suppression or fire size. The heterogeneity of many landscapes and variability of weather patterns is too complex for analytical methods of fire growth (Van Wagner 1969, Catchpole and others 1982, 1992, Anderson 1983) as well as for fire suppression (Anderson 1989, Fried and Fried 1996). A simulation can, however, accommodate highly heterogeneous conditions and represent both fire growth and suppression effects in a detailed manner.

As a step toward the goal of more comprehensive fire planning, a new module has been developed for *FARSITE* to simulate suppression actions. The simulated ground attacks are capable of responding to heterogeneous fuels and topography as well as the changing fire front. Air attack applies a length of retardant pattern by coverage level; it remains effective in stopping fire growth for a specified time period. Not all factors known to affect line construction or retardant can be simulated, however. There are still many unknowns and inconsistencies in studies of line construction (Hirsch and Martel 1996). The approach used for initial attack simulation is therefore simple and deterministic. Its parameters are limited to those that can be determined by the user and which have the most supporting data on their effect on line production. The simpler methods also limit the number of complex interactions that can obfuscate interpretations of simulation results.

This paper demonstrates the use of the attack module developed for *FARSITE* in simulating ground and air attack on a hypothetical wildfire in the Camp Creek Watershed, Sierra Nevada, California.

Methods

FARSITE simulates fire growth using the wave-propagation method referred to as Huygens' principle. Each fire front is represented as a fire polygon. The vertices of a fire polygon are the source of fire behavior calculations for surface fire (Rothermel 1972) and crown fire (Van Wagner 1977). Huygens' principle assumes that a wave front of a given shape can be propagated from points on its edge that act as independent sources of wavelets of that same shape (Anderson and others 1982). In this case, fires are ellipses that become more eccentric with steeper slopes and faster winds (Alexander 1985). Fire size depends on spread rate. Thus, at each vertex, data on fuels, weather, and topography are obtained to calculate the size, shape, and orientation of the elliptical wavelets that determine the local spread rate and direction of the fire front (Richards 1990). The spread rate at each point is multiplied by the timestep to achieve a fixed amount of fire growth in the proper direction. The fuels and topography are input as spatial GIS raster themes and the weather is most often provided as a weather and wind stream (Finney 1998).

Attack Simulation

Attack simulation requires the user to provide realistic data on fireline production and retardant drop configurations for aircraft. The user must be able to justify the input capabilities. *FARSITE* is designed to use this information and record the use of suppression resources. The ground-based attack features of *FARSITE* include three tactics: direct, indirect, and parallel

attack. Direct attack suppresses fire growth immediately at the fire edge while progressing along the fire front. Indirect attack builds impermeable fireline along a predetermined route irrespective of the fire location. Parallel attack builds impermeable fireline at a fixed horizontal distance from the fire front. Both indirect and parallel attacks can conduct burnout operations by lighting fire progressively from the advancing edge of the holding line. All attacks are conducted according to the spatial and temporal resolutions that govern fire growth. This means that line production will be sensitive at those tolerances to spatial variations in fuels and topography and to the temporal variations in fire growth (Finney 1997). The horizontal rate of line production is assumed to be constant in a plane parallel to the ground surface. The horizontal projection of this rate is however a function of the cosine of the slope. This results in less line production per unit horizontal distance up or down steep slopes than on flat terrain.

The performance of any of these ground attacks is dependent on the capabilities of an assigned crew. Crew types and their capabilities are defined by the user in terms of horizontal line production rate by surface fuel type and a flame length limit for direct attack. The user can assign any number of attacks to any number of fire fronts in the simulation. The user's discretion is required for addressing the logistics of crew arrival time and availability because these aspects are not part of the simulation.

The air attack simulation requires the user to specify for each aircraft the length of the retardant drop by coverage level. These relationships can be calculated for many types of aircraft (George 1981, 1992). The retardant pattern is buffered to the width of the distance resolution with the assumption that it is impermeable to surface fire or crown fire spread (but not spotting) for a specified time span. The user must specify the duration that the retardant will effectively stop fire spread; the retardant drop is eliminated after that time expires.

Example Application

The attack features were applied in a simulation of a hypothetical wildfire in the Camp Creek Watershed, Eldorado National Forest, California. Camp Creek is located on the Placerville Ranger District and is a major tributary to the North Fork of the Cosumnes River (fig. 1). The watershed is characterized by steep topography, late successional forests, and surface fuel complexes capable of sustaining high fire intensities when burned under severe fire weather conditions (Sapsis and others 1996). The inner gorge runs in a westerly direction that opens to the Sierra Nevada foothills at the confluence of Camp and Sly Park Creeks.

Camp Creek comprises the largest contiguous parcel of USDA Forest Service land among the surrounding private holdings (fig. 1). Ownership is a mixture of National Forest, industrial private timberlands, and small private parcels, some of which have been developed for housing. Camp Creek is representative of the wildland-urban intermix typical of the Sierra Nevada foothills. Thus, fire managers in this area have been greatly concerned about fuel hazards in and around the developed areas, particularly to the north of Camp Creek. Surface and crown fuels on all lands contribute to a relatively continuous fuel complex with the potential for broad destruction and loss of life if a fire should occur under extreme conditions. The foothills

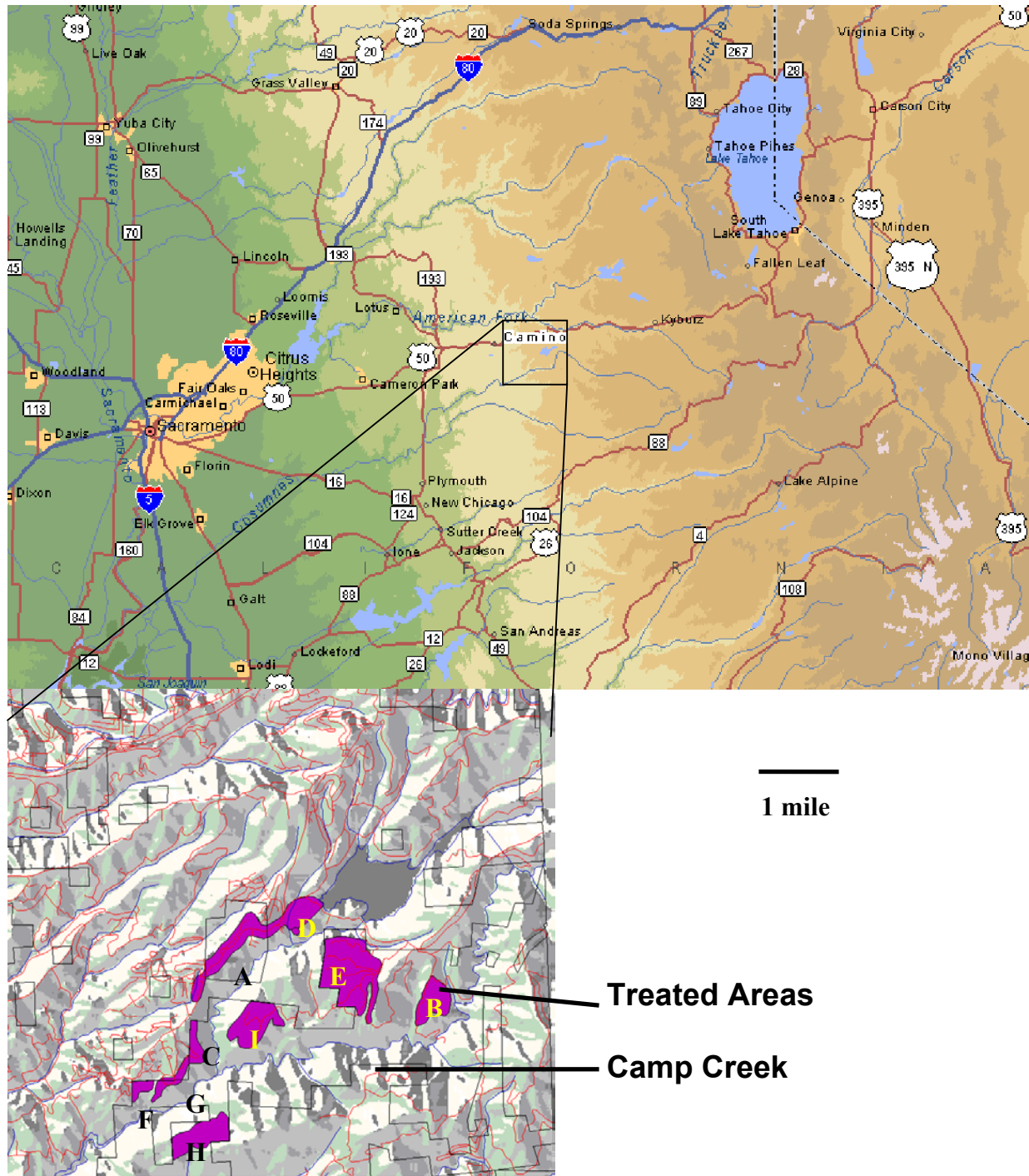


Figure 1. Location map of Camp Creek near the Cosumnes River in the Sierra Nevada Foothills (A). Close-up view of Camp Creek watershed showing the simulated fuel treatment areas (B). Descriptions of each treatment unit (A-I) are listed in [table 1](#).

of the central and northern Sierra Nevada are in general prone to these kinds of fires (i.e., Stanislaus Complex 1987, Forty-Niner Fire 1988, Fountain Fire 1992, and Cleveland Fire 1994) and result in losses up to several 100 million dollars.

The ridge to the immediate north of Camp Creek is populated with thousands of single family homes and three major subdivisions that include Gold Ridge Forest, Sly Park Hill, and Sierra Springs. These areas are known to be at risk from wildfire occurring in the Camp Creek watershed and adjacent lands. Recent real estate listings suggest values in these areas are characterized by moderately valued homes (\$110,000 to \$200,000). Many of the older homes, 20 to 30 years old are two bedroom, one bath and were originally summer homes or second homes for families in Sacramento Valley and Bay Area. Parcel size in the area ranges from 1/4 acre to 1.5 acres for approximately 50 percent of the homes, 45 percent are situated on 3 to 10 acre parcels and the last 5 percent are on parcels larger than 25 acres. Civic Codes and Regulations (CC & R's) for many homes in the organized sub-divisions such as Sierra Springs and Gold Ridge Forest include cedar shake roofs and green islands of vegetation between homes for privacy screening.

The question addressed in this example was: "What are the economic implications and effectiveness of a modest fuel treatment program conducted largely on Federal lands around Camp Creek under severe wildfire conditions?" Two fire simulations were performed: one with no fuel management and the second with surface and crown fuels modified to reflect 15 years of fuel management efforts. Treatments consisted of commercial thinning and slash and surface fuel reduction by burning similar to some of those examined by Van Wagtendonk (1996) (fig. 2). Mechanical thinning was necessary to reduce the crown bulk density (from 0.26 to 0.15 kg m⁻³) and thereby elevate the threshold for transition to active crown fire (Van Wagner 1977), and to raise the effective crown base height (from 1 m to 4 m) to vertically separate the aerial and surface fuels and reduce the potential for transition from a surface to crown fire. Important to these modifications was the removal of the smaller trees with low crown foliage, ladder fuels, and some co-dominant trees that formed a continuous crown layer. Despite the emphasis on smaller trees, actual timber sale data confirm that enough merchantable timber was harvested to largely offset the cost of mechanical thinning. We assumed that this initial treatment cost \$120/acre on Forest Service lands, and \$200/acre on private lands. Prescribed fire was necessary to dispose of logging slash and consume pre-existing surface fuels. Maintenance treatments at 7-year intervals were required to limit accumulations of surface fuels and development of understory ladder fuels and assumed the use of broadcast understory prescribed fire at a cost of \$60/acre (table 1).

Treatment units were located strategically to anticipate wildfires spreading out of Camp Creek to the north. The inaccessibility and fuel hazard in the drainage itself is considered a threat to the surrounding developed lands. The treatment units were primarily located on Federal lands, although a minor portion of some treatments was extended to adjacent private lands assuming cooperation with landowners. The spatial arrangement of the treatments was designed to be practical from both an operational and financial perspective. Treatments were discrete units, located on gentle topography, ridge tops, and in relation to existing roads. These treatments were not intended to be permanent "fuel-breaks" (Omi 1996), but instead dynamic parts of a landscape mosaic that is managed and perhaps extended as a spatial rotation of treatments.

The fire simulation scenario was devised to reflect a combination of factors that represent a realistic and serious threat to developed properties to the north of Camp Creek. This scenario consisted of historically common ignition sources, start locations, extreme fire weather

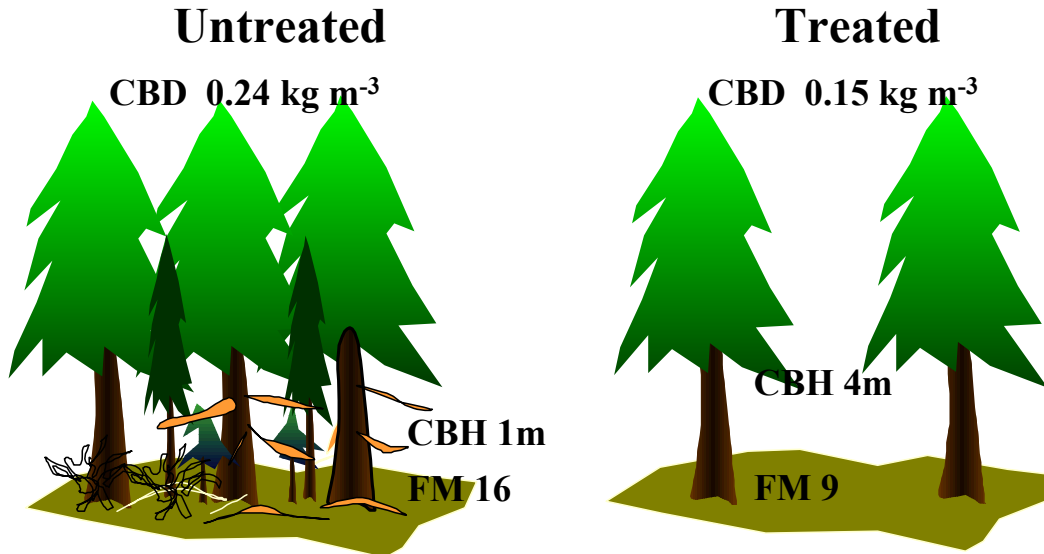


Figure 2. Illustration of fuel conditions in treated and untreated areas. Treatments thinned smaller trees to increase crown base height (m) and some larger trees to reduce crown bulk density (kg m^{-3}). Surface fuels were prescribed burned.

Table 1. Costs and schedule of fuel treatments and maintenance for the Camp Creek Watershed example.

Unit ¹	Size (ac)	Ownership	Initial treatment (years before present)	Maintenance treatment (years before present)	Present net cost of treatments ²	Present cost of perpetual maintenance ³	TOTAL
A	120	FS ⁴	15	8, 1	\$ 49,381	\$ 17,686	\$ 67,067
B	80	FS	13	6	\$ 25,288	\$ 11,791	\$ 37,079
C	60	FS	10	4	\$ 16,593	\$ 8,843	\$ 25,436
D	90	Private	9	2	\$ 37,847	\$ 22,108	\$ 59,865
E	220	FS	8	1	\$ 54,490	\$ 32,424	\$ 86,914
F	50	FS	6	--	\$ 8,376	\$ 7,369	\$ 15,745
G	20	FS	5	--	\$ 3,191	\$ 2,948	\$ 6,139
H	160	FS	3	--	\$ 23,153	\$ 23,581	\$ 46,734
I	140	FS	1	--	\$ 18,375	\$ 20,634	\$ 39,009
TOTAL	940				\$ 236,694	\$147,384	\$384,078

¹ Unit locations on Figure 1.
² Based on 5% discount rate; costs for treatments discussed in text
³ Present value of a perpetual series of payments (\$60/ac USDA Forest Service, \$100/ac private) on a 7-year interval.
⁴ UDSA Forest Service.

conditions, and fire timing. The fire was ignited by humans in the early evening (1800 hours) on August 3rd along one of the forest roads on the north side of Camp Creek. Weather for the following two days consisted of high temperatures of 95 °F with lows of 70 °F. Relative

humidity varied from 35 percent in the morning to 10 percent by afternoon. Overstory winds became strong each afternoon (20-25 mph) and did not subside (10 mph) until about 0300.

Suppression resources arrived and began their attack beginning around 2000 hours with air support for the remaining 2 hours of daylight. Various line production rates were assumed for the different crew types (table 2). Retardant was assumed effective for 2 hours at coverage level 4. A moderate draw-down of regional suppression resources was assumed to somewhat limit resource availability. Direct and parallel attacks with helicopter support were initiated along the backing and rear-facing flanks, progressing toward the head of the fire. Indirect attacks were used along the east and south flanks (table 3).

To illustrate the potential of this kind of simulation, an economic analysis was conducted. Two relevant statistics were determined: the benefit-cost ratio of the treatments, and the positive benefit period (time during which fuel treatment expenses are economical). The benefits were calculated as the present net value of the difference between the costs of the two scenarios assuming a discount rate of 5 percent. The costs of fuel treatments used in the analysis was the combined present value of the treatments and the present value of the future maintenance costs. Because of the large difference between the suppression costs alone and the total of suppression costs plus damages, benefit-cost ratios were calculated for each separately.

Table 2. Fireline production rates (chains/hour) for crew types by fuel model.

Crew Type	Fuel Model							
	1	2	5	8	9	10	16 Custom model, untreated fuels timber with shrub understory ²	26 Custom model, montane chaparral ²
Hotshot crew ¹	20	20	4	15	15	6	6	5
CDF/CDC crew ¹	15	15	3	12	12	4	4	3
Type II dozer	100	100	40	90	85	15	15	40
Type III engine	5	5	2	4	4	2	2	2
⁺ assumes helicopter support		⁺⁺ see Sapsis and others 1996						

Table 3. Chronology of suppression activities. Ground resources are cumulative. Aircraft usage is by 2-hour period

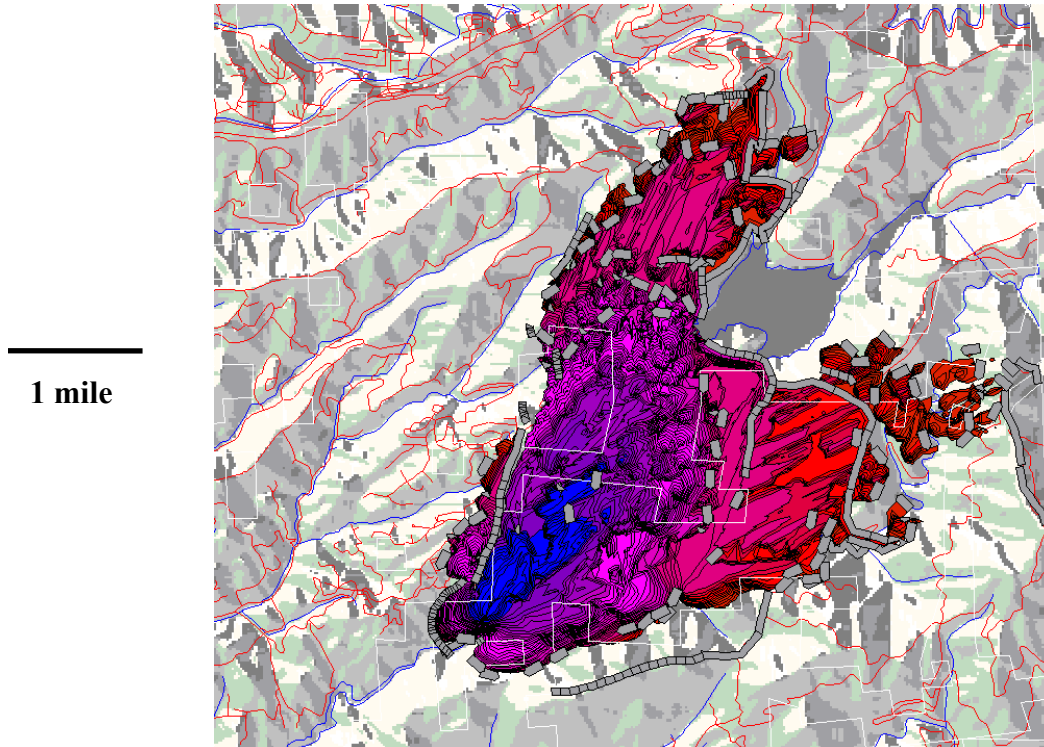
Date/Time	No Fuel Treatments		Proposed Fuel Treatments	
August 3rd				
1800	Fire Starts		Fire Starts	
2000	4 Type III engines 1 CDF/CDC crew ¹ 4 drops ² , 4 drops ³	Direct and parallel attack on west flank and along ridge to the north	4 Type III engines 1 CDF/CDC crew ⁺ 4 drops ² , 4 drops ³	Direct and parallel attack on west flank and along ridge to the north through the fuel treatments
2200	4 CDF crews ¹ 1 Hotshot crew ¹ 1 dozer	dozer and 2 crews build line along ridge to north 2 crews begin parallel attack on south flank	4 CDF crews ⁺ 1 Hotshot crew ⁺ 1 dozer	dozer and 2 crews build line along ridge to north 2 crews begin parallel attack on south flank
August 4th				
0200	4 hotshot crews ¹	Addition crews to north flank, burnout from roads	4 hotshot crews ⁺	Additional crews to north flank, burnout from roads
0400				
0600	8 CDF crews ¹ 8 hotshot crews ¹ 4 dozers 4 drops ² , 6 drops ³	1 dozer to south ridge, indirect 4 crews parallel on south flank	7 CDF crews ⁺ 8 hotshot crews ⁺ 4 dozers 4 drops ² , 4 drops ³	1 dozer to south ridge, indirect 4 crews parallel on south flank
0800	4 drops ² , 6 drops ³		4 drops ² , 4 drops ³	
1000	4 drops ² , 6 drops ³		2 drops ² , 4 drops ³	
1200	12 CDF crews ⁺ 4 drops ² , 8 drops ³	Crews retreat to north and east flanks with high winds and extreme burning conditions	7 CDF crews ⁺ 2 drops ² , 6 drops ³	Crews hold line on north and north-east flanks
1400	2 drops ² , 8 drops ³		2 drops ² , 6 drops ³	
1600	15 CDF crews ⁺ 2 drops ² , 8 drops ³		2 drops ² , 6 drops ³	
1800	12 Hotshot crews ⁺ 2 drops ² , 8 drops ³	Winds subside and crews work north and east flanks	12 hotshot crews ⁺ 2 drops ² , 6 drops ³	crews concentrate on south and south-east flanks
2000	2 drops ² , 8 drops ³			
August 5th				
0400				
0600	2 drops ² , 8 drops ³		2 drops ² , 5 drops ³	
0800	Fire Contained		2 drops ² , 4 drops ³	
1000			Fire Contained	
1	helicopter support			
2	800 gallon retardant drop			
3	3000 gallon retardant drop			

Results

The suppression module added to *FARSITE* was useful in representing an array of realistic tactics. Line production varied noticeably by fuel type and slope. Travel routes by direct and parallel attacks responded as intended to fire activity. Without automating these capabilities, it would have been impossible to effectuate suppression action in the fire simulation. Air attacks were effective at slowing head fire growth by forcing the fire to flank around retardant patterns. Additional benefit from retardant drops included relocation of ground forces to more active portions of the fire’s perimeter, thus increasing the containment rate along the fire perimeter.

The two simulated fires grew to 3,440 acres with the fuel treatments and 6,460 acres with no fuel treatments. Both simulations showed fire growth and suppression were similar along the backing and flanking portions of the fires (fig. 3). The areas where fuels were treated, however,

A.



B.

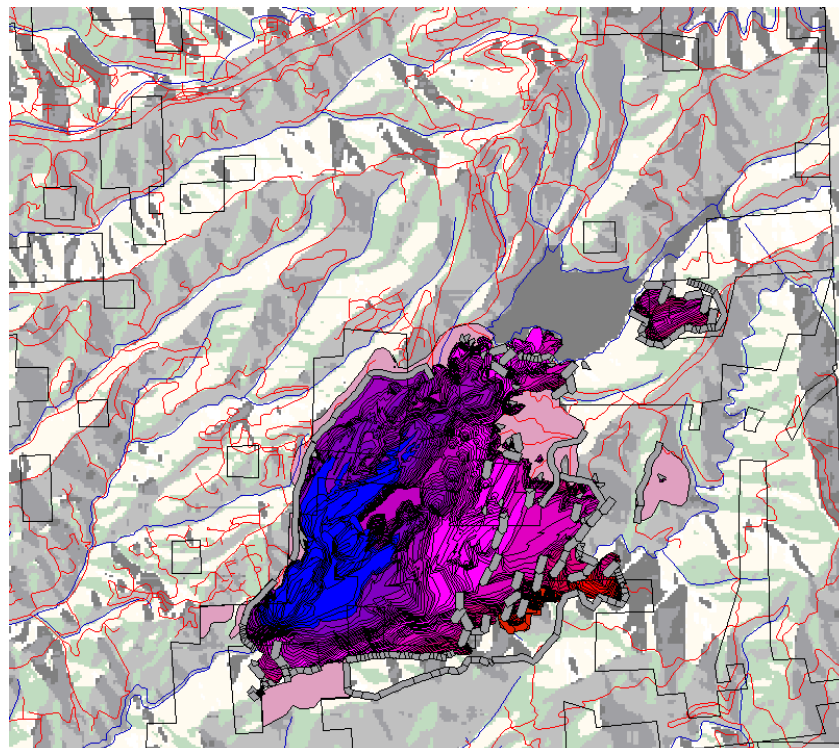


Figure 3. Simulation results August 3rd-5th. Fire growth and suppression patterns with no fuel treatments (6,460 ac, perimeter 40 miles) (A), and with fuel treatments (3,440 ac, perimeter 23 miles) (B).

required fewer resources for suppression because slower spread rates and lower intensities permitted line construction closer to the fire edge (ultimately requiring less line construction), and because lighter fuel loading facilitated faster line construction than in adjacent untreated areas. With fewer resources needed in the treated areas, the remaining resources were free to attack other portions of the fire front. This led to faster containment of the fire during the nighttime and morning hours because crews were directed to construct fire line to link the patches of treated areas. In general, the spatial arrangement of non-contiguous treatment areas was an effective asset to suppression because the method of suppression effort could be flexible about joining the most appropriate treatment units.

The fuel treatments showed a substantial benefit to the suppression effort at the head and forward flanks of the fire in both direct and indirect ways. First, the treated areas directly slowed the heading fire by restricting it to a surface fire with lower intensity than in unmanaged surface fuel. The mechanical removal of ladder fuels and thinned crowns also prevented wholesale torching and crowning in these areas and allowed suppression crews to perform parallel attacks rather than indirect attack. Second, the absence of crown fire activity in the treated areas indirectly aided suppression by limiting the generation of embers from torching trees. In the untreated units, these embers ignited subsequent spot fires down wind approximately $\frac{1}{4}$ to $\frac{1}{2}$ mile and required longer times and more crews for their containment.

The fuels treatments were also apparently effective in helping to prevent losses of homes and private property in the developed subdivisions near the head of the fire. Many homes were assumed lost in the no-treatment scenario when weather conditions became more extreme during the burning period of the following day. High winds drove the fire over the containment lines to the north and east because holding actions in these areas were not completed by that time (in contrast to the treatment scenario). The escaped fire then caused spotting into the residential areas and resulted in an estimated loss of 240 homes compared to 8 homes lost with the fuel treatments. A total of 10 strike teams (5 Type I engines in each) were assigned to the subdivisions because of the imminent threat of uncontrolled fireline compared to 3 strike teams in the scenario with those treatment units.

Costs for the two situations suggested that the greatest differences occurred because of residential property, regardless of whether it was destroyed or merely threatened by the fires. The greatest losses occurred because high value residential property (homes, automobiles, outbuildings, land improvements) was destroyed in the subdivisions. Timber values came in second, primarily because conservative estimates of damages were used to account implicitly for legal and aesthetic proscription of salvage logging on some of the burned forest lands. Although property losses greatly exceeded the costs of suppression, suppression costs themselves were affected by the presence of residential areas. For example, the assignment of Type I engines for structural protection in residential areas was expensive in the no-treatment scenario (10 strike teams; table 4). Type I engines were also assigned in the treatment scenario, but only three strike teams were needed because wildland crews contained the fire before it arrived at the subdivisions.

The fuel treatments contributed to an estimated benefit-cost ratio of 1.47 to 2.94 for suppression costs alone (table 5). Including damages and losses, the benefit cost ratio was 29.8 to 59.6 (table 5). These figures assumed a 50- to 100-year average fire return period for calculating average annual savings (difference between treatment and no-treatment scenarios). Alternately, the positive benefit period was calculated as 147 years for suppression costs only and 2,977 years for combined suppression costs and damages.

Table 4. Estimated fire costs by treatment scenario.

Item/Action	No fuel treatments		Proposed fuel treatments	
Fuel treatments				
Thinning, burning	No acres treated	0	940 ac (present value, table 1)	236,694
Suppression costs				
Type I engines	50 engines (10 strike teams) 72 hours (\$600/hr)	2,160,000	15 engines (3 strike teams) 72 hours (\$600/hr)	648,000
Type III Engines	25 engines (\$85/hr) 156 hrs line building 600 hrs travel 400 hrs logistics 2000 hrs mopup	13,260 51,000 34,000 170,000	20 engines (\$85/hr) 30 hrs line building 480 hrs travel 320 hrs logistics 960 hrs mopup	2,550 40,800 27,200 58,650
Dozers	4 dozers (\$50/hr) 50 hrs 96 hrs travel 64 hrs logistics	2,500 4,800 3,200	4 dozers (\$50/hr) 30 hrs 96 hrs travel 48 hrs logistics	1,500 4,800 2,400
Hotshot	12 crews (\$300/hr) 208 hrs line 144 hrs travel 192 hrs logistics 840 hrs mopup	62,400 43,200 57,600 252,000	12 crews (\$300/hr) 144 hrs line 144 hrs travel 144 hrs logistics 504 hrs mopup	43,200 43,200 43,200 151,200
CDF/CDC	15 crews (\$300/hr) 235 hrs line 120 hrs travel 240 hrs logistics 1050 hrs mopup	70,500 36,000 72,000 315,000	7 crews (\$300/hr) 78 hrs line 84 hrs travel 84 hrs logistics 336 hrs mopup	23,400 25,200 25,200 100,800
Overhead	8 days (\$150,000/day)	1,200,000	6 days (\$100,000/day)	600,000
Water tenders	8 days (\$1,800/day)	14,400	6 days (\$1,800/day)	10,800
Aircraft				
800 gal	30 loads (\$2,000/load)	60,000	26 loads (\$2,000/load)	52,000
3000 gal	68 loads (\$5,000/load)	340,000	49 loads (\$5,000/load)	245,000
Helicopters (1 Type III & 2 type II)	5 days (\$13,800/day)	69,000	4 days (\$13,800/day)	55,200
Suppression Sub-Total	\$5,030,860		\$2,204,300	
Property damage				
Timber	6,460 acres (\$2000/ac)	12,900,000	3,440 acres (\$2,000/ac)	6,880,000
Homes	240 homes (\$160k/home)	38,400,000	8 homes (\$160k/home)	1,280,000
Property	240 homes (\$ 50k/home)	12,000,000	8 homes (\$50k/home)	400,000
Burn Rehabilitation	6,460 acres (\$10/ac) 40 miles perimeter	64,600	3,440 acres (\$10/ac) = 23 miles perimeter	34,400
Property damage Sub-Total	\$63,384,600		\$8,594,400	
TOTAL	\$68,451,460		\$11,035,394	

Table 5. Benefit cost analysis of fuel treatments for Camp Creek (discount rate 5 percent). Positive benefit period is the maximum fire interval over which a financial benefit is achieved by fuel treatment.

A. Suppression costs only			
	Present value of fuel treatment costs¹	Present value of suppression cost difference (Benefit)²	Benefit/ Cost ratio
Assumed 50 year fire return interval.	236,694+ 147,384= \$384,078	$\frac{\$2,826,560}{0.05} * 0.02 =$ \$1,130,624	2.94
Assumed 100 year fire return interval.	236,694+ 147,384= \$384,078	$\frac{\$2,826,560}{0.05} * 0.01 =$ \$565,312	1.47
Positive Benefit Period		$\frac{\\$2,826,560}{\\$384,078 * 0.05}$	147 yrs
B. Combined damages and suppression costs			
Assumed 50 year fire return interval.	236,694+ 147,384= \$384,078	$\frac{\$57,183,082}{0.05} * 0.02 =$ \$22,873,232	59.55
Assumed 100 year fire return interval.	236,694+ 147,384= \$384,078	$\frac{\$57,183,082}{0.05} * 0.01 =$ \$11,436,616	29.77
Positive Benefit Period		$\frac{\\$57,183,082}{\\$384,078 * 0.05}$	2977 yrs
1. From table 1.		2. From table 4.	

Discussion

The addition of the suppression capabilities to *FARSITE* opens up the possibility for improving the analysis of fuel management effectiveness. Specific spatial arrangements of fuel modifications can be subjected to many simulated fire scenarios. When combined with estimates of the associated costs and fire losses, it has the potential for use in economic analysis of fire and fuel management alternatives. The application of these capabilities to the Camp Creek Watershed was our first attempt to use a mechanistic simulation for examining the effectiveness and economics of fuel management on a landscape basis. Obviously, more simulations for Camp Creek (e.g., fire locations, weather conditions) would be required to develop confidence in the results. However, the outcome of this work is easily interpretable and serves as a basis for further development and critique of the methods.

The economic analysis of fuel treatments, suppression costs, and fire damages suggested that for every dollar spent on fuel treatment in this urban-wildland intermix area, somewhere between \$1.47 and \$2.94 would have been saved in suppression costs alone (table 5). This assumed a 50- to 100-year fire free period and was intentionally shorter than the 185 year modern average fire rotation (1908-1992) for ponderosa pine (McKelvey and Bussy 1996). Non-randomness of human-caused ignitions and local fire experience suggest that Camp Creek would be at greater risk than reflected in the average fire rotation value. The actual fire interval at Camp Creek would have to be less than the 147 year positive benefit period to save on suppression costs. A greater potential savings, however, resulted when the benefit-cost figures were calculated for the combined suppression costs plus losses (table 5). The relatively huge

losses contributed to much greater benefit cost ratios (29 to 59) and a positive benefit period of 2,977 years. Thus, if this analysis is correct, fuel treatments would almost always produce a financial benefit given the high value of the resources in this area and the near certainty that severe fires will happen. Fires in the simulated size range (3,440 to 6,460 acres) have been relatively common, occurring once every 5 to 10 years on a given National Forest since 1908 (Erman and Jones 1996).

The proposed treated areas were intended to be practical and proved to be effective in modifying the simulated fire behavior. First the dispersed pattern was probably the least expensive way to accomplish the treatments because the units were located along existing roads and situated on gentle topography so that efficient mechanized harvesting could be used. Second, the treatments were placed strategically in anticipation of threats to high value areas. The high value of residential subdivisions required that fuel treatments should occur between the identified hazard and the values at risk, yet primarily on Forest Service lands that were not contiguous on this landscape. Third, the dispersal of treatment units throughout an area increased their proximity to likely ignition locations. Having treated areas close to an ignition location is helpful in restricting initial spread along one or more flanks and improving the effectiveness of initial attack. Finally, the dispersal of treatment units did fragment the burning landscape and interrupt the potential routes of heading fire spread, which is the fastest and most intense portion. It was obvious in these simulations that the treatments served as localized impediments to the wind driven head fire and thus required the fire to flank around the slower-burning fuels. Although individual units smaller than a fire can and were bypassed (Dunn 1989, Weatherspoon and Skinner 1996), the collective effect of many such units slowed the overall forward fire spread rate. Regardless of their arrangement, the fuel treatments reduced spotting because torching and crowning was limited by the modifications to both surface and crown fuels.

The simulated fuel treatments also proved to be effective at assisting fire fighting operations. Even though the treatment areas were discontinuous and relatively small (the largest being about 300 acres), their strategic placement allowed suppression forces to dynamically connect these treatments by firelines. Faster line construction and burnout was possible in the treated areas; this freed resources for constructing line along other sectors of the fire front. The presence of treated areas reduced the distance and time spent constructing fire line between treated areas in more difficult untreated fuel types. The strategic use of different fuel types was similar to the common practice of using natural landscape features to assist line construction and fire containment (i.e., lakes, streams, ridges, rock outcrops). More importantly, because fuel treatments can be tailored to a particular management situation, it suggests a landscape-level pre-fire strategy that would involve arranging patches of managed fuels for use as links in a chain that suppression forces could join together by fireline at the time of a fire.

Although linear “fuel breaks” are being resurrected in discussions about landscape-level fuel management (Omi 1996, Weatherspoon and Skinner 1996), the dispersed pattern of treated areas could be more flexible in limiting the spread of fires. Assuming dispersed- and network-type fuel arrangements occupy the same fraction of a landscape, dispersed patterns can have shorter distances between the treatments. This increases the amount of treated area encountered at a given time by a random fire on the landscape. Proximity then becomes important because weather conditions typically determine when suppression efforts become effective on large fires and consequently where the fire front is located on a landscape at that time. By increasing the proximity of many treatment units to the fire, the dispersed pattern offers a spatial flexibility for opportunistic use by suppression crews. Multiple treatment units near the fire’s edge can be

connected. By contrast, the greater chance of weather affecting a fire somewhere between widely spaced fuel breaks means it must be controlled directly without the benefit of treatments or indirectly with large burnout operations. Further research, however, is badly needed for assessing the practical implications of these practices and for comparing the effectiveness of the many spatial arrangements of fuel treatments and their maintenance.

A primary assumption of the suppression simulation and this analysis was that the incident management team for the simulated fires were aware of the fuel situation, specifically the locations and condition of the treated areas with respect to fire behavior. This intelligence would be vital for incorporating treatments into suppression strategies. Without this information, the treated areas may be unknown to all but crews assigned to a particular sector of the fire perimeter.

Conclusions

These simulations showed that it is possible to begin assessing the effectiveness of an explicit fuel management program in terms of costs and benefits. More work is needed to replicate this kind of analysis with more potential fire scenarios and in other landscapes that have different values at risk. Ultimately a goal of this kind of mechanistic simulation is to identify and perhaps optimize appropriate landscape-level fuel arrangements that can be put into practice. This is made difficult by the many factors that cannot be predicted for a given fire, namely its start location, burning conditions, crew availability, and suppression strategy. However, it is hoped that the development of realistic tools for simulating the consequences of management activities can lead to better decisions regarding fuel and fire management.

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FUEL Loading and Risk Assessment: Lassen National Forest

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Abstract

The role of natural and prescribed fire is in transition throughout public lands in the West. Land managers are reexamining fire policy and developing strategies which take new perceptions into account. This project targets three watersheds within the Lassen National Forest and examines the historical, present, and predicted future impacts of fire using remote sensing and geographic information systems (GIS) technology. Of concern in these areas are cultural, recreational, and timber resources and anadromous fish populations. In addition, single homes and small communities are scattered throughout the forest, and the safety of them and their occupants is of critical importance.

A 1994 satellite image was used to create a vegetation classification which was cross-referenced to fuel types to create a fuels map layer. A severe burn that occurred late in 1994 was evaluated through a change-detection analysis to update the map layer and indicate the current status of fire fuels. Then fire-modeling software was used to simulate fire behavior under severe conditions with different management scenarios. The results of these efforts will implement long-term planning for the forest and increase knowledge of fire patterns and behavior. This project was sponsored by the USDA Forest Service Remote Sensing Steering Committee.

Purpose

Fire is a complex phenomena which plays an important role in the health of forest ecosystems. While fire suppression was once extensively practiced throughout public lands in the West, current strategies are changing. Land managers are recognizing that suppression has affected ecosystem structure by altering species composition and enlarging tree density (Moore, 1994). Through a greater understanding of the behavior and consequences of both prescribed and natural fire, land managers can make better decisions about its role in forest ecosystems.

The purpose of the Lassen National Forest vegetation-fuels project was to investigate the historical, current, and potential impact of fire on a forest landscape. This impact was examined by using remote sensing and GIS technologies because they employ the best available tools to deal with the large geographic extent of the area and the inherent complex spatial and temporal nature of fire research (Green, Finney, Campbell, Weinstein, & Landrum, 1995).

Three watersheds within the forest were selected for analysis: Antelope, Mill, and Deer creeks. Each contains streams which support anadromous fish populations which are declining throughout the region. In addition, homes and small communities are located in the watersheds and throughout the forest. Lives and structures risk loss or damage by fire. Forest managers are interested in developing strategies which cope with the impact of fire. These strategies apply to the terrestrial and aquatic resources located not only within the target watersheds but also throughout the entire forest. The results of the vegetation-fuels project will assist managers in planning and analyzing watershed problems in the future.

Table 1 lists various activities where remote sensing and GIS can contribute to fire research. Project efforts focused on prefire and postfire areas, but fire extent and intensity mapping, part of the actual fire category, was also included.

Table 1. Role of remote sensing and GIS in forest fire management.

Pre-Fire	Fire	Post-Fire
<ul style="list-style-type: none"> • Identify threats to people and structures • Inventory fire fuels • Assist fire management planning • Prescribed burn preparation 	<ul style="list-style-type: none"> • Fire extent and intensity mapping • Focus fire suppression efforts • Maximize tactical effect • Monitoring prescribed burns 	<ul style="list-style-type: none"> • Impact assessment • Rehabilitation • Evaluate fire management strategies • Update fuels coverage • Evaluate prescribed burns

Objectives for the project included:

1. Identifying management strategies to protect people and structures within the forest from fire.
2. Developing a fuels map that reveals the current fire risk in the forest from a satellite-derived vegetation map.
3. Using historical data to create GIS maps portraying past vegetative cover and the history of fire occurrence and intensity.
4. Examining the impact of a severe burn that occurred in Lassen National Forest in late 1994 through the use of imagery collected in pre- and post-burn periods.
5. Evaluating whether differences exist between historical and current fuel conditions.
6. Employing GIS fire-modeling software to quantify the results of different types of fires within the forest. These models will simulate fires during high-risk conditions with different management scenarios.

Area Description

Lassen National Forest is located in northern California and covers about 1.4 million acres (Figure 1). Elevations throughout the forest vary from a low of 500 feet to approximately 10,000 feet in Lassen Volcanic National Park. The three watersheds in the study contain both public and private land. About half of the Deer Creek and Mill Creek watersheds are publicly owned and managed by the Forest Service. The nonpublic lands are owned by timber corporations and private individuals. Deer Creek is 133,318 acres, and Mill Creek is 74,844 acres. Approximately 10 percent of Antelope Creek's total 55,579 acres are publicly owned and managed by the Forest Service. All three watersheds drain into the Sacramento River.

The creeks within the study watersheds continue to provide habitat for spring-run Chinook salmon despite their declining populations throughout California. Estimates indicate that the habitat for this salmon has dropped from 6,000 to less than 300 miles. Other aquatic organisms and communities which are threatened in California foothill and mountain streams are also present. The natural aquatic resources within Lassen are typical of those currently in jeopardy throughout the region. That makes informed management decisions about fuels and other area problems very important.



Figure 1. Location of Lassen National Forest and study area.

Cultural and recreational resources are also found in the watersheds. Deer Creek was the home of Ishi, the last of the Yahi Indians. Lassen National Forest provides a large variety of recreational activities, including hiking, camping, fishing, and winter sports.

The fire history within the area varies considerably. Foothill fires have historically been, and remain, frequent in contrast to the far fewer fires in the upper elevations. The difference in vegetative cover and fire occurrence between these two areas has resulted from harvesting and fire suppression. It is suspected that fires in the forest now burn with greater intensity but are less frequent than in the past due to fire suppression. Timber stands have been undergoing a transformation from prevalent ponderosa pine to mixed conifer.

Fuels Map Development

A current vegetation map layer, known as the Classification and Assessment with Landsat of Visible Ecological Groupings or CALVEG, was created by the Forest Service Pacific Southwest Region Remote Sensing Lab. The map layer was developed from Landsat Thematic Mapper (TM) imagery using a supervised/unsupervised classification of vegetative cover. Landsat TM imagery has a spatial resolution of 30 meters and is particularly useful for landscape analysis. The initial classification produced a GIS map that delineated the forest vegetation using the CALVEG groupings (U.S. Forest Service Regional Ecology Group, 1981).

Resource specialists from the Lassen National Forest and the Forest Service Remote Sensing Applications Center cross-referenced the CALVEG into a map layer which includes the 13 Northern Forest Fire Laboratory (NFFL) fuel types described by Anderson (1982). The NFFL system classifies fuel into four groups with further distinctions producing the 13 fuel types. The groups are grasses, shrubs, timber, and logging slash (Table 2). The fuel types are represented by numbers and defined by the following parameters: fuel loading, surface area to volume ratio, fuel depth, fuel particle density, heat content, and moisture required for extinction. This classification system was selected because it is used with many fire-simulation models. Figure 2 displays general CALVEG vegetation classes and their NFFL equivalents.

Table 2. Fuel models used in fire-behavior simulation.

<i>FUEL MODEL</i>	<i>TYPICAL FUEL COMPLEX</i>
	Grass Dominated
1	Short grass (1 foot)
2	Timber (grass understory)
3	Tall grass (2.5 foot)
	Chaparral and Shrub
4	Chaparral (6 feet)
5	Brush (2 feet)
6	Dormant brush, hardwood slash
7	Southern rough
	Timber Litter
8	Timber litter with normal dead
9	Hardwood litter/Open pine with grass
10	Timber litter with heavy dead
	Logging Slash
11	Light logging slash
12	Medium logging slash
13	Heavy logging slash

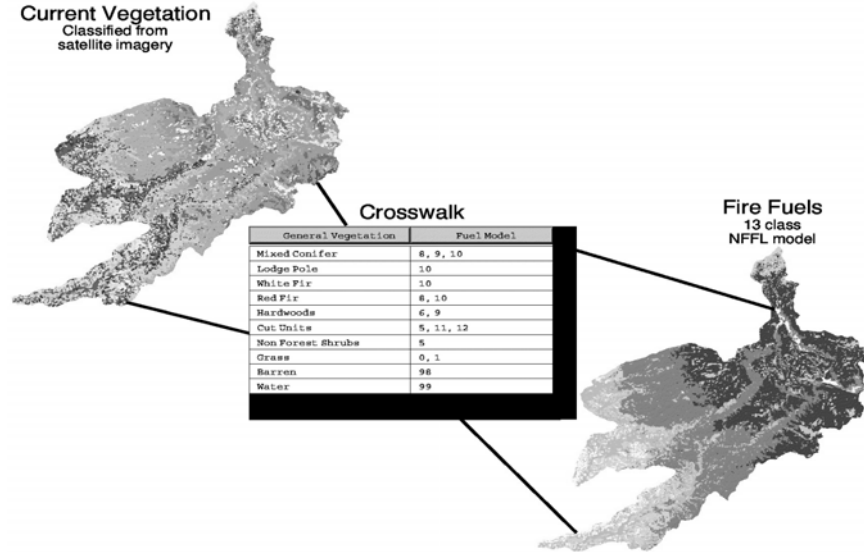


Figure 2. Cross-reference of vegetation classes to the Northern Forest Fire Laboratory fuel types.

Change Detection Analysis

A severe burn, the Barkely Fire, occurred late in 1994 after the imagery used for the vegetation map layer was acquired. To include the change in fuel loads created by the fire, a change-detection analysis was done using Land Use and Cover Change Analysis System (LUCCAS) software (Pacific Meridian Resources, 1996). Designed to work in conjunction with the ARC/INFO GRID module, LUCCAS provides a graphical user interface (GUI) for change-detection analysis.

Landsat TM imagery of the forest was collected for two time periods: pre-burn (1994) and post-burn (1996). LUCCAS compared these images and generated two output files: the image of change and a map of change. The image of change offers a quick look at obvious differences between the pre- and post-burn periods. The grouping of these areas into distinct categories produces the map of change (Figure 3).

Using the output from the change-detection analysis, fuel information was updated from previous classified imagery. Areas identified with changes were visited on foot to determine their current ground cover. This information was then used to bring existing fuel map layers up to date.

Change Detection

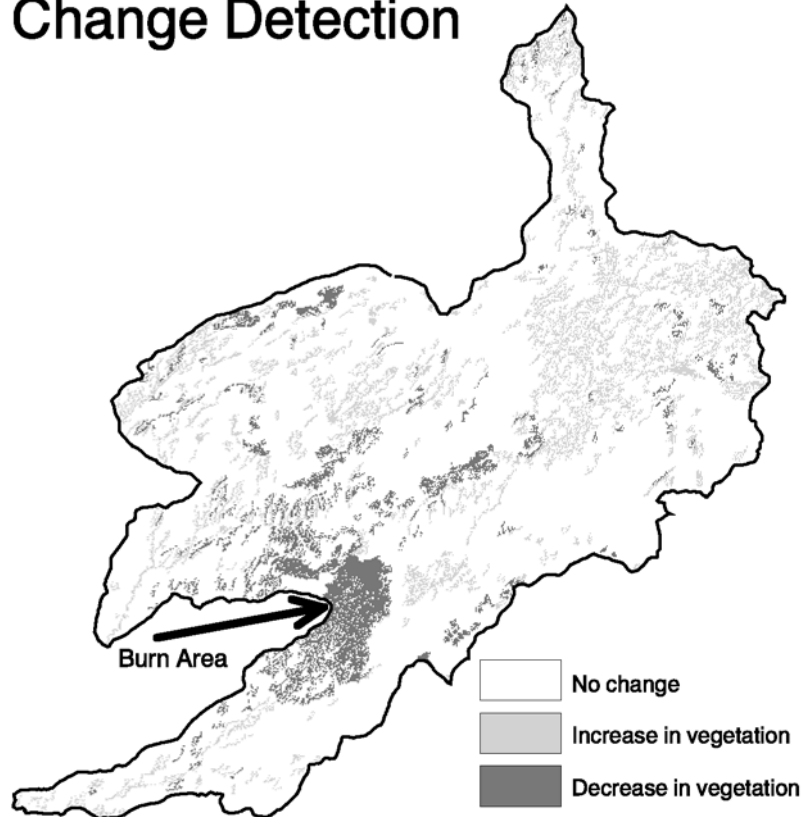


Figure 3. Change detection map of study area used to update fuels map layer.

Historical Conditions

Vegetation conditions were modeled to represent the pre-settlement era through two methods. The majority of the study area was modeled from existing data to approximate potential natural vegetation by the regional zone ecologist. The model integrated information from plot data; soil, slope, aspect, elevation, temperature, and precipitation map layers; lightning ignition patterns, and fire regimes (Fites, 1996). In areas where data was not available, local ecological knowledge and historical photographs were pooled to estimate historical vegetation. The resulting historical vegetation model was cross-referenced to the 13 NFFL fuel types.

Fire Simulation

The fire-growth model FARSITE (Fire Area Simulator) (Finney, 1996) was used to simulate fires within the study watersheds. FARSITE is built upon earlier models such as BEHAVE (Andrews, 1986) and offers a spatial approach to predicting fire spread and behavior. The model relies on elevation, slope, aspect, fuel, crown cover, and weather data to make its predictions. Users can select points to ignite fires, select the duration of the burn, and erect barriers to fire spread. Although the terrain and fuel data are input as raster map layers, FARSITE outputs vectors to represent spatial and temporal fire patterns (Finney, 1996). This

output can be exported in numerical or graphical form and displayed in a GIS (Figure 4).

FARSITE's spatial and temporal patterns are generated through algorithms based on Huygen's principle of wave propagation (Anderson, Catchpole, DeMestre, & Parkes, 1982). In applying Huygen's principle to fire research, fire is presumed to move and advance in an elliptical shape.

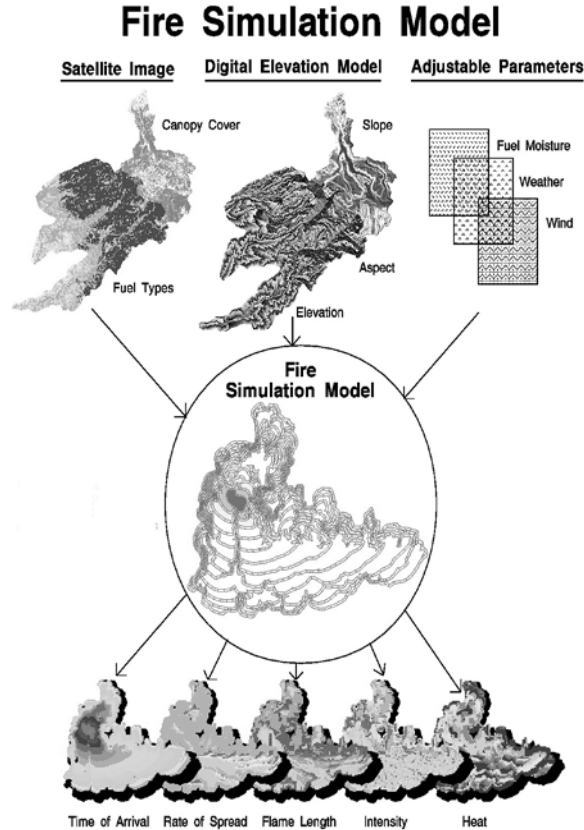


Figure 4. Fire Simulation model inputs and outputs.

In the Lassen project, fires were simulated in high-risk conditions with three fuel types. Situations included dry, hot conditions with strong winds. The fuel types were grass, shrub, and timber. These simulations were designed to create worst-case scenarios and examine their potential consequences on the study watersheds.

Results

A significant shift to more severe fuel types became apparent after comparing present and historical fuel conditions (Table 3). There was a 50,163-acre increase to shrub fuel types. In addition, there was a 101,644-acre loss of timber fuel type 8 (slow-burning ground fires with low flames), a 20,875-acre loss of timber fuel type 9 (a slightly faster-burning surface fire with higher flames), and a 68,634-acre gain in timber fuel type 10 (fires burning on the ground surface with greater intensity). This indicates that the chance of a catastrophic fire occurring in these watersheds has greatly increased.

Table 3. *Difference in acres between the historical and present fuel model types.*

#	Fuel Type	Historic	Present	Change
	Grass Group	acres	acres	acres
1	Short grass	8,246	11,618	3,372
2	Timber grass understory	0	0	0
3	Tall grass	0	0	0
	Shrub Group			
4	Chaparral (6 feet)	19,400	31,262	11,862
5	Brush (2 feet)	5,172	17,754	12,582
6	Dormant brush	690	30,936	30,246
7	Southern rough	4,527	0	-4,527
	Timber Group			
8	Timber with normal dead	106,040	4,396	-101,644
9	Open pine with grass	106,068	85,193	-20,875
10	Timber with heavy dead	9,863	78,497	68,634
	Logging Slash Group			
11	Light logging slash	0	0	0
12	Medium logging slash	0	0	0
13	Heavy logging slash	0	0	0
	Other			
98	Barren	134	134	0
99	Water	1,492	1,920	428

The results of the FARSITE fire modeling reinforce the conclusion that a catastrophic fire is more likely. The three fires simulated in the watersheds for the different fuel types resulted in larger, more intense fires in the present than in the historical fuel layers although they were ignited in the same place with identical weather conditions. In the grass type, 1,251 acres burned in the historical fire compared to 7,304 acres in the present. In the brush type, 1,710 acres burned in the historical fire compared to 4,044 acres in the present. In the timber type, 3 acres burned in the historical fire compared to 175 acres in the present.

A set of arc-macro-language (AML) programs was developed to compare the FARSITE outputs. The AML builds the FARSITE data into an ARC/INFO format and displays the results, which are calibrated to each other for the historical and present layers. The AML also performs change-detection analysis on the FARSITE output for the area the fires have in common (Figure 5). Change detection is helpful in visualizing the different fire behaviors. The AML can also predict how fires will react to different fuel management strategies.

Further tests will be conducted by the Lassen National Forest before any management decisions about the watersheds are made. Several assumptions were made during the project, such as how fuel moisture impacts the fire model, if historical vegetation map layers are reliable, and whether FARSITE truly reflects the way a real fire behaves. These assumptions and others need to be validated by resource specialists who are more familiar with the forest.

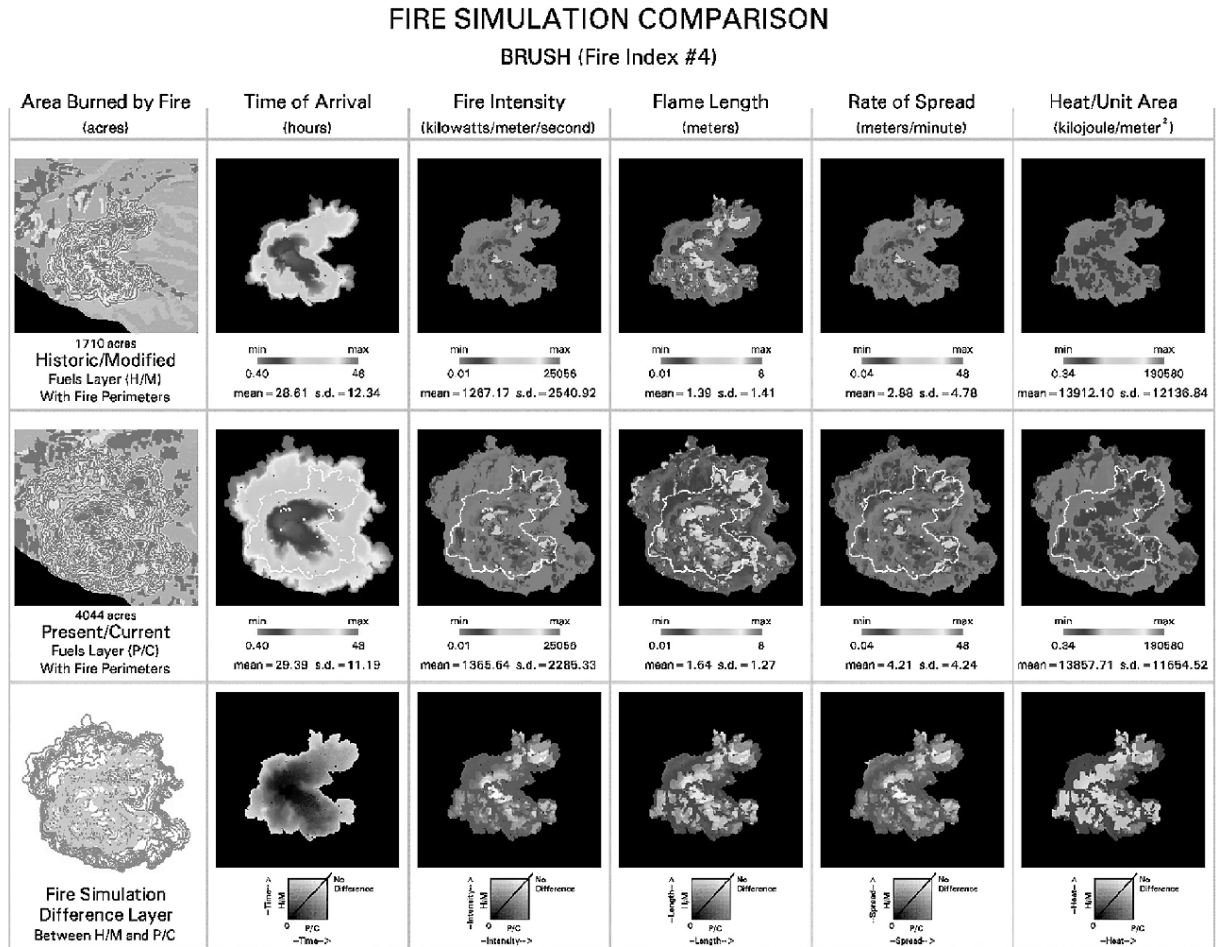


Figure 5. Output of Fire Simulation Comparison AML.

Acknowledgements

We would like to thank Haans Fisk and Lisa Pious of Pacific Meridian Resources for their innovation in the development of the Fire Simulation Comparison AML.

Note: The indication of firms, corporations, or trade names in this paper is for the convenience of the reader and does not constitute an official endorsement of any product or service by the USDA Forest Service.

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Burned Area Emergency Rehabilitation (BAER): Use of Remote Sensing and GIS

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Abstract

The Burned Area Emergency Rehabilitation (BAER) program of the USDA Forest Service requires a quick assessment of watershed conditions within large wildfire areas (over 300 acres) to determine if threats to life, property, or natural resource values have been created as the result of the fire. If emergency conditions exist, rehabilitation measures are prescribed to reduce, or eliminate potential threats. A map of burn intensity for the fire area is one of the tools used in determining whether emergency conditions exist. The current method to gather information about the burn intensity of the effected watersheds is through sketch mapping, and ground verification. Recently developed digital camera technology combined with global positioning systems, and geographic information systems allows specialists to gather the information needed by BAER teams in a fast, accurate and cost effective way. The USDA Forest Service Pacific Southwest Region has applied these technologies to a fire on the Mendocino National Forest in northern California. This resulted in a 20 percent increase in accuracy of burn intensity classification, and more precise location of areas of similar burn intensity. These improvements assisted in the refinement of the identification of potential flood source areas within the burned area, and thereby more efficient prescription of emergency treatment measures.

What is Burned Area Emergency Rehabilitation (BAER)?

The BAER program is an emergency program that gathers information on fire induced watershed conditions in the wake of large wildfires, and uses this information to determine if significant threats to life, property, or natural resources exists (USDA Forest Service, 1995). If emergency conditions exist, immediate rehabilitation treatment measures are undertaken to reduce or eliminate these threats. The BAER inventory, analysis, and rehabilitation treatment prescriptions are completed within three days after the control of the fire, with actual rehabilitation initiated within a week of control of the fire. Rehabilitation measures must be completed before the first damaging storms of the season. All potential treatment alternatives are subject to a least-cost-plus risk analysis to ensure that prescribed rehabilitation treatments are prudent and efficient. In a severe fire year, such as 1996, millions of dollars are spent on BAER treatments. US Department of Agriculture and US Department of Interior, as well as state and local agencies have, or are developing programs tailored after the Forest Service BAER program

for lands under their jurisdictions. This is a result of partnerships that emerged in the aftermath of fires in recent years.

To determine the flooding potential, and the specific flood source areas within the burned area, the BAER survey includes mapping burn intensity as a critical step. Burn intensity is the key measure of the severity of the fire's impact on the ecosystem (Boudreau and Maus, 1996). The term burn intensity refers to the fire effects on the watershed, not necessarily to the intensity of the fire as defined in flame height, canopy consumption, or rate of spread. Typically, burn intensity is mapped using a combination of intensive ground measurements (such as effective ground cover reduction, soil aggregate stability reduction, and hydrophobic soil development) based on a judgement sampling technique, followed by overlook point or aerial sketch mapping, and additional ground verification. These time critical rough sketch maps are used for area calculations, sediment yield calculations, and for locating treatment areas. Burn intensity maps may be further refined as more detailed information becomes available, but often the initial maps may be digitized and become part of the local geographic information system (GIS) planning databases for use in subsequent fire long term recovery planning and environmental analysis.

BAER Requirements

The BAER program calls for a fast and cost effective way to map fire effects on the watershed. The currently used rough sketch mapping techniques potentially results in oversimplification and imprecise line placement and delineation of burn intensities. The burn intensity map needs to be accessible as a paper map and as a layer in a geographic information system to a variety of people involved in the assessment and subsequent rehabilitation program. The map needs to be available at varying scales for visual overlay and display with other resource information, such as watershed boundaries, pre-fire vegetation, soils, and wildlife habitat.

The critical determination of whether a watershed emergency exists, and the magnitude and site specific location of potentially high cost rehabilitation measures are based in part on the burn intensity map. Because of that, the higher the accuracy and precision of this map the more effective and efficient this effort becomes.

Data collection tools

Over the years various attempts have been made at improving upon the burn intensity mapping techniques. Initially this project tested a variety of sensors, cameras, and videography techniques to determine the best scale, image acquisition platform, and resolution that would meet the current need of the BAER effort.

A color infrared digital camera (Kodak DCS 420) coupled with a global positioning system (GPS) was used to image the burned area. The digital camera stores the image on a digital disk, instead of film (Bobbe, 1994) (Figure 1). Each image is actually a 1524 by 1012 array of picture elements, known as pixels. The camera is mounted in a small airplane, and when flown about 12,000 feet above the terrain, each image covers an area approximately 2774 by 1847 meters. Each pixel covers an area of about 3 by 3 meters. A new image can be acquired every three seconds. Images are stored in digital format on a card that can hold about 200

images.

A GPS unit is used to capture location information (latitude, longitude and elevation). This helps to locate the approximate center of each digital image frame, and is used for plotting the flight lines. The flight lines can be used in conjunction with other GIS layers to determine the location of images in relation to landscape features.

While the image acquisition process is underway the BAER burn intensity mapper, who normally would have spent much time sketch mapping the area from a helicopter, instead is able to increase the number of ground observations compared to the previous methodology. GPS data collectors were loaded with a soils-based data dictionary to help in recording important burn intensity parameters. All ground observation points were logged in the portable GPS unit for later electronic overlay with the digital image of the burned area.

Geospatial data for the burned area

The digital camera provides images of the burned area. Additional information, or base layers such as pre-fire vegetation, soils, and topography is needed to properly map the different burn intensities. This information is found in a clearinghouse for geospatial data, also known as a GIS database. Each National Forest, Regional Office, or other land management unit collects and maintains geospatial data for the land under their jurisdiction. In this assessment, we utilized the corporate database for the Forest Service Pacific Southwest Region, collected and maintained by the Mendocino National Forest and the Remote Sensing Laboratory in Sacramento, California (Warbington 1993). The processing of digital camera images was done at the Remote Sensing Lab. Processing included georeferencing individual images from the digital camera to a common base, and mosaicing all the frames into a contiguous coverage for the fire area. The georeferenced image mosaic is projected into the correct coordinate system and datum to be useable with the local GIS database.

The process

A well prepared plan is needed for mapping fire intensities, and to ensure efficient rehabilitation process. The plan needs to cover the following: 1. Available geospatial data for a potential fire area, and how to access these data, 2. Arrange for computer and other equipment that will be used for data collection, processing and display, 3. The availability of properly trained people to collect field observations, image data, to do the data capture and GIS analysis, and to produce the report required for rehabilitation work. Finally, a mobilization plan is needed to start the assessment as soon as the BAER team can access the burn area.

A test of this technology was done on a fire on the Mendocino National Forest in Northern California, known as the Fork Fire, during the summer of 1996. A 30,000 acre portion of the Middle Creek watershed was covered by five flight lines, totaling 150 digital camera images acquired 12,000 feet above ground level (AGL) (Figure 2). Flight plans were input into GPS navigation software to assist with airplane navigation, and to ensure proper coverage. A mosaic consisting of 110 digital images (Figure 3) was assembled and registered to SPOT panchromatic satellite imagery (resolution of 10 meters).

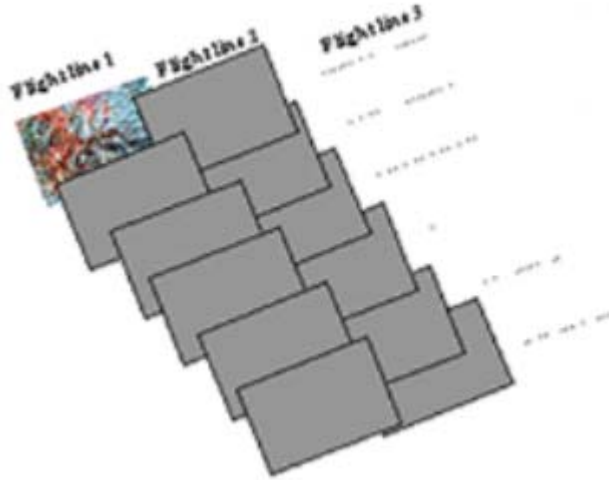


Figure 3 - Digital image mosaicing process

As the acquisition of digital camera imagery was taking place, a team of BAER specialists collected information on specific burn intensities on the ground. Observations on the ground included the amount and degree of litter consumed, depth and color of ash, changes in soil structure and soil crusting, fire-induced water repellency, size and amount of live fuels consumed, and site characteristics (percent surface rock, pre-fire vegetation type, slope, aspect, soil type, etc). GPS coordinates were recorded for each ground location visited.

The burn intensity map

The burn intensity map for the Middle Creek watershed was prepared using a variety of information including the mosaic of digital images printed at a scale of 1:24,000, field notes, GPS data points, aerial overview, and information from the Mendocino National Forest GIS database (pre-fire vegetation, streams, topography). Polygons of burn intensity were manually delineated on the image mosaic (Figure 4). A digital version of the mosaic was used on a workstation to observe specific locations in more detail. The minimum polygon size was about 20 acres, with most polygons in the range of several hundred acres.

The process of integrating ground and aerial observations with the imagery produced a map of burn intensity with a higher degree of accuracy and spatial precision than would have been possible without the imagery. Further, the ability to interface the digital image with pre-fire vegetation and topography information from the GIS allowed even greater accuracy. For example, on the image the areas of burned shrub communities looked similar to the areas of intensely burned forests. Ground observations within representative areas of burned shrub communities, however, indicated only moderate burn intensity. Thus, by using the GIS to overlay the shrub areas on the image it became possible to separate the moderately burned shrub areas from the high intensity forested areas.

It was advantageous to have the digital map early in the process. The display of digital data speeded up the process of identifying critical areas within the burn to focus the limited and

expensive field time. The wildlife biologist, for example, can immediately identify how much, if any critical habitat areas burned at high intensity. The hydrologist can quickly calculate percent of watershed in high burn intensity condition, as well as identify where in the watershed those conditions occur. The archeologist can overlay burn intensity with heritage resources. The soil scientist can overlay the burn intensity map with the GIS data layers of soil erosion groups and slope groups and quickly derive the areas of various burn intensity soil/slope combinations. These figures are needed for calculating predicted soil loss, which is part of the BAER cost-benefit analysis requirement.

This effort with the digital camera was undertaken separate from the regular BAER effort. As a result, two burn intensity maps were created, one by the previous methodology, and one by the new methodology (Figure 5). Upon completion of the burn intensity maps by both efforts an accuracy assessment was undertaken. Based on a number of ground observations, a 20% improvement in accuracy was realized with the new methodology. This is important for two reasons: 1. From the standpoint of ensuring essential protection of life and property in areas that may have not been identified as potential flood source areas, and 2. Avoiding over-prescribing expensive rehabilitation measures into areas that may not be flood source areas.

Water erosion models

The burn intensity map serves as a representation of vegetation cover and runoff factors for use in erosion and runoff models. The image interpreted map, soils layer, and slope groupings from digital elevation models (DEM) are used in the Universal Soil Loss Equation (USLE) or other models to derive factors for soil cover, soil k-factor, and slope angle. Other factors in the equations, such as slope length and rainfall amount and intensity are often constant for a given burn area. The results, in acres of the various soil cover, erosion, and slope groups can be output to a database that can quickly calculate the final figures. This process, currently being done by hand using a planimeter or dot grid, is error-prone and can take several hours. The digitally interpreted map provides a quicker, more accurate method to calculate potential erosion and runoff.

Until now, the BAER effort has been limited by the accuracy of the various maps at its disposal relative to making site specific calculations of erosion and sedimentation. For most fire areas generalized erosion in tons per acre, or sediment generated in tons per square mile for the overall burned area is calculated. Current erosion and sedimentation computer models are available to analyze GIS cell to cell interactions and generate erosion and sediment routing calculations. This can be used with the GIS database that can now be tied to the digital burn intensity map. GIS combined with sedimentation models provides the opportunity to calculate sediment bulking at specific bridges and culverts within sub-watersheds of the burned area, etc. This is the direction that the FS is taking this effort next.

Conclusions - Recommendations

Remote sensing, geographic information systems, and related technologies play a vital part in all aspects of fire management. The color infrared digital camera, coupled with GPS, provide information needed in the Burned Area Emergency Rehabilitation program. The image

mosaic was provided to fire mapping specialists within three days of control of the fire. The imagery combined with GIS layers of pre-fire vegetation, streams, and topography along with field assessment was used for estimating soil loss and eventual rehabilitation measures. The resulting geospatial information is also of great value to wildlife biologist, hydrologist, and archeologist.

The accuracy of the burn intensity map has improved 20% as compared to the traditional method. On the Fork Fire alone, over a quarter of a million dollars were saved, in part because of the results of this test project. Imagery can be readily acquired and made available by existing contractors, provided that a georeferenced base layer is available to rectify the acquired imagery. This process may save lives, property, and significant resource values by more precise and accurate placement of BAER treatments, and reduce the cost of treatment by further refining the determination of whether a watershed emergency exists after the fire, and the location and extent of flood source areas.

Acknowledgements

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Fire Regime Variability by Plant Association in Southwestern Oregon

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Introduction

The Klamath Province of the Rogue River and Siskiyou National Forests in southwestern Oregon is a region of high biological diversity (Whittaker 1960). This is related to the transitional climate and the history of the Siskiyou Mountains. The area is located at the northern end of the range of Mediterranean climates in western North America. Because it is oriented perpendicular to the Cascade and Sierra Nevada Mountains, it extends from dry interior valleys westward to the coast and includes marine environments. It is situated at 40° N latitude and receives storms both from the Bering Sea to the north and tropical storms from the south. The bedrock materials are very diverse and are among the oldest in North America, over 200 million years old. As a result of this diverse climate and geology many endemic species have developed. The Siskiyou Mountains have also acted as a sink for genetic materials that remained and evolved through many climate changes.

Plant diversity is expressed by the numerous plant associations found in the Klamath Province of southwestern Oregon. About 60 plant associations are found, including Western Hemlock, White Fir, Tanoak, Douglas-fir, Port-Orford-cedar, Jeffrey Pine, Western White Pine, Ponderosa Pine, Shasta Red Fir, and the Mountain Hemlock Series (Atzet and others 1996).

The diversity in composition and structure has been enhanced by the disturbance regime, particularly fire. Low intensity fire results in a patchy mosaic of species and ages on forest lands. Agee (1993) has described the fire regime in southwestern Oregon as moderate, that is, a mixture of stand replacement and low severity fires. Fire regimes have been described by Atzet and Martin (1991) for the plant series that occur in this region. Fire return intervals range from 25 years in the White Fir Series to 115 years in the Mountain Hemlock Series.

Fire disturbance has been reduced by active fire exclusion techniques for over 50 years in the Klamath Province and has led to changes in forest composition and structure. Managers are advocating the maintenance of the historical diversity of southwestern Oregon and are demanding more detailed information on fire regimes.

This paper presents fire regime information for management and modeling, derived from tree age and stand structure data, for the plant associations in the Tanoak, Jeffrey Pine, and Mountain Hemlock plant associations in the Klamath Province of southwestern Oregon.

Table 1. Plant association common names, codes, and scientific names.

Series	Common names	Scientific names	Codes
Tanoak	Tanoak-Port-Orford-Cedar/Salal	<i>Lithocarpus densiflorus-Chamaecyparis lawsoniana/Gaultheria shallon</i>	LIDE3-CHLA/ GASH
	Tanoak-Western White Pine/Huckleberry Oak/Common Beargrass	<i>Lithocarpus densiflorus-Chamaecyparis lawsoniana/Xerophyllum tenax</i>	LIDE3-CHLA/ XETE
	Tanoak-Douglas-fir-Canyon Liveoak/ Dwarf Oregongrape	<i>Lithocarpus densiflorus-Pseudotsuga menziesii-Quercus chrysolepis/Berberis nervosa</i>	LIDE3-PSME-QUCH2/BENE
	Tanoak-Douglas-fir-Canyon Liveoak/Poisonoak	<i>Lithocarpus densiflorus-Pseudotsuga menziesii-Quercus chrysolepis/Rhus diversiloba</i>	LIDE3-PSME-QUCH2/RHDI
	Tanoak-Western Hemlock/Evergreen Huckleberry/Western Swordfern	<i>Lithocarpus densiflorus-Tsuga heterophylla/Vaccinium ovatum/Polystichum munitum</i>	LIDE3-TSHE/ VAOV/POMU
	Tanoak/Evergreen Huckleberry-Pacific Rhododendron-Salal	<i>Lithocarpus densiflorus/Vaccinium ovatum-Rhododendron macrophyllum-Gaultheria shallon</i>	LIDE3/ VAOV2-RHMA3-GASH
Jeffrey Pine	Jeffrey pine-Incense Cedar/Whiteleaf Manzanita	<i>Pinus jeffreyi-Calocedrus decurrens/Arctostaphylos viscida</i>	PIJE-CADE27/ARVI4
	Jeffrey Pine-Incense Cedar/Huckleberry Oak	<i>Pinus jeffreyi-Calocedrus decurrens/Quercus vaccinifolia</i>	PIJE-CADE27/QUVA
	Jeffrey Pine/Huckleberry Oak-Pinemat Manzanita-Box-Leaved Silk-Tassel	<i>Pinus jeffreyi/Quercus vaccinifolia-Arctostaphylos nevadensis-Garrya buxifolia</i>	PIJE/ QUVA-ARNE-GABU2
	Jeffrey Pine/Huckleberry Oak-Pinemat Manzanita	<i>Pinus jeffreyi/Quercus vaccinifolia-Arctostaphylos nevadensis</i>	PIJE/ QUVA-ARNE
Mountain Hemlock	Mountain Hemlock/Herb	<i>Tsuga mertensiana/Herb</i>	TSME-HERB
	Mountain Hemlock-Shasta Red Fir/Thin-Leaved Huckleberry/Common Prince's-Pine	<i>Tsuga mertensiana-Abies magnifica shastensis/Vaccinium membranaceum/Chimaphila umbellata</i>	TSME-ABMAS/RULA2/PYSE
	Mountain Hemlock-Shasta Red Fir/Dwarf Bramble/One-Sided Pyrola	<i>Tsuga mertensiana-Abies magnifica shastensis/ Rubus lasiococcus/Pyrola secunda</i>	TSME-ABMAS/RULA2/PYSE

Study Area

The data were collected from the Siskiyou National Forest and the Klamath Province portion of the Rogue River National Forest in southwestern Oregon. The Klamath Province has a variety of rock types and ages. Original igneous and sedimentary rocks have been

metamorphosed, folded, and juxtaposed. Formations decrease in age from east to west. The Condrey Mountain schists straddling the California-Oregon border southwest of Ashland, Oregon, are at least 200 million years old, whereas the Hunters Cove Formation, near Gold Beach, is about 65 million years old (Baldwin 1992). The variety of formations contains metamorphosed igneous and sedimentary rock ranging from granite to peridotite and from sandstone to mudstone.

The combination of geology, climate, soils, and disturbance history has produced a highly diverse flora (Whittaker 1960). The Siskiyou National Forest Plan lists over 100 sensitive species. The forests of the Klamath Province are composed of about 60 plant associations (uniquely identifiable portions of the environment) covering 10 plant series (Atzet, and others 1996). We examined the Tanoak Series, the Mountain Hemlock Series, and the Jeffrey Pine Series because these associations cover the range of environmental and edaphic conditions found in the Klamath Province (tables 1, 2).

The Jeffrey Pine Series is confined to ultramafic soils, which occur throughout the Province. The Tanoak Series dominates warm, wet, coastal sites and inland areas that have deep soils and low evapotranspirational demand (Atzet, and others 1983). The Mountain Hemlock Series occurs at high elevations, sometimes delimiting timberline, where soil and air temperatures are extremely cold (Atzet, and others 1983, Sawyer and Thornburgh 1977).

Methods

Field

Data were collected from permanent plots located on the Rogue River and Siskiyou National Forests. Plots were located so that the variation in vegetation over the landscape was represented. Within plots, a single plant association was present. Five subplots were established around each plot using one-half of the USDA Forest Service's Pacific Northwest Region timber inventory diamond cluster (USDA Forest Service 1970).

Within each variable radius subplot, the diameters of all species of trees were recorded (table 2). Five site trees of each dominant species and three to five site trees of each codominant species were chosen, and heights and ages of these trees were recorded. The ages were noted as estimated where the cores did not reach the pith.

The environmental variables elevation, aspect, percent slope, and slope position were recorded for each plot (table 2). Slope position was defined as ridge top, upper one-third of slope, middle one-third of slope, lower one-third of slope, bench, toe of slope, canyon bottom, edge or in wetland basin, and draw or intermittent stream bottom.

Analyses

The aged trees in each plot were listed in descending order. Patterns of age and/or species change were noted. When a pioneer species was present, the age was noted. If one or more trees of a pioneer species in this age class was present, that was determined to be a disturbance event. The age of the next pioneer species, or several individuals of the climax species, was noted and determined to be the result of a disturbance event. A surety rating for each disturbance event was developed based on whether the age of the tree was an estimate or an

actual count, whether more than one tree was present in the age cohort (with multiple trees indicating higher surety), and the species of trees present. The rating ranged from 1 (unsure) to 10 (positive). A severity rating was also assigned: 1 = low severity--climax trees established after the disturbance; 2 = moderate severity--pioneer species established after the disturbance, but with older climax species that survived the event; and 3 = high severity--pioneer species established after the disturbance with climax species coming in later. These are patterned after Brown's (1994) fire regime severity classes. Date of disturbance was calculated using tree ages and plot date.

Disturbance dates were derived from tree age and stand structure data, rather than fire scar data. This more liberal approach will detect disturbances not usually shown by fire scars. This technique has been used by others (Agee 1991, Arno, and other 1997).

Table 2. *Plant association characteristics: mean elevation (Elev), aspect (Asp), slope, diameter (Dbh), and mean annual temperature (Temp), and mean annual precipitation (Precip).*

Plant Association	Elev (ft)	Asp (deg)	Slope (pct)	DBH (in)	Temp (deg F)	Precip (in)
LIDE3-CHLA/GASH	2491	131	29	42	49.0	86
LIDE3-PIMO/QUVA/XETE	2681	164	28	16	48.5	129
LIDE3-PSME-QUCH2/ BENE2	3035	155	48	40	48.0	62
LIDE3-PSME-QUCH2/ RHD16	2777	185	50	37	48.0	72
LIDE3-TSHE/VAOV2/ POMU	1077	285	49	51	52.0	108
LIDE3/VAOV2-RHMA3- GASH	1464	156	38	45	52.0	122
PIJE-CADE27/ARVI4	2748	173	36	22	49.5	56
PIJE-CADE27/QUVA	4226	182	37	24	45.0	60
PIJE/QUVA-ARNE-GABU2	3081	131	22	20	47.5	120
PIJE/QUVA-ARNE	2258	182	40	14	49.5	120
TSME/HERB	6715	207	33	29	37.4	45
TSME-ABMAS/VAME/ CHUM	5915	225	41	23	39.5	50
TSME-ABMAS/RULA2/ PYSE	6016	165	38	37	39.5	57

Fire severity within each plant series was examined for patterns relating to elevation, aspect, percent slope, and slope position. Aspect was divided into north and south. Two methods were used to define north, 270° to 90°, as well as with a 40° offset, 310° to 130°.

Results and Discussion

Intensity

Fire severity may vary with several factors, including fuel availability and environment. Results show significant differences in severity by plant association, an indicator of environment (table 3).

Table 3. Mean fire severity, 95 percent confidence intervals, and severity rating by plant association.

Plant Association	Severity (95 pct CI)	Rating
LIDE3-TSHE/VAOV2/POMU	2.38 (.29)	Moderate
LIDE3/VAOV2-RHMA3-GASH	2.31 (.18)	Moderate
LIDE3-PSME-QUCH2/BENE2	2.20 (.44)	Moderate
PIJE/QUVA-ARNE	2.17 (.39)	
LIDE3-PSME-QUCH2/RHDI6	1.90 (.11)	Moderate
TSME-ABMAS/VAME/CHUM	1.78 (.51)	
LIDE3-CHLA/GASH	1.75 (.61)	
LIDE3-PIMO3/QUVA/XETE	1.67 (.37)	
PIJE/QUVA-ARNE-GABU2	1.67 (.42)	
TSME/HERB	1.47 (.18)	Low
PIJE-CADE27/QUVA	1.44 (.18)	Low
PIJE-CADE27/ARVI4	1.41 (.22)	Low
TSME-ABMAS/RULA2/PYSE	1.40 (.37)	Low

The Mountain Hemlock/Herb, Jeffrey Pine-Incense-Cedar/Huckleberry Oak, Jeffrey Pine-Incense-Cedar/Whiteleaf Manzanita, and Mountain Hemlock-Shasta Red Fir/Dwarf Bramble/One-Sided Pyrola plant associations have significantly lower intensity fires than the Tanoak-Western Hemlock/Evergreen Huckleberry/ Western Swordfern, Tanoak/ Evergreen Huckleberry-Pacific Rhododendron-Salal, Tanoak-Douglas-Fir-Canyon Liveoak/Dwarf Oregongrape, and Tanoak-Douglas-Fir-Canyon Liveoak/Poisonoak associations. The plant associations that are characterized by lower severity fires are generally drier (mean annual precipitation) and often cooler (mean annual temperature) than the associations with more moderate intensity fires (Atzet and others 1996). The associations characterized by moderate severity fires tend to have higher biomass production, expressed by higher mean diameters (dbh)(table 2).

The environmental variables of elevation, aspect, and slope were examined to determine possible relationships with fire intensity. Plant series were used for these analyses, rather than plant associations, to assure large sample sizes.

Table 4. Elevation, aspect, and slope relationships with fire severity.

	Plant Series					
	LIDE3		PIJE		TSME	
	Mean	se ¹	Mean	se	Mean	se
Elevation (feet)						
0-500	2.80	(.20)	---		---	
500-1000	2.79	(.11)	---		---	
1000-1500	2.31	(.10)	1.50	(.29)	---	
1500-2000	1.93	(.11)	1.53	(.17)	---	
2000-2500	2.01	(.10)	1.95	(.18)	---	
2500-3000	1.84	(.10)	1.59	(.19)	---	
3000-3500	1.85	(.08)	1.25	(.16)	---	
3500-4000	2.20	(.19)	1.77	(.23)	---	
4000-4500	2.36	(.20)	1.82	(.23)	---	
4500-5000	---		1.30	(.15)	---	
5000-5500	---		1.17	(.11)	1.83	(.31)
5500-6000	---		1.40	(.24)	1.45	(.16)
6000-6500	---		---		1.33	(.14)
6500-7000	---		---		1.54	(.10)
Aspect ²						
North	2.02	(.05)	1.55	(.13)	1.51	(.07)
South	2.04	(.06)	1.59	(.08)	---	
Slope (percent)						
0-5	2.21	(.15)	1.86	(.23)	1.20	(.20)
5-15	1.98	(.13)	1.50	(.22)	1.54	(.14)
15-25	2.39	(.14)	1.64	(.14)	1.50	(.15)
25-35	2.08	(.13)	1.38	(.12)	1.50	(.29)
35-45	1.91	(.08)	1.68	(.15)	1.67	(.21)
45-55	2.06	(.10)	2.17	(.40)	---	
55-65	1.92	(.10)	1.17	(.11)	---	
65-75	2.21	(.18)	---		---	

These data show no apparent relationship between aspect (regardless of definition) and slope and fire severity. Slope position also lacked a relationship with fire severity. Fire severity does change with elevation, however, in the Tanoak Series. The moderate fires occur at the lowest and highest elevations, and low severity fires occur at the middle elevations. This relationship does not hold for the Jeffrey Pine or the Mountain Hemlock Series. In old growth forests in the Klamath Mountains of northwestern California, Taylor and Skinner (1995) found a relationship between aspect and severity, but none with elevation or slope position. These analyses suggest plant associations, rather than environmental variables, should be used for modeling severity.

¹ Standard error.

² 270° to 90° N.

Fire Return Interval

Landscape level fire return intervals were determined (figs 1-3). Return intervals for the Tanoak plant associations range from an average of 3.1 years to 23.3 years. Variation about the

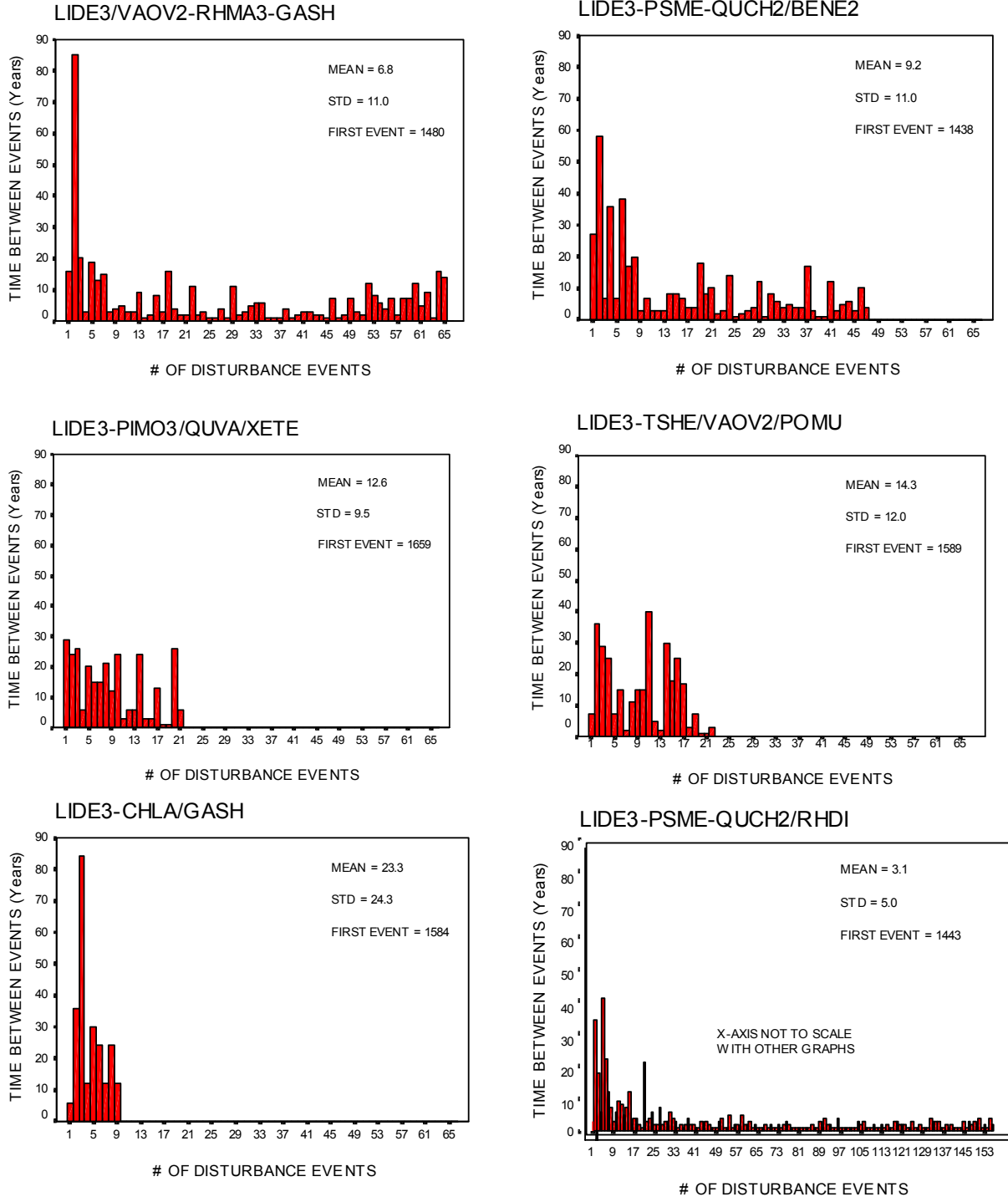


Figure 1. Fire return intervals for the Tanoak Series. The mean, standard deviation (STD), and date of the first event are included on each graph.

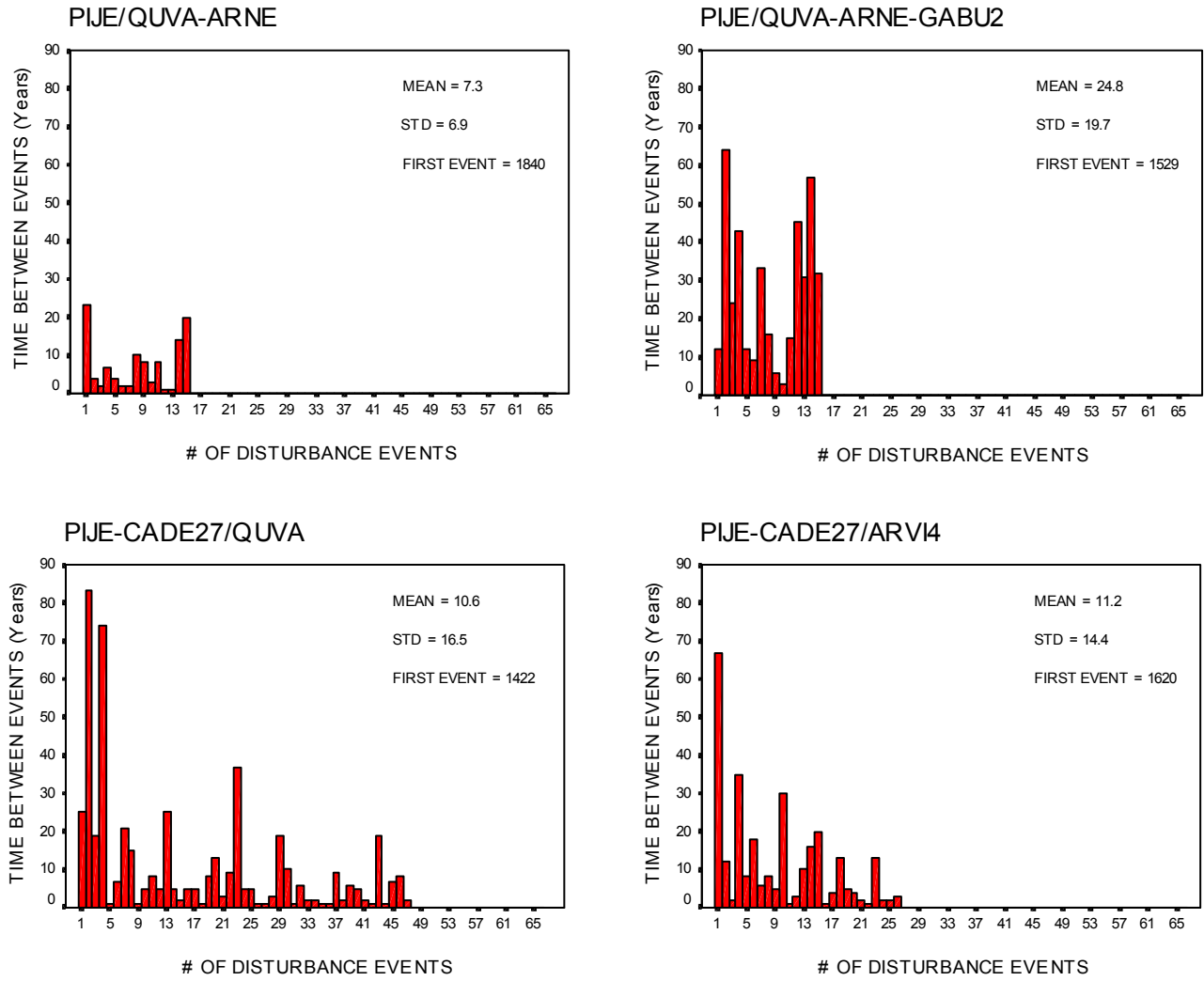


Figure 2. Fire return intervals for the Jeffrey Pine Series. The mean, standard deviation (STD), and date of the first event are included on each graph.

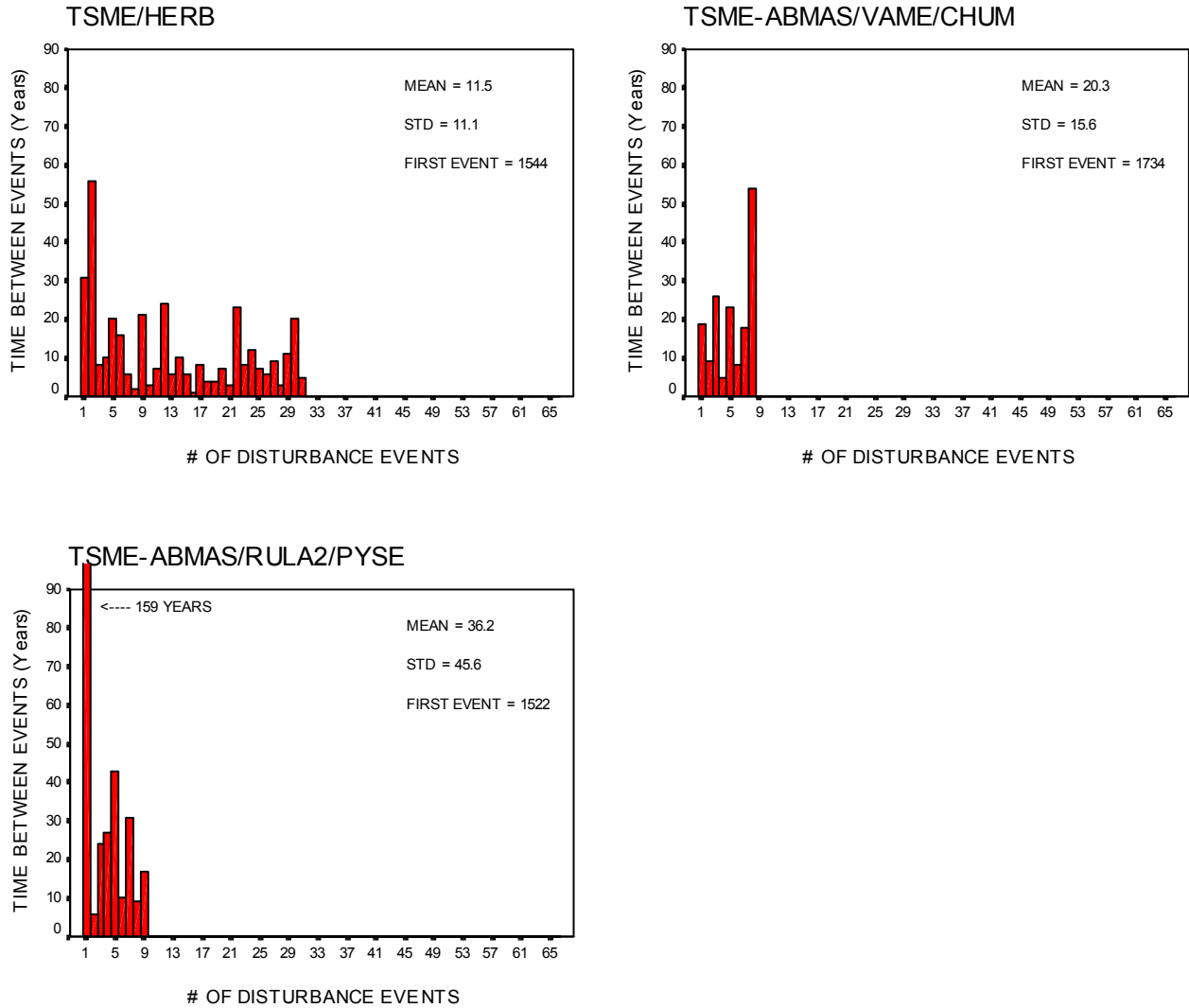


Figure 3. Fire return intervals for the Mountain Hemlock Series. The mean, standard deviation (STD), and date of the first event are included on each graph.

means, shown as standard deviation, is very high. Generally, the drier associations have more frequent return intervals than the wetter associations. Most striking is the chaotic pattern of return intervals. For example, in the Tanoak-Western Hemlock/Evergreen Huckleberry/Western Swordfern association, the intervals are 6 years, 37 years, 29 years, 25 years, 7 years, 15 years, etc. In the Jeffrey Pine plant associations, the fire return intervals range from 7.3 years to 24.8 years, with dry associations showing shorter intervals compared with more moist plant associations. The fire return intervals in the Mountain Hemlock plant associations range from 11.5 years to 36.2 years, with the most frequent intervals in the driest plant association. This may be because of the cooler, moister climate during the Little Ice Age, or it may be because of the preponderance of fire and resulting lack of older trees. These return intervals are markedly

shorter than those reported by Atzet and Martin (1991) for the same area. Fire is more pervasive than fire scars alone indicate.

Shorter return intervals were reported in an unpublished study³ in the southern Oregon Cascades. For example, the Mountain Hemlock Series return interval ranged from 13 to 64 years. Though fire was evident in the stands, examination of aerial photographs showed that fires could not be distinguished on a landscape basis; there was a mosaic of species and structures. This supports short interval determinations, and suggests that low intensity fires occurred, often as understory burns but were often not intense enough to injure cambium and cause mortality. These data are being used in watershed analyses, as a guide for reintroducing fire into the ecosystem.

High variation in mean fire return intervals in southwestern Oregon has been documented in the literature (Agee 1991, Atzet and Martin 1991). Moir and Mowrer (1995) report on the generally chaotic nature of fire across a landscape, and McNell and Zobel (1980) report chaotic fire patterns, similar to those found in this study, in Crater Lake National Park.

Conclusions

Managing forests for natural fire return intervals may require integration of the chaotic patterns into management schemes. The data in this study show that fire is more pervasive than previously thought. Brown (1994) states that in mixed fire regimes (such as those found in the Klamath region of southwestern Oregon), a wide range of stand structures and landscape patterns are probably within the range of natural variability. Thus, managers may have considerable ecological latitude in designing activities to provide ecosystem products. The challenge is to provide a diversity of stand structures.

This paper shows that the fire regime in the Klamath region of southwestern Oregon is indeed highly variable. A simple determination of mean fire return interval does not adequately describe fire as an ecosystem process. Modeling of fire regimes will be difficult because regular patterns can not be used. Although management tends to limit the range of conditions, extremes will occur. In hot, dry years high severity fires will occur. These extremes are necessary for evolution.

Biomass in the forest must be managed for many purposes, particularly in the most productive sites where biomass accumulation is high, with accompanying higher severity fires. Purposes range from urban home fire protection to forest health. The data in this study clearly show that fire was an integral part of the ecosystem, and reintroduction and integration of the chaotic fire regime should proceed with the intent of producing varied, natural stand structures and composition.

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³ Unpublished data on file, Umpqua National Forest, Roseburg, OR.

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Fire History in Riparian Reserves of the Klamath Mountains

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Abstract

Though riparian areas are recognized as having great importance disproportionate to the area they occupy in landscapes, little information is available concerning their past fire history. As a result, a great deal of uncertainty exists about the role of fire in riparian environments. Considering California's Mediterranean climate and the general pattern of frequent fires in most vegetation types, it is logical to assume that fires regularly affected many riparian areas in the past. A preliminary investigation to develop fire histories from riparian reserves was conducted along the Shasta-Trinity divide in the Klamath Mountains of northern California. Fire return intervals (FRI) were developed from fire scars on stumps in several riparian reserve sites along perennial streams. The FRIs for riparian reserve sites were approximately double the FRIs from nearby upland forest sites, while the ranges of FRIs were very similar. These preliminary data suggest that FRIs in riparian reserves may be more variable than in adjacent uplands and tend to be longer. Riparian areas may have enhanced the spatial and temporal diversity of landscapes by acting as occasional barriers to many low- and moderate-severity fires.

Introduction

Although riparian areas usually occupy a limited proportion of forested landscapes, they have been recognized as having ecological importance disproportionate to the area they occupy (Thomas and others 1979). Yet, Skinner and Chang (1996) were unable to find published fire history studies that would shed light specifically on riparian area fire regimes for the forested landscapes of California.

Riparian reserves have recently been designated in the Klamath Mountains (USDA-USDI 1995). One stated goal is to maintain or restore biological and physical processes of the reserves within their range of natural variability. Accordingly, standards and guidelines have been set for such conditions as coarse woody debris accumulations and shading of streams. However, the standards and guidelines have been set based upon studies of riparian environments that have been under a fire suppression management strategy for much of this century. The conditions displayed by many riparian zones may be, at least partly, an artifact of fire suppression. As a result, the amount of shading and coarse woody debris thought to represent 'natural' conditions may be in excess of amounts provided by a historical fire regime.

A pronounced annual drought is characteristic of California's Mediterranean climate despite total yearly precipitation. This annually contributes to conditions where fire can easily ignite and spread in most forest areas. The predominance of vegetation in California's forested environments is well adapted to recurring fires (Chang 1996). As a result, fire has been recognized as one of the more important processes in most California ecosystems (Blackburn

and Anderson, 1993; Martin and Sapsis, 1992; Pinchot, 1899; Skinner and Chang, 1996). Accordingly, fire was acknowledged as an important ecological process in the Klamath Mountains when the riparian reserves were designated (USDA-USDI 1995).

The strong annual drought ensures that riparian reserves, though somewhat buffered by higher moisture conditions, regularly experience conditions where fires can easily burn within them. To provide adequately for the long-term management of riparian reserves within their historical range of variability (Swanson and others 1994), the historical fire regime must be an important and explicit consideration (Skinner 1997).

Considerable uncertainty exists about the role of fire in riparian reserves. Considering California's Mediterranean climate and the general pattern of frequent fires in most forested areas, it is logical to assume that fire regularly affected most forest zone riparian areas before systematic fire suppression. However, lacking empirical data, the potential spatial and temporal variations of fire regime characteristics in riparian areas have mostly been discussed conceptually (Agee 1994). Variation in stream width, seasonal availability of water, and topography would likely lead to considerable variation in the interaction of fire within riparian areas. There exists a great deal of uncertainty regarding the appropriate use and management of fire in riparian reserves largely because of the lack of empirical fire-history data.

This preliminary study assessed the availability of locatable fire scars in riparian reserves for developing fire history and assessed the magnitude of the difference in fire return intervals between riparian reserves and nearby uplands.

Study Area

The study was conducted on the Mt. Shasta Ranger District of the Shasta-Trinity National Forests along the Shasta-Trinity divide in the Klamath Mountains. The terrain in the study area is generally steep and rugged. Elevation of the five sample sites ranges from 1300 m to 1750 m. Four of the five sites were within the Sacramento River watershed with the fifth site in the Trinity River watershed.

The forest type on uplands adjacent to all riparian reserve sites would generally be described as the Klamath enriched mixed conifer type (Sawyer and Thornburgh 1977). Plants common to all riparian reserve sites in the study were western azalea (*Rhododendron occidentale* [Torrey & A. Gray] A. Gray) (nomenclature follows Hickman 1993), Port Orford cedar (*Cupressus lawsoniana* A. Murray), willows (*Salix* spp.), and various grasses, sedges, and forbs associated with wet areas (Skinner and Chang 1996).

Methods

Five sites in riparian reserves were selected. The riparian reserve component for each site was a perennial stream of at least first order. Stream orders were taken from standard 1:24,000 scale, 7.5 minute topographic maps. As each site had been previously logged, stumps were used to identify fire scars.

For two of the sites paired riparian reserve/upland components within 500 m were selected. The riparian reserve component of these two sites were both first order streams (North Fork Shotgun Creek and Root Creek) on south-facing slopes. The paired upland component had

similar elevation, slope steepness, and aspect conditions to those of the riparian reserve component.

Two riparian reserve sites, one a second order (Scott Camp Creek) and the other a third order stream (Soapstone Gulch), were on north trending, gently sloped swales. No nearby comparable, logged, upland component was available for these sites.

The fifth site was an unnamed first order stream on a steep, north-facing slope in the East Fork of the Trinity River watershed. This fifth site had two upland components designated East Fork Trinity A (EFTA) and East Fork Trinity B (EFTB) that were on opposite sides of the stream. Although both sites were considered upland sites, they were partially within the riparian reserve because logging had taken place to within approximately 10 m of the stream channel. No separate riparian reserve component was sampled here. The return intervals for fires shared by the two sites were assumed to approximate the return intervals for fires that would have affected the riparian reserve.

For each site, fire history data were gathered from stumps over approximately a 1-2 hectare area. Fire intervals were identified from scars at stump height by counting exposed annual rings aided by a 10-20X hand lens. A single slab from the stump with the greatest number of scars on each site was cut, sanded, and analyzed under a microscope to develop fire intervals. These intervals were used as references for adjusting fire dates of intervals from fire scars that had been identified in the field using techniques described by Arno and Sneek (1977). Finally, based upon the composite fire history (Dieterich 1980), descriptive fire statistics were developed for each site.

Results and Discussion

Median fire return intervals and other descriptive statistics were developed for each site (Table 1). These data reveal that the riparian reserve sites recorded fire scars less frequently than nearby upland sites.

Table 1. Descriptive statistics for fires recorded in the study.

Site	Median FRI (range)	Period of record	No. of stumps
Root Creek Riparian	33(7-65)	1673-1880	4
Root Creek Upland	7(3-44)	1749-1924	14
N.F. Shotgun Cr. Riparian	16(5-56)	1740-1924	9
N.F. Shotgun Cr. Upland	8(4-64)	1710-1916	16
Scott Camp Creek	21(12-71)	1622-1887	18
Soapstone Gulch	42(9-52)	1688-1933	15
EFTA	13(6-47)	1591-1921	11
EFTB	13(4-47)	1525-1921	14

The two sites on opposite sides of the stream (EFTA, EFTB) show similar FRIs to the other upland sites. The descriptive fire statistics for these sites and the fires they have in common were recorded (Table 2). The fires in common burned uplands on both sides of the riparian zone. Presumably, many of these fires, and at least some of those recorded on only one side, would have burned within the riparian reserve. The median and range of FRIs for the shared fires appear similar to those of the other riparian reserve sites.

Table 2. Medians and ranges of fire return intervals for the two sites (EFTA, EFTB) on opposite sides of the tributary to the East Fork of the Trinity River. Each site is shown individually along with the shared fires.

Variable	EFTA	EFTB	Shared fires
Median Fire Return Interval	13	13	27.5
Range of Fire Return Intervals	6-47	4 – 47	6-47

Overall, the median FRIs for the sites in the riparian reserves was at least twice as long as those of the adjacent uplands. Similarly, the median FRI for the shared fires of EFTA and EFTB was approximately twice the value of each site individually. Interestingly, considerable differences were not found between the ranges of intervals recorded in the riparian reserves and those on the adjacent upland sites. These limited data suggest more variability in the fire intervals (and thus possibly fire behavior) within the riparian reserves than in the adjacent uplands.

That past fires were recorded less often in riparian reserves of perennial streams should not be surprising given the moist (humid) conditions that would often likely reduce fire intensity. A reduction in fire intensity would possibly have affected the recording of the fires in several ways. Fires burning with lower intensity would be less likely to scar trees. Fires entering the more humid riparian reserves may often have burned in a more spotty pattern than in the uplands. A spotty pattern would have caused the fires to miss burning adjacent to many trees. Thus, fires that may have affected the riparian reserves would be less likely to leave a record of fire scars. Additionally, the moist, humid conditions may have just limited the extent of the fires within the riparian reserves so that portions of the reserves would not be burned for periods longer than those of the adjacent uplands.

These limited data suggest that riparian areas with perennial water may serve as effective barriers to many low-severity and some moderate-severity fires, influencing landscape patterns beyond their immediate vicinity. Although riparian areas provide for increased habitat diversity of themselves, by potentially affecting fire spread and intensity, riparian areas may contribute to landscape heterogeneity in the uplands. Providing information regarding the fire/riparian/landscape interactions would potentially be an important component of future landscape-level fire history studies.

Sites with a history of past logging had to be chosen to adequately develop fire history for the riparian reserves. Few trees with open wounds displaying multiple scars were located within the riparian reserves along perennial stream courses. Most of the fire history in these areas was recorded in scars that had healed over. Without stumps to view the entire cross-section of each tree, few of the historical fires would have been detected. Because this method of detection appears necessary, it will be difficult to undertake fire histories in riparian reserves that do not have a history of logging.

However, the lack of external fire scars and less record of fire is not likely to be characteristic of upper reaches of riparian reserves where streams are intermittent. Taylor and Skinner (1998) have recently completed a landscape-level fire history study near Happy Camp in the Klamath Mountains. Their data reveal that fires were frequent (median FRIs: 9.5 - 18 yrs) and readily scarred trees on sites in steep upper reaches of intermittent streams. It is likely the intermittent channels in these upper reaches acted as chutes in which fires spread easily and possibly burned more intensely compared with the landscape overall.

Conclusion

These limited data suggest that fires were frequent in the riparian reserves studied. However, fires appear to have been recorded in riparian reserves of perennial streams less frequently than in the adjacent uplands. Nonetheless, in the upper reaches of watersheds where riparian reserves are associated with intermittent streams, fires appear to have burned with frequency similar to the surrounding uplands. These preliminary results, the ecological importance of riparian areas, and the uncertainty associated with attempting to develop long-term plans for riparian reserves point to the need for more intensive landscape level fire history studies. Landscape level studies that provide data on the long-term influence of fire on pattern and structure in the uplands (Taylor and Skinner 1998) should be combined with a more intensive look at the interactions of fire with riparian reserves. Developing successful, long-term management plans for riparian reserves in California is likely to be problematic without a serious consideration of the physical and biological potential for fire and its ecological function in those environments.

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Variation in Fire-return Intervals Across a Mixed-conifer Forest Landscape

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Abstract

Fire was the most frequent and widespread disturbance in forested landscapes of northern California, but little is known about fire regimes in Douglas fir-mixed conifer forests. In this study, we identify and compare fire return intervals in 11 Douglas fir-mixed conifer sites in the southern Cascades that vary in species composition and topographic position. Thirty fire scar samples were taken from USDA Forest Service ecological plots. The calendar year and season of fire was determined by cross-dating and identifying the position of each scar in an annual growth ring. Fire return intervals (FRI's) varied ($p < 0.05$) with topographic position but not with vegetation composition ($p > 0.05$). Plots grouped by forest dominants have similar median fire return intervals (12, 15, and 15 years). When plots are grouped by topographic position, upper-slope sites have the shortest fire return interval (7 years), middle-slope sites burned less often (16 years), and lower-slope sites burned at the longest interval (25 years). Most fires (80 percent) occurred during the dormant season, but 11 percent of fires occurred in latewood and 9 percent occurred in earlywood. FRI's did not vary in the study area from the early 19th century (1800—1848) to the early Euro-American period (1849—1904). Active fire suppression after 1905 eliminated burning in all but one plot. Small-diameter *Abies concolor* and *Pinus ponderosa* have increased in the understory, causing potential changes in long-term vegetation composition.

Introduction

Fire plays an important but complex ecological role in California's mixed-conifer forests. The near absence of fire in these forests since the turn of the century is one of the primary causes of dramatic compositional and structural change that has been observed in these forests (Bonnicksen and Stone 1981, Kilgore and Taylor 1979, McNeil and Zobel 1980, Vankat and Major 1978). Historically, low-severity fires burned every 5-36 years through mixed-conifer forests and thinned the understory (Skinner and Chang 1996). A century of fire suppression has caused dead fuel to accumulate and understory fuel ladders to form that reduce the possibility that surface fires can occur without erupting to the canopy and replacing the stand. Attempts to restore these mixed-conifer forests to more fire-resistant conditions will require a deeper understanding of prior disturbance and vegetation characteristics.

Mixed-conifer forests cover 647,000 hectares in California (Sierra Nevada Ecosystem Project 1996), but these forests vary in species composition and structure throughout the state. For example, in the mixed-conifer zone, Douglas fir (*Pseudotsuga menziesii* (Mirbel) Franco) increases in importance northward. Little is known about fire regimes in these mixed-conifer forests, especially those in the Cascades and northern Sierra Nevada (Skinner and Chang 1996).

Most data on fire regimes in mixed-conifer forests come from the southern Sierra Nevada, which experiences a dryer climate than places farther north (Skinner and Chang 1996). The higher precipitation in northern California is important because it may foster distinct disturbance regimes by influencing forest structure and composition, fuel types, and rates of fuel production.

In this paper we identify fire return intervals (FRI's) from mixed-conifer forests dominated by *Pseudotsuga menziesii* in the Southern Cascades, relate variation in FRI's to variation in vegetation and topography, and compare our FRI's with those from mixed-conifer forests of the southern Sierra Nevada to determine if there is a regional difference in FRI's.

Study Area

The study area includes a portion of southwestern Lassen National Forest in the southern Cascades of northern California. It encompasses the middle portion of the Mill Creek and Deer Creek watersheds that originate in or near Lassen Volcanic National Park. Elevations in the study area range from 900 to 1,700 meters. Precipitation falls mostly between November and April as rain or snow. At the town of Mineral, near the northern border of the study area, annual precipitation is 1,350 mm and mean annual temperature is 7.4°C (Taylor 1990).

Mixed-conifer forests in the study area vary considerably in species composition and structure. *Pseudotsuga menziesii* is found on most sites, but *Pinus ponderosa* var. *ponderosa* (Dougl.), *Pinus lambertiana* (Dougl.), *Abies concolor* ((Gordon & Glend.) Lindl.), and *Calocedrus decurrens* ((Torrey) Florin) also occur in the canopy. *Pinus jeffreyi* (Grev. & Balf.) occurs locally. Understory hardwoods occur on some sites and include *Quercus kelloggii* (Newb.), *Quercus chrysolepis* (Liebm.), and *Cornus* spp. A dense layer of small-diameter saplings and small trees occurs in the understory of many sites.

The influence of humans on the fire regimes of the study area adds an important dynamic to the process of vegetation change. Native-American fires undoubtedly contributed to fires caused by lightning here as in most of California (Lewis 1993), and the potential for ignitions by Native Americans persisted in or near the study area through 1911 (Kroeber 1961). In 1849, thousands of Euro-Americans passed through the center of the study area along the Lassen Trail (Strong 1973), and there is no evidence to suggest that Euro-Americans heavily grazed cattle or sheep in the forests of the study area during the subsequent decades. Fire suppression followed the establishment of the Lassen Peak Forest Reserve in 1905 (Strong 1973).

Methods

Vegetation Sampling

Forest structure and compositional data for this study came from 11 USDA Forest Service ecological plots sampled in 1985. The sites were chosen to represent the observed structural and compositional variation in the old-growth Douglas fir-mixed conifer forests of the west side of Lassen National Forest. Stems in each plot were tallied by species and diameter class. Stems less than 2.5 centimeters in diameter were not counted, and no age data were collected. We recognize that inferring species population dynamics from size class alone is problematic when age-diameter relationships are unknown (Veblen 1992), but we reasoned that

trees greater than 50 centimeters in diameter at breast height reflect the composition of the pre Euro-American forest and stems less than 50 centimeters suggest recent regeneration patterns. We used TWINSpan (Gauch 1982) to group plots with similar overstory composition using density per hectare of stems less than 50 cm. Stems less than 50 cm diameter were excluded from this grouping process because they are thought to represent the period of fire suppression. Oaks were excluded from this analysis because they predominantly maintained an understory structural position in these pre Euro-American mixed-conifer forests through sprouting.

Fire History

Fire history was determined from the fire-scar record preserved in living trees and stumps. We revisited these 11 sites in June of 1996. At each site, a reconnaissance was made over a 0.25 to 3.0 hectare area of uniform topography and aspect. One to five samples were collected at each location with a chain saw (Arno and Sneek 1977) based on their proximity to the ecological plot, the number of visible fire scars, and the structural integrity of the tree or stump. A total of 30 samples were collected for this study.

Samples were prepared in the laboratory by sanding both surfaces to a high polish using successively fine grades of sandpaper (Stokes and Smiley 1968). Precise calendar dates were assigned to fire scars through cross-dating and the season of each fire was inferred based on the position of scars within each annual ring (Baisan and Swetnam 1990, Caprio and Swetnam 1995, Dieterich and Swetnam 1984). Fire scar data from individual samples were then combined to create a composite fire record for each site and the study area as a whole (Dieterich 1980).

Results

TWINSpan identified three compositional groups based on the relative dominance of stems over 50 centimeters (table 1a). Group A is dominated by *Pseudotsuga menziesii*, *Pinus ponderosa* and *Calocedrus decurrens*. Group B is dominated by *Abies concolor* and *Pinus* spp., but *Pseudotsuga menziesii* is sometimes also dominant. Group C consists of a mix of conifer species with none dominant. There were differences in overstory and understory species composition in all three vegetation groups (table 1b). Understory stems are sparse or absent in Group A. The understory lacks *Pseudotsuga menziesii*; only *Abies concolor* and *Calocedrus decurrens* are present. The understory of Group B is denser than Group A and is heavily dominated by *Abies concolor*. *Pinus* spp. and *Calocedrus* are under-represented in the group's understory compared to overstory dominants. *Pseudotsuga menziesii* occurs only in the understories of the two sites with overstory representation of *Pseudotsuga*. Group C includes three sites with dense understories that consist largely of *Abies concolor* and *Pinus ponderosa*. Although common in the overstory, *Pinus lambertiana*, *Calocedrus decurrens*, and *Pseudotsuga menziesii* are often absent or under-represented in the understory.

Table 1. Density of stems (ha^{-1}) > and < 50 cm diameter at breast height (dbh) sorted by TWINSPAN overstory forest groups. Species listed: Pipo: *Pinus ponderosa*; Pije: *Pinus jeffreyi*; Pila; *Pinus lambertiana*; Cade: *Calocedrus decurrens*; Psme: *Pseudotsuga menziesii*; Abco: *Abies concolor*.

(A) Density of stems > 50 cm dbh

Group	Plot	Pipo	Pije	Pila	Cade	Psme	Abco	Median FRI ¹	FRI Range
A	21	20	---	3	---	19	---	8	2 – 28
A	159	---	---	---	55	19	7	16	7 – 19
B	22	6	---	2	4	27	8	17	11 – 26
B	31	---	3	14	---	---	37	9.5	6 – 43
B	60	14	---	6	5	22	14	13.5	6 – 17
B	137	9	---	4	5	---	8	25	10 – 57
C	23	6	---	22	11	2	40	15	10 – 22
C	55	7	---	6	---	5	5	7	2 – 19
C	61	11	---	11	23	8	5	7	2 – 33
C	136	---	---	---	1	15	17	34	24 – 36
C	157	50	---	13	5	12	---	24.5	19 – 34

(B) Density of stems < 50 cm dbh

Group	Plot	Pipo	Pije	Pila	Cade	Psme	Abco	Time since last fire	Year of last fire
A	21	---	---	---	---	---	---	36	1949
A	159	---	---	---	11	---	32	105	1880
B	22	---	---	---	---	11	11	87	1898
B	31	---	---	106	---	---	63	93	1892
B	60	---	---	---	---	32	43	87	1898
B	137	---	---	---	6	---	69	87	1898
C	23	---	---	32	---	---	11	89	1896
C	55	22	---	---	---	96	43	87	1898
C	61	277	---	---	---	74	---	82	1903
C	136	---	---	---	11	---	427	89	1896
C	157	77	---	---	---	---	43	87	1898

¹ Median fire return interval (FRI) is from 1800 through the last fire.

Fire frequency did not change from the early to late 19th century (fig. 1). During the pre Euro-American period (1800-1848), there were 0.73 fires per year when all sites are considered together. During the following 56 years (1849-1904), there were 0.75 fires per year on average. There is no significant difference in the mean fire intervals of the first and second periods (T-test, $p > 0.05$). In contrast, fire frequency was low (0.02 fires per year) and mean FRI's are significantly longer in the suppression period compared to the combined pre-settlement and early settlement period (T-test $p < 0.05$).

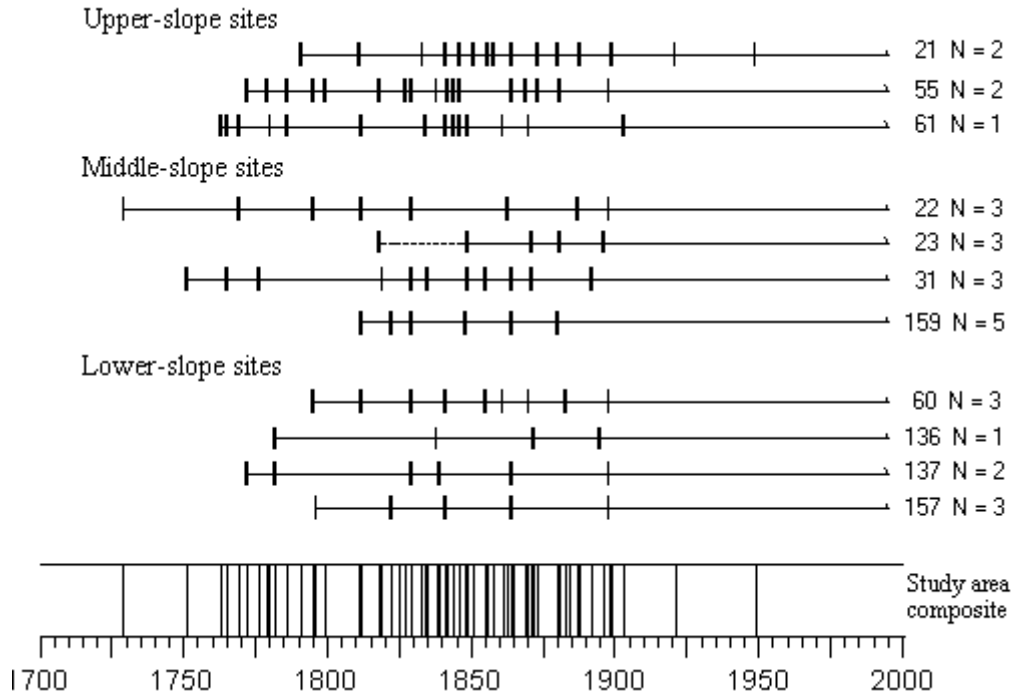


Figure 1. Fire chronologies by slope position (see table 2 for more detail). The upper seven horizontal lines in the graph are composite records for each site. The bottom section shows a composite chronology of all sites in the study area. Note that there is no appreciable change in the fire intervals until the 20th century.

The position of scars within annual growth rings indicates that 80 percent of fires occurred after the trees had completed growth for the year. Of the remaining fire scars, 11 percent occurred in latewood and 9 percent occurred in earlywood. Growing season fires occurred at least once in 6 of the 11 plots.

There was some correspondence of fire years between the widely scattered sites. Since 1800, 45 percent of fire events within the study area were recorded at two or more sites and 17 percent were recorded at three or more sites. The most widespread fires occurred in 1812, 1829, 1841, 1846, 1849, 1864, and 1898. The 1829 fire event was most extensive; five widely distributed sites in our study area burned.

Median FRI's did not vary by vegetation group (Kruskal-Wallis H test, $p > 0.05$), and maximum and minimum intervals overlap among vegetation groups (table 1). In contrast, median fire return intervals varied by topographic position (Kruskal-Wallis H test, $p < 0.05$). Upper slopes recorded shorter median FRI's than both middle and lower slopes (table 2). Three of the four lower-slope sites recorded especially long median FRI's; the one exception was a southwest-facing slope.

Table 2. Fire return intervals (FRI's) of 11 USFS plots in the southwestern Cascades according to topographic position.

Topographic Position ¹	Plot	Aspect	Number of samples	Median FRI	Range of FRI	Number of FRI's	Tree species sampled ²	TWINSPAN groups
Upper slope	21	NW	2	8	2 – 28	14	Pipo	A
	55	SE	2	8	2 – 19	16	Pila	B
	61	SE	1	7	2 – 33	13	Psme	C
Middle slope	22	SE	3	17	11 – 26	7	Pila, Cade	B
	23	NW	3	15	10 – 22	3	Pila	C
	31	NE	3	10.5	6 – 43	10	Pipo, Pila	C
	159	SW	5	16	7 – 19	5	Pipo, Pila, Cade	C
Lower slope	60	SW	3	13.5	6 – 17	8	Cade	B
	136	None	1	34	24 – 56	3	Pila	B
	137	NW	2	25	10 – 47	5	Pipo, Cade	C
	157	NE	3	24.5	19 – 34	4	Pipo, Cade	A
All sites	----	----	----	15	2 – 56	----	----	----

¹Median FRI's differed by topographic position (Kruskal-Wallis H-test, $P < 0.05$).

²Species abbreviations are as follows: Pipo, *Pinus ponderosa*; Pila, *Pinus lambertiana*; Psme, *Pseudotsuga menziesii*; Cade, *Calocedrus decurrens*.

Discussion

Before fire exclusion in 1905, median FRI's range from 7 to 34 years when cross-dated fire records are combined from multiple trees at a site, and FRI's varied from a minimum of 2 to a maximum of 57 years (table 2). These FRI's fall within the broad range of intervals reported for other Douglas fir-mixed conifer forests. Agee (1991) found a 17-year median interval in the Siskiyou Mountains of Oregon, but he had a minimum FRI of only 12 years; three of our sites have a shorter median composite interval. In the Klamath Mountains of northern California, Taylor and Skinner (1998) report median site FRI's ranging from 5.5 to 116 years and a pre Euro-American median composite interval of 14.5 years. Using fire records from individual trees, Bekker (1996) found that the median FRI was 8 years on south aspects and a median of 14 years on north aspects. Our data also suggest that FRI's vary by aspect (table 2), but our small sample size precludes any such analysis.

Fire return intervals reported from mixed-conifer forests of the southern Sierra Nevada fall within the range of intervals of this study (Skinner and Chang 1996). Kilgore and Taylor (1979) reported FRI's from 2 to 39 years and means that ranged from 8 to 18 years. They included lower-slope sites in their study, but their data was not presented by slope position. Three of our four lower-slope sites show a median FRI longer than their highest mean. Caprio and Swetnam (1995) reported mean FRI's from 5 to 11 years in *Pinus ponderosa*-mixed conifer forests between 1700 and 1900. These means are comparable to our medians on upper and middle-slopes, but our lower-slope medians are longer than the intervals they report. The longer FRI's in our study may reflect differences in FRI's, the differential tendency of species to record fire, or sample depth compared to these other studies. Kilgore and Taylor (1979) sampled from 4 to 6 pine or cedar and Caprio and Swetnam (1995) sampled from 4 to 14 stumps of unknown species in each collection area. We collected from 1 to 5 samples of *Pinus ponderosa*, *Pinus lambertiana*, and *Calocedrus decurrens* per site (table 2).

Our comparison of the composition and density of stems greater and less than 50 centimeters suggests that Douglas fir-mixed conifer forests may be changing in composition from stands with high tree diversity to stands that are dominated by fewer species. In particular, the increase of shade tolerant *Abies concolor* suggests that fire exclusion may be at least partially responsible for these changes as in other California mixed-conifer forests (McKelvey and Johnston 1992, Minnich 1995, Skinner and Chang 1996, Vankat and Major 1978).

The changes in forest composition and structure that are suggested by our study may have important implications for conservation. Increases in the mortality of mature trees have been associated with understory competition (Ferrell 1996, Savage 1997). High canopy density and decreased conifer diversity may also have a deleterious impact on some open-forest avian wildlife (Minnich and others 1995). The increased dominance by only a few tree species in these mixed-conifer forests may have long-term consequences for wildlife and forest management that may not be easily modified by selective logging because *Abies concolor* is of lower commercial value than the *Pinus* spp. that are being replaced.

There was no change in the occurrence of fire from the early to the late 19th century in our study area. Observers from the latter half of the last century and more recent researchers have suggested that shepherd fires either replaced or exceeded the frequency of Native American burning (Coville 1898, Muir 1877, Vankat and Major 1978). These herder fires were intended to improve pasture and may have been largely limited to higher elevations and more mesic sites (McKelvey and Johnston 1992). Instead of a reduction of FRI's, some research suggests that the loss of herbaceous fuel caused by overgrazing livestock may explain the abrupt end to burning in the southern Sierra Nevada and the Southwest during the early to mid-19th century (Caprio and Swetnam 1995, Savage and Swetnam 1990, Swetnam 1993). In contrast, data from the southern Cascades suggests little change occurred in FRI's in mixed-conifer forests until governmental fire suppression was implemented about 1905 (Bekker 1996, McNeil and Zobel 1980).

The persistence of fire in our study area through the late 19th century concurs with these latter studies. It seems improbable, however, that this persistence in burning was caused by shepherders. Given the rugged nature of the topography of our study area, it is unlikely that our sample locations were strongly affected by either a reduction of herbaceous fuel caused by overgrazing or by shepherd fires. Many if not most of the fires that occurred since 1800 were probably caused by natural ignitions.

The season in which a fire occurs strongly influences its ecological effect (Agee 1993). In our study, intra-annual scar positions suggest that 80 percent of fires occurred after trees had stopped radial growth for the year. The remaining 20 percent of fires occurred during the latewood and earlywood portions of annual growth rings. In the southern Sierra Nevada, Caprio and Swetnam (1995) noted that more fire scars occurred in the latewood than dormant portion of the tree ring. They interpreted this to mean that most fires burned during the mid-summer or early fall. In the southern Cascades, Bekker (1995) found 17 percent of scars occurred in earlywood, 22 percent in latewood, and 60 percent in the dormant portion of the tree ring.

Differences in intra-scar position probably do not simply reflect burning at different times of year. They can be caused by difference in the timing of cell division in trees due to latitude, elevation and slope aspect. If intra-scar position does reflect burning during different months, variation between our study area and the southern Sierra Nevada may suggest different landscape-scale patterns of burning. Southern Sierra fires often originate at low elevations that are more fire-prone earlier in the year (Caprio and Swetnam 1995). In our study area, topographic complexity may limit the encroachment of such low-elevation fires; the poor

coincidence between most fire dates in our study suggests that topography may limit fire diffusion.

Continuous change in vegetation composition across topographic gradients has been recognized for decades (McIntosh 1967, Whittaker 1967), and variability in disturbance may show a similar gradient (Caprio and Swetnam 1995, Harmon and others 1983, Morrison and Swanson 1990, Veblen and others 1992). Neither vegetation nor disturbance can be expected to mimic topography, but our results suggest that the complex terrain of our study area may have limited the diffusion of fire. This lack of fire continuity is suggested by the limited correspondence between fire years and by the high correspondence between topographic position and FRI's. Our data suggest that upper slopes burned between two and four and one-half times more often than lower slopes, and the one riparian site (plot 136) experienced the longest median and minimum FRI, although this record is from a single sampled tree (table 2).

These differences in FRI between upper and lower-slope sites may reflect the increased severity of fire with slope position that is typical of mountainous terrain (Rothermel 1983). Low-intensity fires occurring on lower-slope sites may be less likely to register fire scars than high-intensity fires of middle and upper slopes. If this effect is significant, our FRI's may reflect the probability of scar-formation as much as the occurrence of fire. We believe that the effect of this constraint has been somewhat reduced in our study because most of our FRI's are based on scars recorded in multiple trees at each site.

The limited data presented here suggest that median FRI's correspond better with topographic position than to forest composition. Sites with similar vegetation occur on both upper and lower slope positions, but fire intervals tend to closely follow slope position. Consequently, the extrapolation of fire regimes using mapped vegetation in complex terrain may be imprudent. Topographic variables are easier to characterize and are considerably more stable over time than are ecological processes (Swanson and others 1994). Furthermore, an increased focus on the relationship between historic fire processes and topography may improve our understanding of fire regimes and the influence they have on ecosystem structure and dynamics.

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Pre-Twentieth Century Fire History of Sequoia and Kings Canyon National Park: A Review and Evaluation of Our Knowledge

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Abstract

Fire history investigations, utilizing fire scar records from trees, have been carried out in Sequoia and Kings Canyon National Park for nearly 25 years. However, the objectives for each study and the specific types of vegetation where the studies have been conducted have varied greatly. As a result, our knowledge about pre-twentieth century fire regimes in different vegetation communities and locations within the park varies considerably.

To provide improved information for fire management we have compiled and synthesized the state of our knowledge about pre-twentieth century fire frequency regimes and evaluated the consistency and strength of these data. For each of the 12 broad vegetation classes in the park we summarized pre-Euroamerican fire history data (pre-1860) derived from both local studies and data from other areas of the Sierra Nevada. This knowledge has become important input into resource and fire management planning. The current data suggested there was a “lazy-J” shaped fire frequency pattern over an elevational gradient. A spatial reconstruction of pre-Euroamerican fire frequency regimes was produced by mapping this data set over the park using GIS. We also examined the application and accuracy of this knowledge for each of the 12 vegetation classes and rated the information based on specific criteria. A fire frequency regime “knowledge” map for the park was developed that provided spatial information on the quality of our fire frequency reconstruction. We determined that current information was representative of only about 16% of the park’s vegetated area, with several vegetation classes having little or no information. The highest quality information was closely associated with giant sequoia groves, lower mixed-conifer forest, and ponderosa pine forest, a result of where the majority of the fire history studies have been focused. Additionally, sites tended to be located on ridgetops or on slopes with south aspects. We found a poor understanding of past fire regimes in many areas, particularly at low and high elevations and on north aspects. Because the role of fire in these areas could be significantly different from the sampled locations, we believe caution should be used in extrapolating current knowledge. As park management increasingly focuses on restoration of fire based on attributes of historic pre-Euroamerican fire regimes, it is crucial that we build a solid knowledge foundation for fire management planning.

Introduction

Over the last 25 years, fire history studies based on tree-ring analysis of fire scarred trees, have been carried out within or adjacent to Sequoia and Kings Canyon National Park. While the

purpose of the investigations has been to obtain dates of past fires, the specific objectives and techniques have varied. They have provided important ecological and management information ranging from reconstructing changes in fire frequency due to Euroamerican settlement, to understanding the relationship between fire and forest structure, to showing the interaction of climate and fire. Several of these have been seminal studies on fire history (Kilgore and Taylor 1979; Swetnam 1993). As the breadth of areas and plant communities sampled from throughout the park has expanded so has our knowledge and understanding about the underlying characteristics and variability of the pre-Euroamerican fire regimes. As a result, we have become more aware of the complex patterns and relationships of past fire regimes.

The concept of fire regimes is important since it allows us to view fire as a multi-faceted variable rather than a single event within an ecosystem (Whelan 1995). Thus areas can be classified as having a certain type of regime that summarizes the characteristics of fires, within some range of variability which can have both spatial and temporal attributes. The idea is also important because it permits us to estimate how altered the fire regime has become due to human activities and facilitates decisions on what management actions are needed to preserve or restore the regime. Fire regimes are normally defined according to specific variables including: intensity, frequency, severity, season, extent, and type of fire (Gill 1975; Heinselman 1981). For our analysis we used data acquired from fire-scarred trees in the form of fire return intervals to reconstruct a conservative estimate of fire frequency regimes. This knowledge about reconstructed frequency regimes is important for informed science-based ecosystem management (Morgan et al. 1994).

The park has recently begun to utilize and integrate this data within a GIS framework to provide information for ecologically sound management and for optimizing burn program planning (Caprio et al. this proceeding). Various models used in this GIS analysis were directly or indirectly derived from the fire history data (data from tree-ring analysis of fire scars) and historic fire records (historic data obtained from mapped fires). Using this information on fire frequency regimes in various vegetation types, an “ecological needs” model was developed to produce a map of “fire return interval departures” (FRID). This model highlights areas that have deviated most from their historic fire regimes beginning with Euroamerican settlement over 100 years ago. This modeling approach also showed potential as a tool that may be applied in other resource management settings.

Our objectives for this paper are to review our knowledge, explain methods, and provide an evaluation of the fire history data from the park and utilized within the GIS model. First, we will review the process used in reconstructing fire frequency regimes spatially across the park and describe some aspects of its utilization. Second, we present an evaluation of our knowledge about the quantity and quality of the fire history data used within the model and review limitations or problems in the application of these data. This provides the park with an improved understanding of fire in ecosystem function, with the potential for this knowledge to provide practical information to support the fire management program, and to improve future fire history sampling strategies.

Study Area

Sequoia and Kings Canyon National Park (SEKI) is located in the south central Sierra Nevada and encompass some 349,676 ha (864,067 ac) extending from the Sierra crest to the

western foothills on the eastern edge of the San Joaquin Valley. Topographically the area is rugged with elevations ranging from 485 to 4,392 m (1,600 to 14,495 ft). Major drainages are the Kern, Kaweah, Kings, and San Joaquin Rivers. The elevational gradient from the foothills to the higher peaks is steep with rapid transitions between vegetation communities. Three broad vegetation zones dominate the park (slightly over 200,000 ha are vegetated), *foothills* (485 to 1,515 m) composed of annual grasslands, oak and evergreen woodlands, and chaparral shrubland, *conifer forest* (1,515 to 3,030 m) with ponderosa (*Pinus ponderosa* Dougl.), lodgepole (*P. contorta* Dougl. var. *Murrayana* Englm.), giant sequoia (*Sequoiadendron giganteum* [Lindl.] Buchholz), white fir (*Abies concolor* Lindl. & Gord.), and red fir (*A. magnifica* Murr.) forests, and *high country* (3,030 to 4,392 m) composed of subalpine with foxtail pine (*P. balfouriana* Jeff.), white-bark pine (*P. albicaulis* Englm.), alpine vegetation, and unvegetated landscapes. A variety of classification schemes have been defined for vegetation within the park (Rundel et al. 1977; Vankat 1982; Stephenson 1988; Potter 1994).

The climate is distinctly Mediterranean with cool moist winters and warm summers with little rainfall, although seasonal summer thunderstorms occur sporadically at higher elevations. Precipitation increases as elevation increases, to about 102 cm (40 in) annually, from 1,515 to 2,424 m on the west slope of the Sierra, and then decreases as one moves higher and to the east (Stephenson 1988). Substantial snow accumulations are common above 1,515 m during the winter. Total annual precipitation during the period of record has varied from 30 to 130 cm at Ash Mountain in the foothills and from 38 to 214 cm in Giant Forest at a mid-elevation location.

European settlement of the area began in the 1860s with extensive grazing, minor logging, and mineral exploration. The park was founded in 1890, originally with the intent of protecting sequoia groves from logging, but has been expanded to include much of the surrounding rugged, high mountains and some foothills areas (Dilsaver and Tweed 1990).

Fire History Studies

Fire history investigations were begun about 25 years ago by Kilgore and Taylor (1979) and have continued intermittently through the present. While the specific objectives and techniques among the fire history investigations have varied. The main impetus for the studies has been to provide information for the restoration of fire within park ecosystems. The investigations have sought to obtain information on fire frequency in specific vegetation types (Kilgore and Taylor 1979; Warner 1980; Pitcher 1981, 1987; Swetnam et al. 1992), for use in understanding forest stand structure and dynamics (Pitcher 1981; Keifer 1991; Stephenson et al. 1991; Swetnam et al. 1992), for investigating the relationship between fire and climate (Pitcher 1981; Swetnam et al. 1992; Swetnam 1993; Caprio and Swetnam 1993, 1994), to examine fire over elevational gradients (Caprio and Swetnam 1995), and to investigate the relationship between fire and growth responses in giant sequoias (Caprio et al. 1994; Mutch 1994; Mutch and Swetnam 1995). This research has given the park a growing understanding of the of pre-Euroamerican fire regimes and their complexity.

Historically, fire played a key ecological role in most Sierra Nevada plant communities (Kilgore 1973). In conifer forests fire shows an inverse relationship between fire frequency and elevation (Caprio and Swetnam 1995). The cause of fires prior to Euroamerican settlement is usually attributed to ignitions by lightning or native Americans. However, since the actual source of these fires cannot be determined, the specific cause(s) remain largely unknown. The

seasonal occurrence of pre-settlement fires was similar to the contemporary late summer-early fall fire season (Swetnam et al. 1992; Caprio and Swetnam 1995). Fire intensity was variable both spatially and temporally (Stephenson et al. 1991; Caprio et al. 1994). In much of the mixed-conifer zone, fires were primarily non-stand replacing surface fires (Kilgore and Taylor 1979; Warner 1980; Pitcher 1987; Caprio and Swetnam 1995), although exceptions exist (Caprio et al. 1994). Specific regional fire years have also been identified (years in which fires have been recorded at sites from throughout the southern Sierra Nevada), usually occurring during dry years (Brown et al. 1992; Swetnam et al. 1992; Swetnam 1993). These data also document long-term variation (1000-2000 years) in the fire regime associated with climatic fluctuations (Swetnam 1993).

Fire regimes in the Sierra Nevada changed dramatically beginning with Euroamerican settlement around 1850-1870 (Kilgore and Taylor 1979; Warner 1980; Caprio and Swetnam 1995). Factors that contributed to this decline include the loss of native American populations that used fire and heavy livestock grazing that reduced herbaceous fuels available for fire spread (Caprio and Swetnam 1995). Additionally, the occurrence of fires of large size decreased dramatically during the twentieth century because of active fire suppression. These changes in fire regime led to unprecedented fuel accumulations in many plant communities, structural and composition changes, and have resulted in an increased probability of widespread severe fires (Kilgore 1973).

Methods

Fire Return Intervals

Mean and maximum fire return intervals were either obtained from the literature or derived from crossdated fire-history chronologies (fire dates from scarred trees) collected at sites within or near the park. Fire frequencies, based on the return intervals, reported in this paper are “point frequency” estimates (Agee 1993) derived from specific sites usually less than one hectare in size. From the crossdated chronologies, means and an “averaged maximum” return intervals were calculated using a randomization procedure. The procedure produced a more robust average interval estimate for the maximum intervals relative to a simple average or moving average. It calculated the two mean return interval estimates for 100 runs of the procedure. Each run used the number of fire intervals from a composite site record and randomly selected this number of intervals from the pool of interval lengths. The “average maximum”, a conservative estimate, was the mean of the maximum length interval selected from each run. To produce a fire frequency estimate without the influence of Euroamerican settlement (through grazing and decrease in Native American populations), we only used fire history data prior to 1860 for ponderosa, mixed conifer, and red fir forests and to 1870 for subalpine forest (based on Kilgore and Taylor 1979, Caprio and Swetnam 1995, and Caprio unpublished data). This interval estimate was summarized by vegetation class and scaled up to the landscape level using GIS. In synthesizing the data, local data were given greater weight than data from more distant locations. GIS analysis and mapping was carried out using Arc/Info, Grid, and ArcView and their extensions (ESRI 1997).

Vegetation Classification

We used the base vegetation layer from the park GIS for the spatial analysis of the fire frequency regimes by universally applying the estimates of fire frequency for each vegetation class throughout the park. The vegetation layer was derived from a series of field classifications collected in the 1960s and 1970s (NPS no date). Because slightly differing methodologies and vegetation classifications were utilized for the original classifications, the original maps were reclassified to produce a generalized vegetation map with a similar classification scheme (12 broad classes) across both Sequoia and Kings Canyon National Park (D. Graber and N. Stephenson per. comm.).

Evaluation Criteria

A “confidence estimate” was made on the data for the mean and maximum fire frequency intervals using several evaluation criteria (Table 1). The criteria were: the existence of fire history data for a vegetation class, was the data replicated, how well the data corresponded to the park’s vegetation, and the quality of the fire-frequency data within the different vegetation classifications and aspects. Decision criteria were developed for evaluating our knowledge about the available fire history data and applied to the fire frequency information for each of the vegetation classes.

Table 1. Criteria used in evaluating the fire history data used in reconstructing fire frequency regimes.

1. Does fire frequency regime information exist?
 2. How many sites have been collected within a vegetation class?
 3. From where was the fire frequency regime information obtained?
 - a) local (within or adjacent to park)
 - b) within region (southern Sierra Nevada)
 - c) outside region (similar vegetation in other regions)
 4. How independent were sites within a vegetation type?
 5. How well distributed were sites within the park?
 - a) well (>2 sites within each park zone if vegetation exists in zone)
 - b) poor (<2 sites within each park zone)
 6. Were sites crossdated using dendrochronological methods?.
 7. Was the distribution of sites representative of north and south aspects within a vegetation class?
-

The aspect classification was derived from USGS 7.5 Minute quads (aspects (south=106 to 285° and north=286 to 105°). It was designed to capture relatively large areas of continuous aspect (greater than about 300 ha in size). Smaller micro-topographic aspects were not considered as important in determining widespread fire occurrence across the landscape. Level areas without aspect were added to the south aspect category, the assumption being that they mostly resemble south aspects.

Results and Discussion

Reconstructing Pre-Twentieth Century Fire Frequency Regimes

Fire Return Intervals

Fire scar data from within or adjacent to the park were based on 80 sampled sites that represented eight of the 12 major vegetation classes used in GIS mapping of park vegetation (Table 2). Estimates for the remaining classes were obtained from published literature. Average and maximum fire return intervals for the 12 vegetation classifications in Sequoia & Kings Canyon National Park varied from four to 187 years (mean) and six to 508 years (average maximum). The shortest fire return intervals were found in the lower mixed-conifer forest, particularly forest dominated by ponderosa pine and the longest fire return intervals were found in subalpine forest, usually dominated by foxtail pine or white-bark pine. A plot of the relationship between mean fire return interval and elevation showed a “lazy J”-shaped relationship (Fig. 1). We speculate that the relationship was primarily governed by productivity (fuel production) and the potential for fire ignition and spread. The relationship was strongest in coniferous forest with a direct relationship between elevation and fire frequency although information for some vegetation classes is weak or nonexistent for the Sequoia-Kings Canyon area. At lower elevations the data indicated a reduced frequency and suggested an inverse relationship. The latter information represents our best estimate, but is based on limited data and may be subject to change. However, these frequencies agree favorably with our knowledge about the life-history traits of woody chaparral species (Keeley 1981; Naveh 1994). Direct extrapolation of frequencies from conifer forest into lower elevations would result in very short return intervals (<5 years) which could not be tolerated by most of these species, although the dominance of sprouting species does suggest a moderate frequency. If high frequencies did exist, it would suggest that extensive shifts in vegetation within this zone have occurred over the last 130 years, probably shifting from more open grassland with pockets of chaparral to the current composition.

Table 2. Average and maximum fire return intervals for the 12 major classifications in Sequoia & Kings Canyon National Park. Data are for the period prior to 1860 (1870 for subalpine conifer). The primary source(s) for the data are enumerated under "Reference" heading and are listed at the bottom of the table. Fire frequency regime classes for each major vegetation class were based on mean maximum fire return intervals. The frequency classes were used to reconstruct fire frequency regimes spatially across the park.

Vegetation/Terrain Class (class code #)	Code	Mean	Max.	Freq. Class	Knowledge	Reference
(1) Ponderosa Mixed Conifer	PIPO	4	6	v. high	good	1,2,3,16,177
(2) White Fir Mixed Conifer	ABCO	10	16	high	good	1,2
(3) Red Fir Mixed Conifer	ABMA	30	50	low	poor	1,4,5
(4) Lodgepole Pine Forest	PICO	102	163	v. low	v. poor	5,6,18
(5) Xeric Conifer Forest	XECO	30	50	low	v. poor	5,7,8,17
(6) Subalpine Conifer	SUAL	187	508	v. low	poor	5,9
(7) Foothills Hardwood & Grassland	FHGR	10	17	mod.	v. poor	5,10,11
(8) Foothills Chaparral	FOCH	30	60	low	estimated unknown	12
(9) Mid-Elevation Hardwood	MEHA	7	23	mod.	v. poor	3,19
(10) Montane Chaparral	MOCH	30	75	low	estimated unknown	12
(11) Meadow	MEAD	40	65	low	estimated unknown	8
(14) Giant Sequoia Forest	SEGI	10	16	high	good	13,14,15
(12) Barren Rock	ROCK					
(13) Other (mostly water)	OTHR					
Missing Data	MISS					

1 Caprio and Swetnam 1993, 1994, 1995; 2 Kilgore and Taylor 1979; 3 Stephens, unpublished data in Skinner and Chang 1996; 4 Pitcher 1981,1987; 5 Caprio unpublished data ; 6 Keifer 1991; 7 Taylor, unpublished data in Skinner and Chang 1996; 8 Skinner, unpublished data in Skinner and Chang 1996; 9 Caprio, Mutch, and Stephenson unpublished data ; 10 Mensing 1992; 11 McClaren and Bartolome 1989; 12 SNEP 1996; 13 Swetnam et al. 1991; 14 Swetnam et al. 1992; 15 Swetnam 1993; 16 Warner 1980; 17 McBride and Jacobs 1980; 18 Sheppard 1984; 19 Stephens 1997

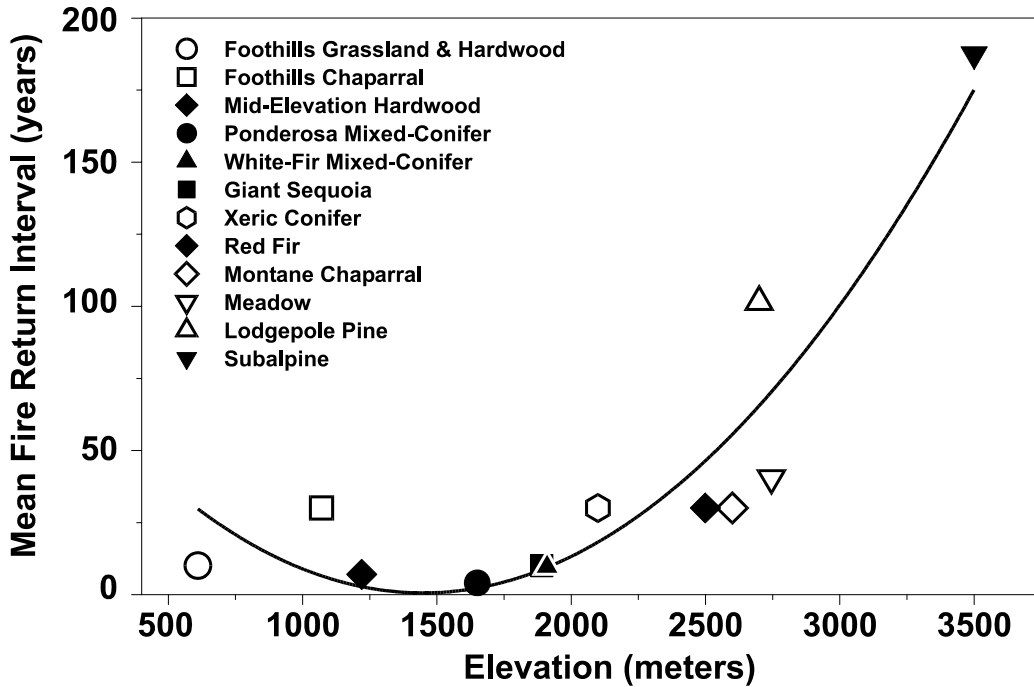


Figure 1. Relationship between mean fire return interval and elevation for the 12 major vegetation classes within Sequoia and Kings Canyon National Park. Elevation data for vegetation classes was obtained from Rundel et al. (1977), Vankat (1982), Potter (1994), and from the park's vegetation maps.

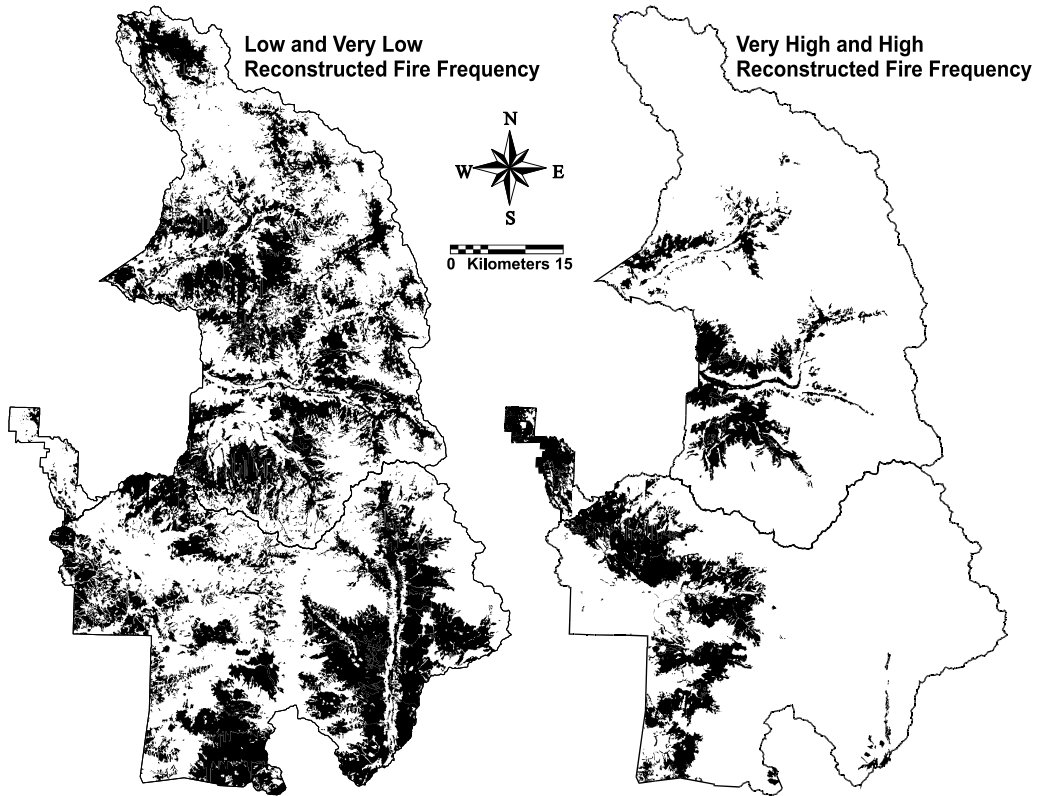


Figure 2. Distribution of vegetation classed as having a low or very low reconstructed fire frequency (left) or having a high or very high reconstructed fire frequency (right) based on average maximum return intervals.

Using these data as our best available information, we reconstructed fire frequency regimes by applying the frequency estimates to all major vegetation classes. To provide an easier to interpret reconstructed frequency map we aggregated similar intervals into five frequency classes (Table 2) for mapping (Fig. 2). The five frequency classes were: very high - <7 yr; high - 7 to 16 yr; moderate - 17 to 25 yr; low - 26 to 100 yr; and very low - >100 yr.

Several significant time-dependant attributes of the fire history data were not considered in this original model. First, the analysis does not consider the stochastic variation in fire intervals through time (fire interval distributions) among or within vegetation types. Such interval dependent effects of fire events can have significant influences on plant demographics and long-term plant community structure (Whelan 1995; Bond and van Wilgen 1996; Chang 1996). Additionally, the fire regime may not be stable over time but may fluctuate with environmental and climatic factors (Clark 1989). Thus, fire history data from a short 100-200 year period should be interpreted with this caveat in mind. The mid-to-southern Sierra Nevada is fortunate in having long-lived sequoia forests where long fire chronologies exceeding 2,000 years have been developed (Swetnam et al. 1991, 1992; Caprio et al. 1994; Baisan this conference). These are providing long-term information about changes in fire frequency related to climatic fluctuations (Swetnam 1993). However, even without this information the model of fire frequency regimes provides a valuable resource for understanding past fire regimes and guiding park management decisions.

Utilizing the Fire History Data

The park is currently integrating information about fire history with other data sets using GIS models to improve fire management tools and to obtain a better understanding of past and present ecological processes within the park. Model development was motivated by the National Park Service's mission statement to "protect and preserve" natural resources, with fire being an important process to apply in working towards this goal. The reconstructed fire frequency regimes were used to develop an "ecological needs model". This model provided a rating index to rank areas on the need for reintroducing and maintaining fire within a particular vegetation community. This index was used to quantify the departure of the vegetation type from its pre-Euroamerican settlement fire return interval. All areas within the park's 12 broad vegetation classes were rated based on *fire return interval departures* (FRID) (Caprio et al. this proceedings). Inputs into the model were RI_{max} and *TSLF* where, RI_{max} is the maximum average pre-Euroamerican settlement fire return interval for vegetation class (with 12 broad vegetation classes within the park), and *TSLF* (time since last fire) is the time that has passed since the most recent fire from historic fire records or using the baseline date of 1899 derived from the fire history chronologies. Both values depended on data from the fire history record. The reconstructed return intervals (RI_{max}) used in the model were derived from data summarized in this paper (Table 2). The *TSLF* was derived from historic fire records (these extend back to 1921) or was based on the last widespread fire date (1899) recorded by the fire history reconstructions (see Caprio et al. this proceedings).

We also estimated the mean annual area burned prior to Euroamerican settlement within each of the 12 broad vegetation classes within the park using the summarized fire return intervals (Table 3) and the area of each of the 12 vegetation classes, obtained from the park's GIS vegetation layer. This provided an estimate of which vegetation classes experienced the greatest fire load (a measure of how much area can be expected to burn over time) in the past and where

future fire load may be greatest as fire is reintroduced back into the ecosystem. Because fire frequency estimates from some vegetation types and aspects were weak (see section on data evaluation), actual values should only be considered as approximate at this time. Additionally, these averaged values do not consider differences caused by year-to-year variation in climate, number of ignitions, or fire spread potential that would have caused temporal variation in area burned annually. The fire history data also suggested there may be variation by vegetation class. Lower elevation forests may have burned during any given year, the result of a longer and more consistent summer dry period, while forest types such as red fir or lodgepole may burn under more specific conditions. In designing long-term fire management strategies, such variations should be given consideration since they may play a role in the dynamics of some species or communities (Whelan 1995; Bond and van Wilgen 1996).

Table 3. Estimated mean number of hectares burned annually within each of the 12 major vegetation classes based on the fire return intervals from Table 1. Two estimates were calculated to present a range of possible values. Estimates were based on the mean maximum fire-return interval and average fire-return interval (in parenthesis). The estimate based on mean maximum provided a conservative estimate of area burned annually. Not considered were potential differences in fire frequencies on north versus south aspects, which would probably result in a reduced number of hectares burned annually.

Vegetation Class (class code #)	Return Interval (yrs)		Area (ha)	Area Burned (ha·yr ⁻¹)	
	mean max.	(mean)		mean max.	(mean)
(1) Ponderosa Mixed Conifer	6	(4)	16,568	2,761	(4,142)
(2) White Fir Mixed Conifer	16	(10)	31,460	1,966	(3,146)
(3) Red Fir Mixed Conifer	50	(30)	26,511	530	(884)
(4) Lodgepole Pine Forest	163	(102)	39,215	241	(384)
(5) Xeric Conifer Forest	50	(30)	13,700	274	(457)
(6) Subalpine Conifer	508	(187)	31,488	62	(168)
(7) Foothills Hardwood & Grassland	17	(10)	8,882	522	(888)
(8) Foothills Chaparral	60	(30)	8,856	148	(295)
(9) Mid-Elevation Hardwood	23	(7)	3,564	155	(509)
(10) Montane Chaparral	75	(30)	10,836	144	(361)
(11) Meadow	65	(40)	5,459	84	(136)
(14) Giant Sequoia Forest	16	(10)	4,055	253	(406)
Total			200,594 200,59294422	7,140	(11,776)

Evaluation of Our Knowledge

Criteria

The decision criteria (Table 1) we developed for evaluating our fire history knowledge were applied to each of the 12 major vegetation classes. Criteria were designed to provide feedback to management and researchers on the reliability of the knowledge and to furnish guidance to improve future fire history sampling strategies. Other possible criteria we did not include in this evaluation were elevation and slope.

1. Existence of Data

We reviewed whether pre-Euroamerican settlement fire history data existed for each of the specific vegetation classes. If fire frequency estimates based on fire history data did not exist we sought other sources of information. In all cases, information from these other sources was of poorer quality and often a speculative estimate. Pre-Euroamerican fire history data existed for eight of the 12 vegetation classes. Classes without data included foothills chaparral, mid-elevation hardwood forest (estimate based on post-settlement fire history), foothills grassland and hardwood, montane chaparral, and meadows.

2. Number of Observations

In reviewing the fire history data, we also examined how many observations went into determining a fire frequency estimate, with each fire-history site considered as a single replicate or observation. The number of observations, for those vegetation classes for which we had data, varied from one site in xeric conifer forest to 20 sites in giant sequoia forest.

However, adding additional observations within a specific vegetation class did not always add precision to our estimates. This may be a result of the park's current vegetation classification not capturing the actual variability within a vegetation type. For example, in lodgepole pine forests, data from different sampling sites show large differences in the length of fire return intervals, 163 years in the Siberian outpost area (Keifer 1991 - see also Sheppard (1984) for similar long intervals in the San Jacinto Mountains) to 20 - 64 yr on the Chagoopa Plateau (Caprio unpublished data). This variation might be explained by lodgepole's occurrence over a diverse range of environmental conditions, including a wide range of elevations and moisture conditions (Rundel et al. 1977). These fire frequency differences may reflect differences in site productivity, fuel accumulation, and ignition rates. A similar situation may also exist with other vegetation classes, particularly xeric conifer and red fir. This underscores the importance of replicate sampling to capture local variation.

3. Source of Data

We evaluated the geographical source of the fire history data and rated it based on distance criteria. The criteria were: 1) source of data was local (within or adjacent to park), 2) from within the region (southern Sierra Nevada), or 3) from outside the region (similar vegetation in other regions). Local information was given a greater weight because these data should represent local fire regimes more accurately. As source distance from SEKI increased, changes in vegetation and climate would increase and the information would be potentially less representative of local conditions.

4. Distribution within Vegetation Classes

We were also interested in how well fire history collections represented each particular vegetation class across the landscape. In other words, how representative were our current fire history sites in providing information about a particular vegetation type. Our evaluation indicated that a majority of the fire history sites were associated with giant sequoia groves. This was not unexpected given the mandate and emphasis park managers have put on obtaining

information about fire's role in and near sequoia groves. Nearly all fire history data available from in or near the park originated from two investigations: centered on the Grant Grove and Redwood Mountain area (Kilgore and Taylor 1979), more recently by sampling in Mountain Home, Atwell, Giant Forest, Big Stump, and Mariposa Groves (Swetnam et al. 1992; Caprio and Swetnam 1993, 1994, 1995).

5. Distribution

We also considered broad park-wide differences in forest characteristics, particularly between eastern and western portions of the park that could strongly influence fire regimes. West-side forests of the Sierra Nevada are typified by fine-scale, low contrast mosaics whereas east-side forests, typically at higher elevations within the park (see Fig. 3), are more fragmented and form medium-scale, high-contrast mosaics (Franklin and Fites-Kaufmann 1996). We conjecture that differences in fire frequencies would exist within vegetation classes when compared between the Kern River drainage and upper Kings River drainages (east-side) and forested zones on the west side of the park because of these patterns. We would expect reduced frequencies on the east-side due to smaller forest stand size with reduced fire contagion across the landscape. Support for this conjecture is provided by Allen et al. (1995) and Wardle et al. (1997) who observed reduced fire frequencies as forest island size decreased or topographic isolation increased, although exceptions are reported (Bergeron and Brisson 1990; Bergeron 1991). Because the vast majority of our fire history data has come from west-side forests, we felt care should be taken in extrapolating these data to east-side drainages. Dividing the park into four broad "zones" (Fig. 3): the Kern drainage, the Kaweah drainage (also including a small portion of the Tule drainage), the lower Kings drainage, and the upper Kings drainage (including a small portion of the San Joaquin drainage), allowed us to better evaluate the distribution of the data across the park. Of the 80 sites in or near the park only one was located in the Kings River drainage, with the majority in the Kaweah drainage.

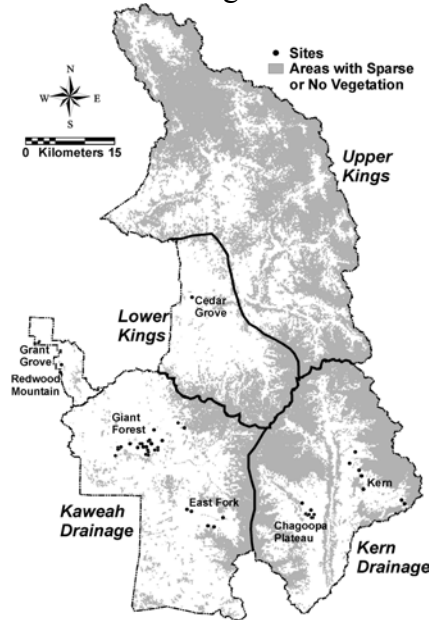


Figure 3. Locations of fire history sample sites within Sequoia and Kings Canyon National Park and four sample "zones" used to evaluate distribution of sites within the park. The majority of sites were located within the Kaweah River watershed with no information available from the upper Kings River watersheds.

6. *Crossdating*

Use of dendrochronological techniques allows the actual calendar year of each fire, and in some cases the season, to be determined from fire scarred samples (Stokes 1980; Ahlstrand 1980; Caprio and Swetnam 1995). Crossdating allows fire dates to be both temporally and spatially explicit, adding a substantial amount of precision to fire history data. Fire histories based on ring counts, as opposed to crossdating, can result in less accurate fire frequency estimates (Madeny et al. 1982) and hinder the use of fire history data spatially over a landscape where strict temporal precision is required.

7. *Aspect*

We also evaluated our fire history knowledge by aspect, which was critical in the application of our GIS reconstructions across the landscape. Aspect can have a strong influence on fire with south and southwest aspects in the northern hemisphere being more favorable for ignitions and fire spread (Agee 1993; Pyne et al. 1996). These aspects receive greater solar radiation and tend to be warmer and drier with consequent differences in productivity, decomposition, fuel load and fuel characteristics, and fire behavior. Thus we expected fire frequency regimes on north aspects to be different from those on south aspects with a similar elevation and vegetation. This hypothesis is supported by a limited number of published fire history investigations. In ponderosa pine ecosystems of the central Rocky Mountains, Laven et al. (1980) report an average fire frequency of 34.9 years on south aspects and 64.3 years on north aspects (although they report that sample depth was limited on north slopes). Additionally, in the Jemez Mountains, New Mexico, Allen et al. (1995) found lower frequencies on north facing slopes than on south aspects in ponderosa pine and mixed-conifer forest.

Of the 80 fire history sites evaluated, 69 were located on south aspects with six of the remainder located in areas adjacent to south aspects (Fig. 4). Only five of the sites represented north aspects which constituted 80,882 ha (40.3%) of the 200,594 ha that are vegetated within the park (Fig. 5). Distribution and composition of vegetation classes was among aspects was probably strongly influenced, although not solely, by fire regime characteristics. Most classes were more common on south aspects, with the exception of lodgepole pine. The strongest affinities for south aspect were ponderosa pine mixed-conifer, xeric conifer, subalpine conifer, and foothills grassland and hardwood forest.

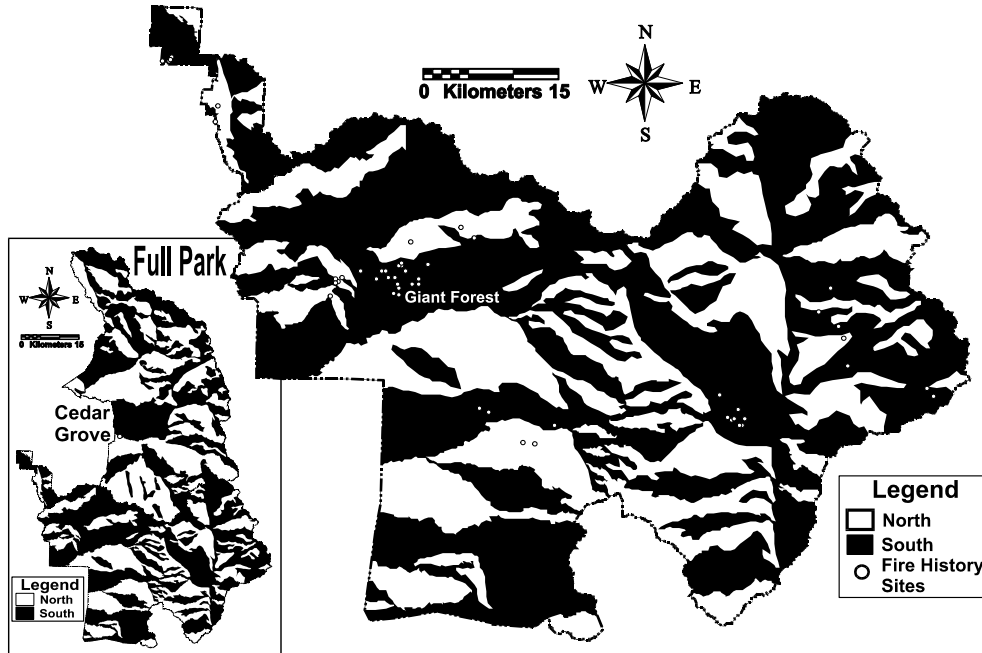


Figure 4. Relationship between fire history site locations and north versus south aspects within the park. Most sites sampled over the last 25 years have been located on south aspects (south=106 to 285° and north=286 to 105°).

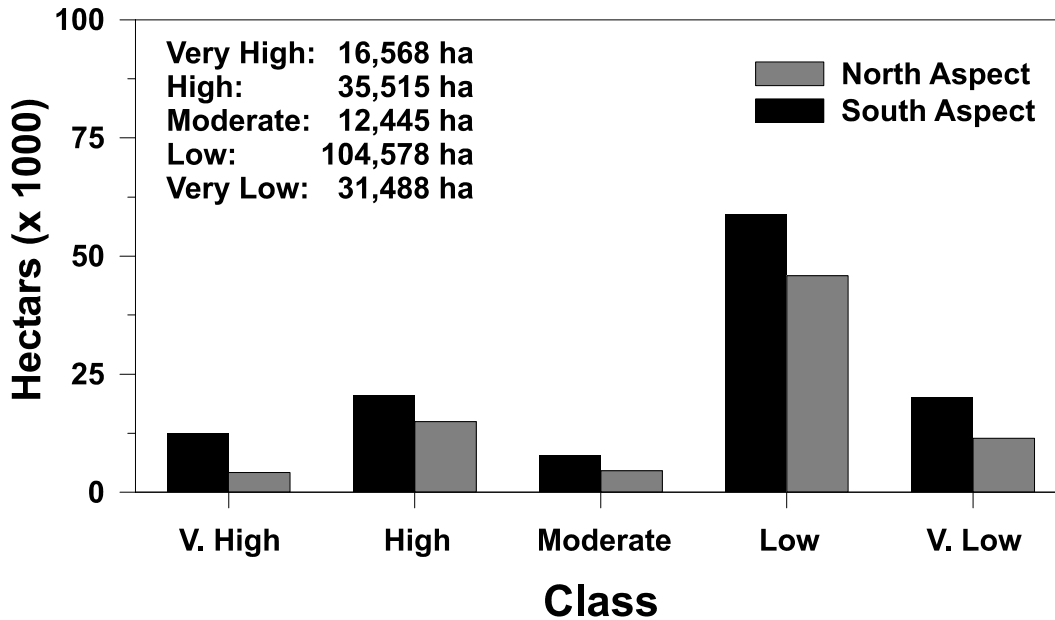


Figure 5. Area of the park within each of the five fire frequency regime classes (average maximum interval) by aspect. The majority of the park was classed with a low frequency (25-100 yr). With the exception of the very high class, the distribution of classes by aspect was similar. The difference in the very high class was due to the higher proportion of the ponderosa pine vegetation class on south aspects. The slightly higher values on south aspects for all frequency classes were a result of flat land areas being included with south aspects.

Rating the Data

Using these criteria in a decision making process we evaluated our knowledge about fire history in the 12 vegetation classes and classed our results into six knowledge categories. These knowledge classes were used to develop a park-wide map that showed areas with good quality information and other areas where information was more speculative. A summarized description of the knowledge classes are as follows:

- **Estimated or Unknown:** No local data were available or the source of data was from literature that only reported frequency values as an estimate.
- **Very Poor:** Two or fewer independent local sites have been sampled or information was derived solely from the literature from sites sampled outside the region.
- **Poor:** Data from 3-5 local sites existed but the spatial extent of the sampling was extremely limited, some information available from outside the local area.
- **Good:** Data existed from multiple independent sites within a vegetation class located in or near the park, but gaps remained.
- **Excellent:** Adequate information from all categories existed. Our evaluation showed that no vegetation class fit this category due to the lack of information from north aspects and poor distribution from throughout the park.

The five knowledge classes were assigned to each vegetation class (Table 2) and mapped spatially across the park using the vegetation classification (Fig. 6). Most land area classed as good class fell in the lower conifer belt on the west side of the park, an area of moderate-to-high fire frequency with abundant fire scar material. This is also the area where most prescribed burning is planned or has been carried out, although it does not consider the lack of knowledge on north facing aspects. This area accounts for about 26% of the park (16% if aspect was considered) (Fig. 7). Areas of poor knowledge were generally located at higher elevations and in lower elevation grasslands and shrublands, areas of longer return intervals or areas that contain little or no fire scar material.

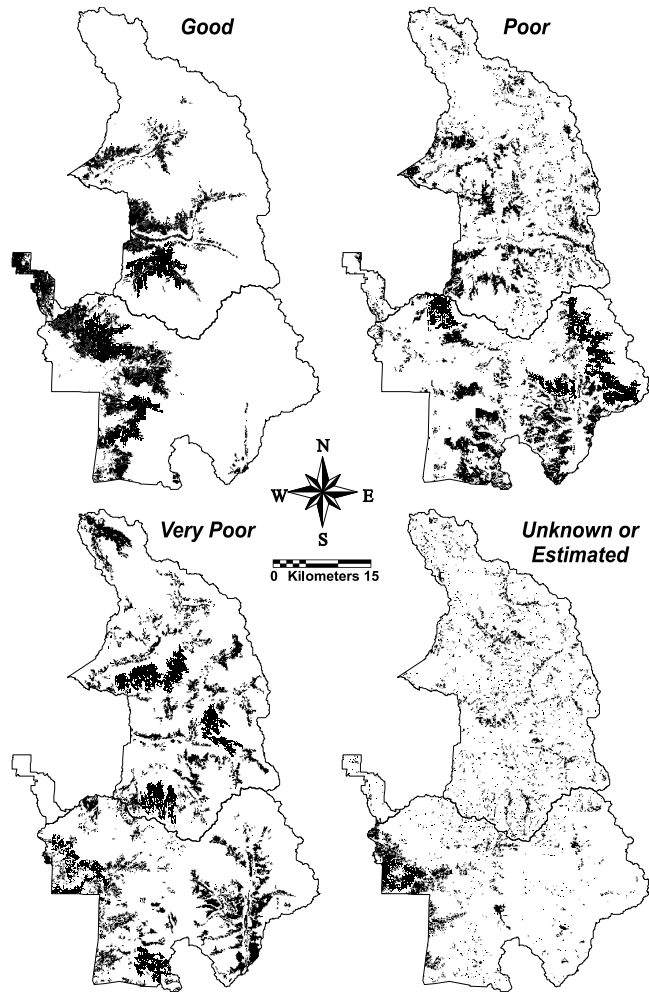


Figure 6. Maps of the spatial distribution of our knowledge about fire frequency regimes from throughout SEKI. The highest quality data exist for the mid-elevation mixed conifer and ponderosa pine belt with poor quality information from vegetation classes found at both the lowest and highest elevations.

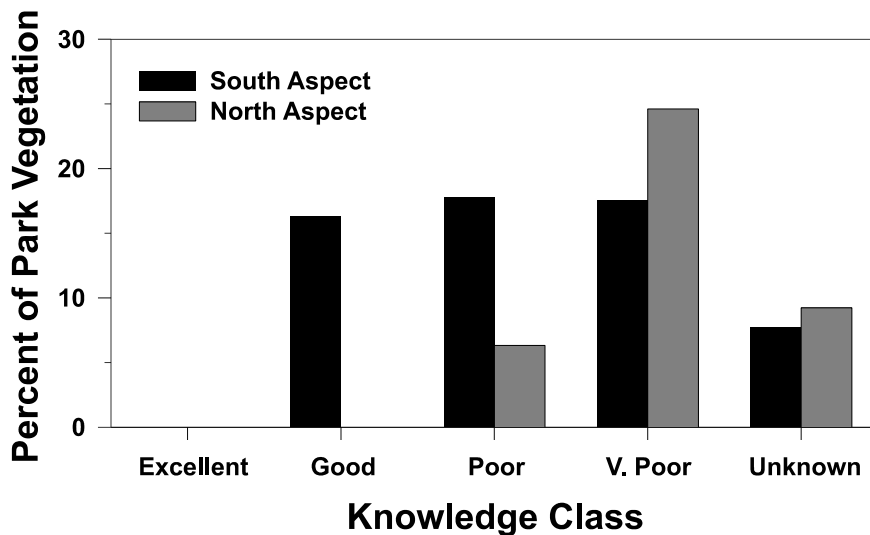


Figure 7. Percent of park vegetation in each “knowledge” class by aspect. For only about 16% of the park area do we consider our knowledge about past fire regimes to be good (26% if aspect is not considered).

Conclusions and Management Implications

Combining field data with GIS and historical knowledge can provide multiple perspectives on ecosystem dynamics to support ecosystem management (Allen 1994). Our synthesis of the fire history data for Sequoia and Kings Canyon National Park and its integration with our vegetation model using GIS allowed us to reconstruct fire frequency regimes spatially across the park. The spatially explicit fire history data illustrated the essential role of fire in shaping ecological patterns at local and landscape levels. The results emphasized that fire frequencies varied over the landscape in heterogeneous patterns we are still unraveling. The current data set provides a working model of fire frequency regimes across the park. Ongoing fire history investigations are underway to address questions raised in this evaluation and to provide verification of the model. However, this analysis has given the park better understanding of the complexity of the pre-Euroamerican fire regimes. Fire return intervals appear to have been shortest at mid-elevations in ponderosa pine forests. Our results show decreasing fire frequency with increasing elevation both above and below this point, although our knowledge for lower elevations remains uncertain. The reconstructed fire frequency data have been used to develop a GIS model (FRID) accentuating areas most in need of burning and to provide estimates of area burned annually prior to Euroamerican settlement. Both are valuable input into fire management planning.

As GIS applications become increasingly valuable in implementing ecological management at a landscape level land managers must be aware of the limitations as well as the potential uses of these tools. Detailed maps produced by GIS are only representations of the landscape several steps removed from on-the-ground reality and thus subject to misinterpretation. For this reason we evaluated our knowledge about fire history used as input. We found that we lacked or had limited information from many areas and some vegetation classes. For example, our fire history knowledge for north aspects was extremely limited and we recommend care be exercised when extrapolating this information from south aspects. Additionally, most of our high quality information about past fire regimes has been derived from lower elevation ponderosa pine and mixed-conifer forest where high fire frequencies were prevalent. Depending on the application, extrapolating these findings to the landscape as a whole may be inappropriate for some areas and vegetation classes. Differences in fire frequency regimes may be great enough that loosely interpreting burn frequencies could produce detrimental impacts.

Obtaining adequate baseline information about fire history is crucial for defining pre-Euroamerican fire regimes and their variability across landscapes. This information will assist us in understanding a key process that has shaped ecosystems at a variety of landscape levels and scales. This knowledge will also assist fire managers in building a science-based foundation for fire and ecosystem planning and management activities into the future.

Acknowledgments

David Graber provided insight on portions of the analysis and Linda Mutch reviewed and made useful comments on the paper. The analysis of fire history data presented in this paper were largely a result of the sampling efforts over many years by Bruce Kilgore, Thomas Swetnam, and their colleagues. Without the information from these and other fire history studies

we would be essentially ignorant of past fire regimes in the park. As time passes the value of this data will grow as remnant fire scarred material irretrievably disappears from the landscape.

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PROJECT LEARNING TREE: PROVIDING LEADERSHIP IN TEACHING FIRE ECOLOGY TO STUDENTS

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Abstract:

For the past 20 years, Project Learning Tree (PLT) has provided a strong leadership role among conservation and environmental education programs. Organized as a network of state and community based organizations and agencies providing workshops for educators, PLT has the capacity to not only influence the environmental education of school-age children, but also their teachers. Workshop goals are to introduce K-12 teachers to the PLT materials and provide time for participants to meet with resource specialists who often lead tours and hold discussions about resource management strategies and issues.

The PLT program, developed and sponsored nationally by the American Forest Foundation, was completely revised in the early 1990's. This update introduced new teaching strategies and included additional resource management concepts such as urban forestry, ecosystem management, biodiversity and fire ecology.

This paper will focus on how the PLT program addresses the introduction of fire ecology to students. References to additional fire ecology materials are included.

Key Words: environmental education, fire ecology, teachers, students

Introduction

Project Learning Tree (PLT), helping to advance environmental literacy of both school-age children and their teachers. PLT is sponsored by the American Forest Foundation in partnership with state and community agencies and organizations. Affirming a 20-year tradition of successfully providing teaching materials through training workshops for educators, the PLT program continues to train, on the national level around 50,000 teachers annually. PLT's materials help teachers develop students' environmental awareness and knowledge, and critical thinking and problem-solving skills. This is underscored by PLT's teaching philosophy: teachers should not teach students what to think, rather help them develop the skills of how to think.

To improve the implementation of this strategy, the program was completely revised during the early 1990s. New materials were developed such as a 400-page book of teaching activities for educators of students grades preK-8, and a set of teaching modules that focus on a variety of environmental topics for high school teachers. The program makes these available through specially designed workshops where teachers meet with a trained facilitator, and learn how to effectively use the materials.

One of the new modules for secondary teachers, *The Changing Forest: Forest Ecology* includes a section on fire ecology. This module was designed to help students develop the

knowledge they will need to comprehend and act on environmental challenges such as how policies are formed that direct the management of public and private forests lands. Through a series of student activities and team projects, students gain an understanding of forest ecology. It prepares them to appreciate the competing demands placed on forests. A more detailed look at forest-related issues is presented in PLT's (*Exploring Environmental Issues: Focus on Forests*). In this module, students are presented with case studies. They learn how to size up an environmental issue, identify the players and their points of view.

During the revision of PLT's program materials, the national Wildfire Coordinating Group (NWCG) expressed interest in helping support the development of several lessons that would address the role of fire in forest ecosystems. Looking for a way to include this topic within a widely disseminated set of materials used by teachers, NWCG worked closely with the PLT staff to develop activities that would effectively explain the nature of fire and its role in wildland ecosystems. To this end, PLT has included several fire ecology lessons in its activity guide for elementary and middle school teachers and placed a major emphasis on fire in the Forest Ecology module for high school teachers.

A description of the Forest Ecology module and its emphasis on fire

The Changing Forest: Forest Ecology features a curriculum strategy that emphasizes these points:

- examines the ecological systems of a forest.
- analyzes interrelationships in forest ecosystems.
- explores factors that shape forests, both natural processes and human influences.
- presents how private citizens, public officials, forest landowners, and professional foresters are involved in managing forests.
- helps students play a role in management decisions about forests.
- demonstrates why it is important to have scientific information when making decisions about forest issues.

As with all PLT's activity guides, this module contains extensive background information, student activities and appendices. The materials also adhere to standards set for quality environmental education programs as outlined in Environmental Education Materials: Guidelines/or Excellence, developed by the North American Association for Environmental Education.

A focus on fire ecology:

The fire ecology portion included in PLT's materials develop these points:

- the historical and present use of fire by humans.
- the influence of wildfire on the rural-urban interface.
- the concept that fire is part of nature.
- that when living in areas where fire is prevalent, there are personal risks.
- people can take personal responsibility for their own safety in fire prone ecosystems.
- that all wildfire is not "bad".

- control and suppression of wildfire has changed forest ecosystems.
- forest resource managers can use fire as a management tool.

Implementation of these programs has just begun. In California, during 1997, over 300 educators attended workshops that introduced them to the high school Forest Ecology module, and 2500 participated in workshops featuring the PreK-8 activity guide. Emphasis placed on the fire ecology section varies. In many settings, such as during the week-long "Forest Institute for Teachers" held each summer, educators receive additional information about wildfire and how it influences forest management practices. In shorter workshops, videos and other published materials are used to develop interest in the subject. The Temperate Forest Foundation's video "The Two Sides of Fire" and their publication, "Fire Ecology", provide excellent introductions to this topic.

In an effort to prepare PLT workshop leaders to do a better job of introducing fire ecology themes in their workshops, the California PLT program has proposed to provide additional training for the nearly 400 PLT workshop leaders. A plan to hold an introductory level training in fire ecology for these environmental educators, is still not funded. In 1998, a new publication: Learning to Live with Fire, produced by the California Department of Forestry and Fire Protection, will be made available through PLT workshops and other fire education public outreach channels.

Conclusion

Recently, the Project Learning Tree program has taken a lead role in introducing educators and their students to the concepts of fire ecology and resource management issues associated with this topic. The program offers teachers and children a new perspective of how resource managers now understand and utilize fire to manage forest and grassland ecosystems. Whether these materials can do an adequate job of introducing the public, especially teachers, to the principles of fire ecology and a new understanding of fire's role in the environment will take time to assess. Meanwhile, support for this effort should become a primary goal of organizations and agencies whose mission is fire protection and education.

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Prescribed Burning in the California State Park System

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Abstract

The evolution of the California Department of Parks and Recreation, Prescribed Fire Program, is discussed, including the ecological failures and successes. Future directions are considered in carrying out the restoration of natural fire cycles under modern moister warmer climatic regimes and in a wide variety of ecosystems in California. Guiding ecological principals are summarized as well as the influence of American Indian practices on long term fire regimes. The first prescribed burn occurred on June 13, 1973 at Montana de Oro State Park; political opposition and academic criticism was endured. A series of burns followed, in and around the South Grove, Calaveras Big Trees State Park starting in 1975. Cuyamaca State Park burns began in 1977 and Big Basin Redwoods State Park in 1978. Prescribed fire was planned for more than 7,000 acres in 1997.

Introduction

The Prescribed Burn Program of the California Department of Parks and Recreation (DPR) is currently funded at \$180,000 per year. Funding is mainly allocated to the Statewide Burn Team that conducts prescribed fires by using priorities set at a statewide level. The State Park System consists of 22 districts covering more than 1.6 million acres in 264 units and 75 sub-units (Natural and Cultural Preserves, Wilderness Areas, etc.). Statewide priorities are carried out at the discretion of each District Ecologist. These priorities include:

- Restoration of natural fire cycles in primeval forest and woodland ecosystems (500- to 5,000+ year-old dominants).
- Restoration of natural fire cycles in ancient forests, woodlands, and savanna ecosystems (100- to 500-year-old dominants).
- Restoration of natural fire cycles in short term shrubland, grassland, and wetland ecosystems (less than 100 years to late successional vegetation).
- Fuel reduction at parklands-urban interface (for protection of core ecosystems from external wildfire threats)
- Experimental Burns (to determine fire cycles in ecosystems where fire chronologies cannot be determined in standard methods such as tree ring analysis and to determine effects of burning on sensitive and alien taxa).

This paper describes the history and guiding ecological principles of the California Department of Parks and Recreation's Fire Management Program and the future direction of the Program for the restoration of natural fire cycles unique climates and ecosystems of California.

History of Prescribed Fire

In 1972, James P. (Jim) Tryner, Chief of the Resource Management and Protection Division, convinced Director William Penn Mott, Jr. to endorse prescribed burning, first at Montana de Oro State Park on California's central coast, then in the South Grove at Calaveras Big Trees State Park on Sierra Nevada west slope. At that time prescribed burning was not in vogue, and political opposition and academic criticism were high. However, both Jim Tryner and Fredrick A. Meyer, Supervisor of the Environmental Resources Section, saw fire restoration as the most important ecosystem management activity for the State Park System. The State Park and Recreation Commission was split on the issue. The State Park Plant Ecologist, Dr. W. James Barry, prepared a plan for a modest burn (35 ac) for the coastal terrace at Montana de Oro; the plan was orally presented by Jim Tryner to the State Park and Recreation Commission for approval. Barry was told by one commissioner, that "if he went ahead with his plan, his career with the Department of Parks and Recreation (DPR) would be over!" Director Mott countered this threat by appointing a committee headed by Commissioner Tom Bonnikson and Barry to evaluate the controlled burn plan. Thereafter, Bonnikson and Barry worked closely in conserving a prescribed fire program for DPR. Bonnikson was working on his Ph. D. at the time; his dissertation on topic was on the natural role of fire in the Sierra Nevada redwood groves. The Montana de Oro State Park citizens advisory committee voted 16 to 1 against the experimental burn, local biologists, among many others, were opposed to burning and brought on much bad press. A number of meetings were held with concerned citizens of the Morro Bay area near Montana de Oro State Park before the burn. At these meetings Barry presented the scientific evidence of the role of fire, but the issue was emotional. Barry established permanent plots in the scrub and grassland areas to be burned. Native bunch grass stands were also mapped, and the general vegetation was mapped and documented. Meyer decided that he personally should light the match to protect the new staff member from possible reprisal. On June 13, 1973 the first prescribed burn was conducted by DPR. By October, many of the annual grasses had been replaced with California poppy (*Eschscholzia californica*). Within a 3-year period after the burn, stands of purple needlegrass (*Nassella pulchra*) increased in size and new stands were established in the burn plot, whereas no increase occurred outside the burn plot. Purple needlegrass top biomass increased from 320 g/sq m to 426 g/sq m. Similar results occurred for this taxa in plots in La Jolla Valley Natural Preserve, Point Mugu State Park in southern California where Gale and Goode (1981) and Gale (1983) found purple needle grass increased from 29 percent cover pre-burn to 47 percent post burn in plots burned in June 1981 and resampled in 1983.

The Montana de Oro burn was followed by a series of prescribed burns at the South Grove, Calaveras Big Trees State Park starting in November, 1975. The prescribed fire plan was written by Barry, who sought the expertise of Harold Biswell to carry out the plan. At that time, Dr. Biswell, Professor Emeritus, School of Forestry, University of California, Berkeley, was the authority on prescribed fire. By the end of the burn season (May 18, 1976), 740 acres along the

South Grove rim and the south facing slope were burned. On December 8, 1976 fire was introduced to the grove itself, proceeding down from the north rim and entering the upper end of the grove.

Harold Biswell conducted prescribed burns in Cuyamaca Rancho State Park in the spring of 1977. Experimental burns continued in the park through 1979. The results were compiled by Dr. Earl W. Lathrop and his students. Pure deer grass (Muhlenbergia rigens) stands were burned on December 15, 1978 and April 16, 1980. The December burn showed 145 percent foliar recovery in 1.5 years, while the April burn showed 143 percent recovery in only 3 months. Other montane meadows burned in December showed a complete change in dominance from alien annual grass Vulpia myurus to the native perennial bunchgrass, Melica imperfecta. Jeffrey pine (Pinus jeffreyi) and California incense cedar (Calocedrus decurrens) seedlings decreased on winter burn plots, while oak (Quercus kelloggii and Q. agrifolia) seedling production was increased Martin (1981). Lathrop (1981) noted that Arctosaphylos pungens, a non-sprouter, was not recovering after the test burns. This is a dominant in the current understory of Jeffrey pine forests and woodlands, as well as a common component of chaparral.

Under Dr. Biswell's leadership, burners Jason Greenlee, Barry, and burn crews, conducted the first ever prescribed burn, in coast redwood forest, on May 9, 1978 at Big Basin Redwoods State Park. Ironically, this was the 50 year celebration of the State Park System; Big Basin was the first of the existing State Park System units (Yosemite Valley and the Mariposa Grove was the first State Park, in 1864, but it was returned to Federal jurisdiction as a National Park in 1906). Also in 1978 Harold Biswell and Ranger Glenn Walfoort developed a "Fire Management Plan and Program of Prescribed Burning for that Portion of Calaveras Big Trees State Park Outside The Calaveras South Grove". Glenn Walfoort became our first expert in the techniques of prescribed fire.

Management burns began at Point Lobos State Reserve in 1981. Permanent vegetation plots were established and monitored which showed the increase in native taxa and subsequent biodiversity following annual fall burns which were continued for more than a decade. The grassland burn plot was burned after sufficient rainfall to germinate alien, winter annual grasses. Large stands of creeping wildrye (Lymus triticoides) invaded alien annual grassland plots; this taxa was not recorded for the burn plot before the initial burns. Similar increases were recorded for purple needlegrass. Overall diversity of native taxa increased in most quadrants after a single burn. A large, 2-acre stand of alien black mustard (Brassica nigra) burned with 10 m flame lengths during the initial burn. After 5 years of burning, this stand had diminished to a few individuals. Relatively cool prescribed fire of March 25, 1982 was conducted in the understory of a Monterey pine (Pinus radiata) stand on heavy clay soils. The thick duff and litter had accumulated since the 1930's when pines invaded the grassland as shown in early vegetation maps. The fire fried the cambium layer of the shallow root system of the pines, which occurred mainly at the duff-mineral soil interface. A massive die-off of pines followed, and public criticism had to be addressed. Although the objective was to restore grasslands to this area, we had planned to do it gradually rather than all at once. Giant wildrye (Leymus condensatus) increased dramatically in the burn plot, especially in coastal sage scrub stands.

At Point Mugu State Park, test burns in native grasslands, coastal sage scrub and coast live oak woodland began in 1981. Dr. Richard Vogl and his students established permanent plots and analyzed pre- and post-burn changes in the vegetation. June burns were found to dramatically increase purple needlegrass whereas October burns favored the alien Harding grass (Phalaris aquatica L.). Numerous tests were conducted on the control of this aggressive alien

bunchgrass. Winter burns were conducted between 1983 and 1986. Creeping wildrye increased from 16.7 percent in pre-burn plots to 30.8 percent in post-burn plots. The alien bunchgrass, meadow fescue (*Festuca arundinacea*), decreased dramatically between 1983 to 1985 while native forbs nearly doubled in burn plots (Gale 1987).

Dr. Biswell served as special consultant to the DPR from 1975 to 1982. He set up a training program that focused on hands-on prescribed burning and little classroom work. Originally the training was in the form of field days with demonstration burns. Formal training through University of California, Davis Extension, began around 1980 and was conducted in Yosemite National Park, Calaveras Big Trees State Park, Mount Diablo State Park and Cuyamaca Rancho State Park. He used the expertise of the National Park Service Park Scientists such as Dr. Jan van Wagtenonk, as well as the authors.

After 1982, the DPR set up its own training program with course work provided at the William Penn Mott, Jr. Training Center at Asilomar State Conference Center. Classroom training was augmented by burn experience of a given number of hours in order to become a burner or a burn boss. The DPR requires completion of a 14-week prescribed fire training program for all those who conduct prescribed fires on State Park System lands. The training assures that burners are knowledgeable in planning and executing prescribed burns.

Beginning in 1991, training has been focused toward the formulation of a Statewide Burn Team. This team has consisted of permanent employees who worked at various other jobs within the DPR, and who fit burn team participation into their other responsibilities. This structure has relied a great deal on the personal dedication of the individual team members, the understanding and flexibility of immediate supervisors, and the willingness of burn bosses to accept crew members who might be available for only 1 day of a burn that might take 2 or more days. Although this structure still exists, it has been greatly augmented by the addition of a seasonal crew from the Sierra District. With few exceptions, this crew has been available for any burn, any duties, anywhere in the State.

Between 1973 and 1987, a total of 9,134.54 acres were burned and 154 prescribed burns were conducted in the State Park System. These were primarily experimental, training and fuel reduction burns, but always with the long term objective of restoring fire into natural ecosystems. Prescribed fire has been funded through the Statewide Resource Management Program since 1980. Calaveras District Resource Ecologist Wayne Harrison was appointed as the first Statewide Prescribed Fire Coordinator in 1993. About 900 acres were burned in 1993-94, followed by 1,700 acres in 1994-95, and 4,166 acres in 1995-96. In 1996-97 district ecologists proposed to burn 7,129 acres in 38 separate burns; however, the actual acreage has not yet been compiled.

Current Status

An important addition to the overall management of the Statewide Burn Program was the appointment of Supervising Ranger Frank Padilla to the part-time position of Southern California Prescribed Fire Coordinator in 1996. For 1997-98 district ecologists have proposed 50 projects, and about 3,000 acres have been burned as of October 15, 1997.

The DPR's prescribed Fire Training Program is currently modeled after the standardized training protocols developed by the National Wildfire Coordinating Group. This training, for

fire crew members and burn bosses, establishes minimal standards for specified prescribed burn activity levels. The DPR also relies more on specialized courses than it did in the past.

Current level of funding is \$180,000 per year. The current structure and funding level make it difficult to supply all the needs of the 22 districts covering more than 1.6 million acres and 264 park units. Districts that lack a burn team member with extensive experience to plan prescribed burns are at a disadvantage. Alternative restructuring and expansion of the program is being formulated in a 5 year fire management plan that considers needs and alternatives into the 21st century.

The Natural Role of Fire in California

In addition to lightning set fires, American Indians used fire in a multitude of plant communities. Fire was one of the earliest human tools. The post-glacial California vegetation has evolved under a frequent fire regime. American Indian use of fire is considered by the DPR to be natural, and is included in the restoration of natural fire cycles. These cycles are usually determined by studying fire scars, tree ring widths, and analyzing ash layers in soil profiles and sediment layers. Historical accounts are also useful, but often misleading as native societies were often disrupted before European contact. Many European diseases and alien plants spread rapidly. For example, the tribes of the Great Central Valley were nearly extinct by 1833 due to malaria. The source of this epidemic has been traced to Captain Cook's crew that landed in Seattle around 1779. Fur traders carried the disease from Seattle to California where it spread throughout the Valley. Other endemics, such as smallpox, were less geographically limited.

During the Spanish occupation of California, American Indian burning practices were forbidden by decree of the Spanish Governor in 1797. This proclamation provides an insight into the widespread practice of aboriginal burning. It also signals the beginning of natural ecosystem modification, in Spanish California and at least in some portions of the Sierra Nevada foothills. The use of California grasslands for domestic grazing animals dates from the arrival of the first Spanish colonists in 1769. Before that time, the grasslands, woodlands, and forest understories were subjected only to limited grazing by native ungulates and rodents. Controlled grazing began around 1773 and has continued in many rangelands to the present. The first widespread permanent grazing began in 1824, when land grants for the vast cattle ranchos were made under the Mexican Liberal Colonization Act. Tens of thousands of cattle in great herds overgrazed the lush California grasslands, causing the first major human-induced impact on the rich resources of California. After domestic grazing animals were introduced, the pristine bunchgrass communities quickly disappeared from most of California.

Historical accounts, where native societies had not yet been disrupted, are important to the understanding of aboriginal burning. On October 3, 1543, Juan Rodriguez Cabrillo first landed in San Diego Bay. He set sail northward and for the next 3 days noted valleys and plains and "smokes" along the coast. He sailed to San Pedro Bay, which he named "Bahía de los Fumos or Fuegos" for the smoke of fires seen there (Bancroft 1886:70-71). This was the first European recording of indigenous use of fire in California.

Juaquin Miller visited Yosemite Valley and in 1887 noted his observations: "In the Spring... the old squaws began to look for the little dry spots of headland or sunny valley, and as fast as dry spots appeared they would be burned. In this way fire was always the servant, never the master... By this means, the Indians always kept their forests open, pure and fruitful, and

conflagrations were unknown" (Biswell 1989:48). Miwoks of Yosemite Valley and other indigenous peoples help guide our philosophy of prescribed burning--such as the "new "use of differential burning, as was practiced in Yosemite Valley,--into the 21st century.

Evolution of Modern Vegetation and Recent Studies in the Sierra Nevada

The Pleistocene epoch ended somewhere between 10,400 to 13,700 B.P. This marks the beginning of deglaciation; by 11,000 B.P. most of the Pleistocene megafauna were extinct (Woolfenden 1996). Deer, elk, and smaller animals, however, have persisted to this day. This mass extinction reflects dramatic climatic changes from cold-dry to warm-dry at the beginning of the Holocene epoch (modern geologic time). The "lightning era" started at least 10,000 B.P. (Langenheim and Greenlee 1983), which was an important ignition source. Human occupation is known from Tulare Lake, in the San Joaquin Valley as far back as 12,275 B.P. and along the shores of ancient Lake Lahontan between 10,000 and 12,000 B.P. (John Foster, pers. comm.). As glaciers waned, dense coniferous forests of a species mix unlike any modern plant community inhabited the west slope mid-elevation Sierra Nevada. The climate was much colder and wetter than at present. With continual warming at the end of the Pleistocene, a dry, open conifer forest with a montane shrub understory and an increased number of oaks invaded from the Great Central Valley. This climatic change marked the beginning of the Holocene epoch. Tree lines extended to higher elevations and xeric desert plants invaded over the Sierran crest. Increased fire frequencies are recorded as charcoal layers in the soil (Woolfenden 1996). Lake Tahoe was at least 13 ft below the rim during this dry period, between 4,800 and 5,200 B.P.; this is recorded by carbon dating rooted snags still present in the lake. In the Sierra Nevada, American Indian populations were highest during the "oak period" (John Foster, pers. comm.). Precipitation began to increase as indicated by an increase of subalpine conifer forests and the re-establishment of montane conifer forests. Cooler conditions 4,000 to 3,000 B.P. caused whitebark pine, mountain hemlock, red and white fir, and California incense cedar to migrate to lower elevations. This was the beginning of the formation of the modern westside Sierran forests. A brief warm-dry period occurred between 1100 and 700 B.P. (Woolfenden 1996). Snags rooted 35 ft below the current lake level of Donner Lake have carbon dates of 500 P.B. (John Foster, pers. comm.). This warm dry period was followed by a 400 year phase with average conditions cooler and wetter than the present and with multiple advances and retreats of alpine glaciers (Woolfenden 1996).

A marked climatic shift occurred in 1850 A.D., shortly after large numbers of Europeans and Asians invaded California. The abnormally cool, dry conditions of the past 2 centuries (the "Little Ice Age") shifted to the relatively warm and wet conditions that have characterized the past 145 years. Thus, the attempts to restore natural ecosystems must not use the early 1800's as a baseline (Stien 1996:25). Rather, the climate is likely more similar to the "Medieval Warm Period" of 1100 to 700 P.B.--although perhaps moister and dependent on carbon dioxide build-up in the atmosphere and natural climatic shifts that cannot be predicted with certainty. More violent fluctuations in climate are occurring and are likely to become even more common and intense, whether moist or dry conditions occur. Natural fire cycles are likely to be more frequent if the climate is warm and dry; cycles will be less frequent if the climate is warm and moist (but more frequent than at present). This pattern has been shown for Sierra redwood groves in which frequent small fires occurred during the Medieval Warm Period (27 to 46 per century) and less

frequent but more widespread fires occurred during cooler periods from about 1500 to 1000 B.P. and after 700 P.B. (13 to 29 per century) (Swetnam 1993). The oldest dated fire occurred in 3125 B.P, thus more than 3,000 years of fire history has been recorded. Fire chronologies showed greatly reduced fire occurrence after about 1860. Swetnam (1993) attributed this reduction in fire frequencies to intensive sheep grazing, a decline in fires set by Miwok Indians, and fire suppression policies. In Yosemite Valley pollen analysis show a decline in Pinus pollen and an increase in Quercus pollen around 1200 A. D., which correlates with the permanent occupation of the valley by Sierra Miwok who used a wide variety of resources, particularly acorns. The Miwok and other American Indians practiced intensive vegetation management, including the use of fire. Correlation with the dates of Miwok settlement, the large charcoal peak in sediments, and rapid, sustained vegetation change strongly support the contention that original American Indian inhabitants of Yosemite initially burned the pine forests and converted them to oak savannas (Woolfenden 1996:65). Climatic change must also be accounted for. Stien (1995:29) notes that fire frequencies in the Sierra Nevada since 1850 should have increased, but have decreased to their lowest level of the past 2,000 years.

Reconstructing California's Ancient Landscapes

Proto-historical accounts of the Sierra Nevada give us a glimpse of the character of natural ecosystems before Eurasian occupation, such as the openness of the forest canopy and the antiquity of forest stands. The forest understory usually was devoid of a shrub layer but included a well developed herbaceous understory. Fire was frequent and primarily uncontrolled. Fire was either ignited by lightning or set by American Indians over the past 11,000+ years. Thus, the vegetation within the Sierra Nevada ecosystem evolved under frequent fire. American Indian burning had a number of objectives, these included the stimulation of food and fiber plants, the maintenance of open forests and woodlands for easier movement and hunting, and the use of fire for protection and warfare (Biswell 1989, Lewis 1973).

At Calaveras Big Trees State Park, South Grove, fire chronologies have been worked out since 1611 A.D. Between 1700 and 1864 fire return intervals are quite evenly spaced (33 per century) (Baisan [this volume]). A severe drought occurred in 1863-64 and valley ranchers began driving large numbers of livestock (somewhere between 1 and 2 million head) into the Sierra Nevada. With normal understory forage decimated, natural fire would not carry far; indeed, there were only two fires recorded--1875 and 1887-- for the South Grove over the next 100 years. The next fire scare is in 1975 recording the first prescribed burn in the South Grove watershed. This long term absence of fire lead to extreme fuel build ups and a "new" understory vegetation--a thicket dominated by white fir (Abies concolor) and, to a lesser extent, California incense cedar (Calocedrus decurrens). We have learned that fire alone cannot restore the structure primeval and ancient ecosystems; rather, understory thinning is also necessary. Under Walfoort's direction, 20,000 understory trees were removed from the South Grove in the late 1970's. Understory thinning projects are currently underway at Calaveras Big Trees, Sugar Pine Point State Parks and at Empire Mine State Parks where Arctosaphylos visida is being removed.

At Annadel State Park, Douglas-fir (Pseudotsuga menziesii (Mirbel) Franco var. menziesii) seed trees have been removed because they have replaced Quercus forests, due to long fire return intervals. Because prescribed fire alone cannot replace these recent invaders, Douglas-fir is being removed from the understory by volunteers.

Restoring the Natural Role of Fire

During the past 10 to 20 millennia, the flora and vegetation of California's Mediterranean climate evolved under a frequent fire regime and low intensity grazing from native ungulates (Barry 1972:4). After Eurasian occupation of California, fire and grazing regimes have been drastically altered. For thousands of years, fires were intentionally set by American Indians from spring to autumn (timing depended on purpose and site). Unchecked lightning fires occurred, mainly in summer months. Fires often burned for months, but were generally of low intensities--in contrast to current firestorms. Fires burned every year in the same region but burned in a mosaic pattern, which crept through plant communities without crowning out. A particular patch of woody vegetative cover may have burned entirely one to three times every 20 years. This variation is dependent on environmental factors such as slope, aspect, soils, precipitation, etc. The tree and shrub understories were often dominated by bunchgrasses that remained green at the base all year. These native bunchgrasses burn cool and sporadic, in contrast to the highly flammable alien annual grasses and forbs now found associated with California tree and shrub communities. For example, mustard dominated sites can have a flame height of 10 m, whereas under the same fuel moisture conditions, native grasses would have a flame height of less than 0.5 m. Many alien annual grasses and weedy forbs are adapted to heavy grazing and soil disturbance. Thus, they have displaced the natives, lowering natural diversity. Once established, alien weedy taxa are extremely difficult and costly to control. Prescribed fire, at a given time of year, appears to be the most promising tool for restoring many California plant communities (with the exception of zonal desert communities). Although prescriptions are site-dependent, spring burning appears to be the best for native grasses in coastal and maritime climates of southern California whereas summer appears to be best where coastal fog influences interior areas. Autumn is best in foothill and mountainous regions of the State. Winter may be best in the Great Basin Ecological Province. Differential burning techniques began at Pacheco State Park where south-facing slope grasslands were burned April 11, 1997; north-facing slope oak woodlands will be burned in the autumn of 1997.

Prescribed fire may be used with limited use of herbicides and hand removal, depending on the alien taxa present. All these tools require different prescriptions, dependent on the site specific micro climate, alien taxa present, and associated plant community. To complicate matters, transportation corridors also act as weed corridors. If aggressive weeds are not controlled along road right-of-ways, then all efforts to control them on adjacent lands are futile. Prescribed fire has two important roles along transportation corridors: to help prevent wildfire from starting along roadways and to control some aggressive alien weeds from spreading to wildlands and agricultural lands.

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Beyond Initial Fuel Reduction in the Giant Sequoia-Mixed Conifer Forest: Where Do We Go From Here?

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Abstract

After nearly a century of fire regime disruption, altered fuel and vegetation conditions throughout many California forests increase the risk of severe and undesirable wildland fires. To address these changes, Sequoia and Kings Canyon National Parks' fire management program focuses first on reducing heavy forest floor fuel loads, and then on restoring and maintaining the natural fire regime where possible. Data from 28 long-term monitoring plots in the giant sequoia-mixed conifer forest indicate that the mean total fuel reduction from initial burns was 71 percent. This result demonstrates that the initial restoration burn objective of 60-80 percent fuel reduction was achieved by using the current burn prescriptions. Data from 12 of the older monitoring plots show that 10 years after the initial burns, mean total fuel load reached 63 percent of prefire levels. The accumulation of fuels after the initial burns resulted in a different fuel complex than was originally treated. Woody fuels accumulated faster than duff due to branches and small trees (unnaturally dense from lack of fire) killed by fire that fell to the forest floor. The need for repeated burns is therefore indicated after approximately 10 years to prevent a return to the unnatural fuel loads present before the initial restoration burns. The timing of this first reburn for fuels restoration falls within the range of historic fire return intervals for this forest type (2-30 years). In recent reburns conducted in two giant sequoia-mixed conifer forest areas initially burned 8 and 12 years ago, three monitoring plots show a mean total fuel consumption of 75 percent. As stand density returns to more natural levels after repeated burns, branch and tree mortality is not expected to contribute as significantly to the future fuel load. Because the number of areas that have been burned more than once is limited, drawing conclusions about the timing and effects of repeated burns is not yet possible. However, monitoring of additional reburns will help address many questions that have been raised, including the effects on giant sequoia regeneration. The results from this ongoing adaptive management program may be particularly interesting to managers of other parks or wilderness areas where fire is considered the most appropriate means for the restoration and management of ecosystems.

Introduction

Throughout many California forests, unnaturally heavy amounts of dead and down fuels have accumulated after nearly a century of attempted fire exclusion. In addition, an increase in small trees in the understory, limited by fire in the past, has resulted in an unusually high density of young trees. These altered fuel and vegetation conditions increase the risk of severe wildfires that may result in unnatural or undesirable fire effects. Reproduction has also been limited for

species that depend on fire for regeneration, such as giant sequoia (Sequoiadendron giganteum [Lindley] Buchholz).

In the giant sequoia-mixed conifer forest of the Sierra Nevada, pre-Euro-American fires burned at intervals ranging from 2-30 years as evidenced by fire scars in the giant sequoia annual ring record dating back nearly 2,000 years (Kilgore and Taylor 1979, Swetnam 1993). The heavy forest floor fuel load and increased stand density after the century-long disruption of the natural fire regime are well-documented in this forest type (Kilgore 1972, Parsons 1978, Vankat and Major 1978).

To begin to address these changes, Sequoia and Kings Canyon National Parks' fire management program focuses first on reducing heavy forest floor fuel loads by using fire, and then on restoring and maintaining the natural fire regime to the maximum extent possible. An active program of prescribed fire began in 1969. For the past three decades, the parks have focused on fuel reduction burns, in part because of the extent of the recognized imminent hazard. A specific objective of the program is to reduce heavy fuels that expose park developments and cultural and natural resources to damage from severe wildland fire. The first fire planned in an area is known as a 'restoration burn', because it restores forest floor fuel loads to lower levels. The primary objective for the initial restoration burn is 60-80 percent consumption of total fuel load.

A long-term monitoring program began in 1982 to assess objective achievement and document changes in fuel and vegetation in areas where fire is intentionally applied. Repeated burns were indicated both to maintain reduced fuels and to continue progress towards natural process restoration.

Methods

Study Area

Sequoia and Kings Canyon National Parks are located in Tulare and Fresno Counties, California, in the southern Sierra Nevada. The giant sequoia-mixed conifer forest is located at elevations from 1,650-2,200 meters (5,400-7,200 feet), on all aspects, in drainage bottoms, broad upland basins, and occasionally on steep slopes and ridgetops. Soils are coarse textured and acidic and soil depth ranges from shallow to very deep. The giant sequoia-mixed conifer forest is dominated by mature white fir (Abies concolor [Gordon & Glend.] Lindley), red fir (A. magnifica Andr. Murray), and giant sequoia, but also includes sugar pine (Pinus lambertiana Douglas), ponderosa pine (P. ponderosa Laws.), Jeffrey pine (P. jeffreyi Grev. & Balf.) and incense cedar (Calocedrus decurrens [Torrey] Florin) in small varying amounts. Understory trees are primarily composed of white fir and incense cedar. The forest floor is typically sparse, with few herbs, and <20 percent shrub cover.

Burning Conditions

All areas in this study were burned between 1982 and 1997 within the same range of burning conditions specified for the giant sequoia-mixed conifer forest (U.S. Department of Interior, National Park Service 1992a). Fuels are best described by Northern Forest Fire Laboratory (NFFL) Fuel Model 8 (Albini 1976). The time since the last fire in all plots was

greater than 40 years. Temperatures ranged from 4-24°C (40-75°F), relative humidities from 25-50 percent, and mid-flame wind speeds from 0-10 kilometers per hour (0-6 miles per hour). Fuel moisture ranges included: 1-hour time lag fuel moisture (TLFM), 3-13 percent; 10-hour TLFM, 4-14 percent; 100-hour TLFM, 5-15 percent; 1,000-hour TLFM, 10-20 percent. The range of backing fire rates of spread was 0-20 meters/hour (0-66 feet/hour) with flame lengths from 0-0.6 meters (0-2 feet). Head fire rates of spread ranged from 40-180 meters/hour (132 to 594 feet/hour) with flame lengths from 0-1.5 meters (0-5 feet).

Field Data Collection

Monitoring data were collected from a network of permanently marked 20 x 50 meter plots established using a stratified-random sampling design within the park areas designated for prescribed fire. Within each forest plot, fuel load and tree density were recorded prefire, immediately postfire, and 1-, 5-, and 10-years postfire.

Fuel load was measured using the planar transect method (Brown and others 1982). Total fuel load included: duff (the consolidated, decomposing organic layer above mineral soil), 1-hour (0-0.61 centimeters [0-0.24 inches] in diameter), 10-hour (0.62-2.53 centimeters [0.25-0.99 inches]), 100-hour (2.54-7.59 centimeters [1.0-2.99 inches]), and 1,000-hour (3.76 centimeters [3 inches]) TLFM woody fuels. To obtain overstory tree density, all trees >1.37 meters (4.5 feet) in height were tagged, mapped, identified to species, measured for diameter, and recorded as live or dead (U.S. Department of Interior, National Park Service 1992b). Tree seedlings (trees <1.37 meters in height) were not included in this study.

For immediate postfire fuel reduction and tree mortality, 28 plots that burned in 17 different prescribed fires between 1982 and 1995 were analyzed. To examine long-term postfire fuel accumulation and changes in tree density over time, 12 plots that reached the 10-year postfire stage were evaluated. These plots burned in seven separate prescribed fires: one in 1982 (four plots), one in 1984 (two plots), three in 1986 (one plot each), and two in 1987 (one and two plots respectively).

Results and Discussion

Are We Achieving Our Objective?

Mean total fuel load \pm one standard error was 63.6 tons/acre \pm 5.8 prefire and 18.3 tons/acre \pm 3.1 immediately postfire, a 71 percent reduction in mean total fuel load ([fig. 1](#)). This result from 28 monitoring plots indicates that the initial fuel reduction objective was achieved (60-80 percent total fuel reduction) in the giant sequoia-mixed conifer forest by using current burn prescriptions.

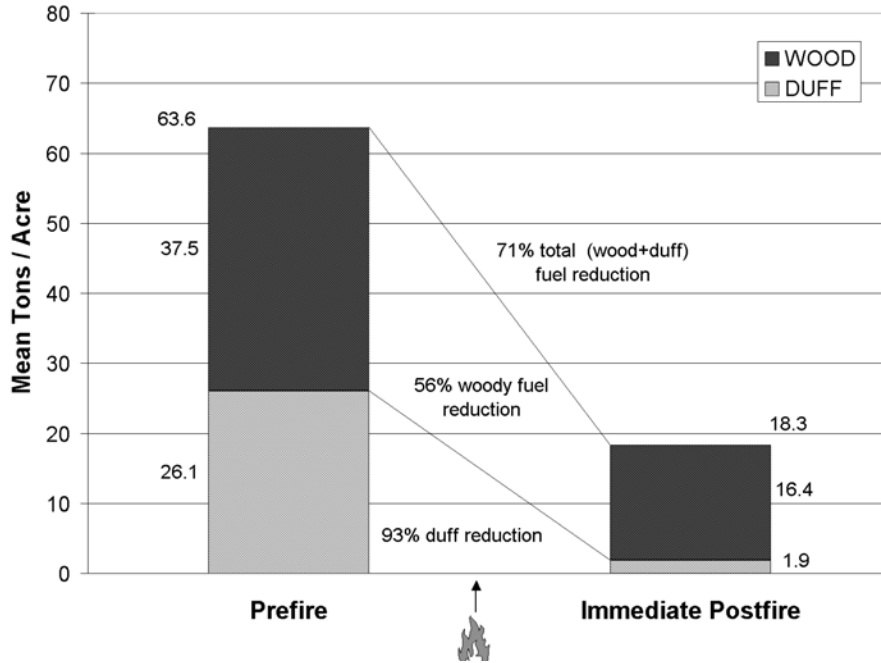


Figure 1 Initial fuel reduction in the giant sequoia-mixed conifer forest. Mean total fuel load +/- one standard error and mean wood and duff load (n=28 plots) before and immediately after initial restoration burns.

What Other Postfire Changes Occur?

In addition to fuel consumption as a direct result of the fire, fuel accumulation after restoration burns is tracked over time. Immediate postfire mean total fuel load ± one standard error was 25.1 ± 5.1 for 12 plots that reached the 10-year postfire stage. Ten years after fire, the mean total fuel load for these 12 plots was 41.8 ± 4.0 (fig. 2). These results indicate that mean total fuel load reached 63 percent of prefire levels 10 years after fire. Woody fuels (most of which are >2.5 cm in diameter) accumulated much faster than duff, reaching 80 percent of prefire levels after 10 years, compared to only 37 percent of prefire levels for duff. Projected fuel loads based on annual fuel accumulation rates obtained over 6 years in Yosemite National Park, show that fuels would reach prefire levels approximately 11 years after fire (van Wagtendonk and Sydoriak 1987); this fuel accumulation rate is somewhat faster than that observed in this monitoring study.

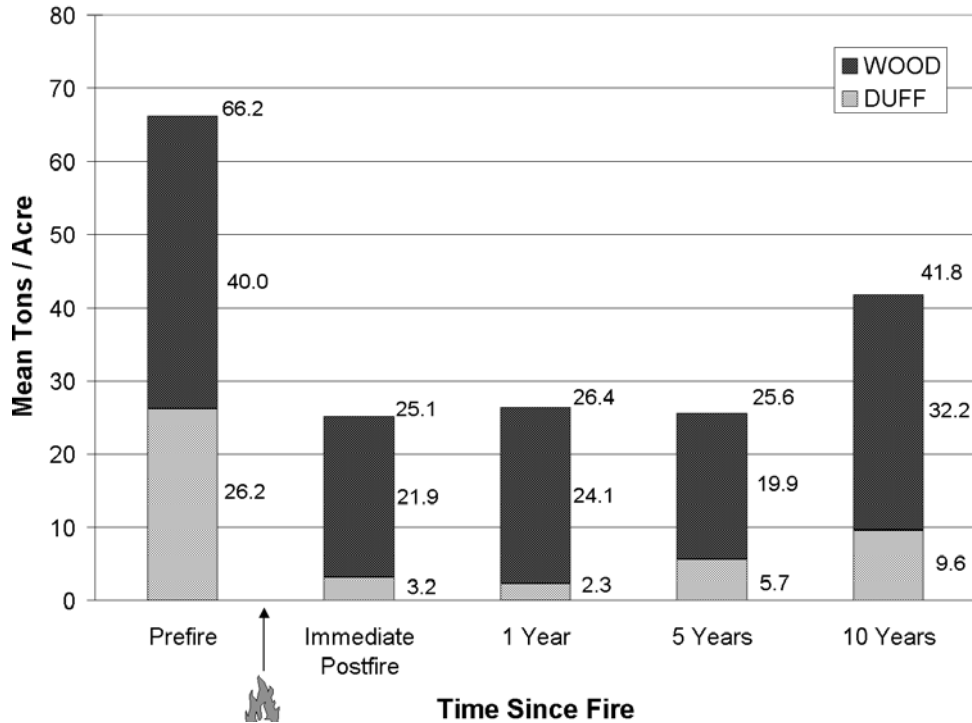


Figure 2 Fuel accumulation after initial restoration burns. Mean total fuel load \pm one standard error and mean wood and duff load ($n=12$ plots) before, immediately after, and 1, 5, and 10 years after initial restoration burns.

Two factors influence the difference between the prefire and postfire fuel complex. First, a greater proportion of duff was consumed (93 percent) compared to woody fuel (56 percent). In addition, woody fuel accumulated because of branch and tree mortality after the initial restoration burn; these branches and trees then fall to the forest floor over time (Parsons 1978). Tree mortality is greatest in the smallest diameter classes (<30 cm) where mean tree density is reduced by 77 percent for trees <10 cm, 54 percent for 10-20 cm, and 29 percent for 20-30 cm trees 1-year postfire (fig. 3). Tree mortality in the larger size classes (>30 cm) ranges from 0 to 15 percent.

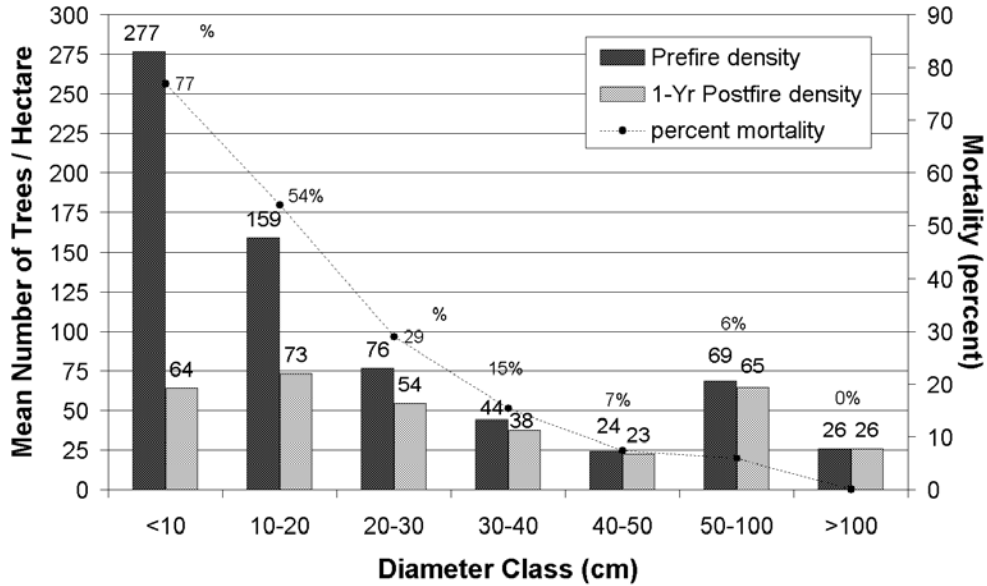


Figure 3 Tree density and mortality in initial restoration burns. Mean total tree density (all species combined) before and 1-year after initial restoration burns with percent mortality by diameter class (n=28 plots).

The smaller trees are more susceptible to fire and also occur in unnaturally high densities because of the lack of fire over the past century. Mortality in these smaller size classes is, therefore, not unexpected. Although not currently a specified objective, decreasing stand density is an expected and desired outcome of the restoration effort. A reduction in stand density will decrease the ability of fire to spread from the surface fuels into the crowns under severe conditions. In addition to a reduction in stand density, relative species composition shifts over time after fire. Ten-years postfire, the relative density of giant sequoia in seven plots is three times the prefire level because of a decrease in white fir density and postfire regeneration and recruitment of young giant sequoias into the smallest diameter class (Keifer, In Press).

The New Situation

The relatively rapid accumulation of woody fuels demonstrates that a second burn after about 10 years may be needed to reduce both the fuels not consumed by, and the fuels accumulated as a result of, the initial fire. Many areas in the parks treated initially by restoration burns have reached or exceeded the 10-year postfire phase. For the past 30 years, the park staff has focused on initial restoration burns because of the extent of the fuel hazard problem. Many of the areas burned early in the program did not get further attention after receiving the first fire application because the park staff concentrated on areas that had not burned in more than 40-80 years. Although the intention was to return to many of these areas for subsequent burns, areas that had not been burned took precedence. Assuming similar fuel accumulation rates continue, fuel load would reach prefire levels about 15 years after the initial fire. The park staff was concerned that neglecting areas initially burned could result in fuel hazards that the initial burns were intended to mitigate.

How Do We Address the New Situation?

Recently, funding has been requested and obtained specifically to address the need for follow-up, or repeated, burns in areas of the parks that have already been burned once. Data from monitoring plots in these “reburn” areas address the questions of changes in fuel load and vegetation after repeated burns.

In 1996, a giant sequoia-mixed conifer forest area that was first burned 12 years ago was burned again. Also, an area that was first burned 8 years ago was burned again in 1997. Data collected before the second burns from two monitoring plots in 1996 and one plot in 1997 indicate that the 8-12-year postfire mean total fuel load had exceeded the initial prefire fuel load (fig. 4). Woody fuel was more than twice that of the initial prefire level. Data collected immediately after the second fire, or reburn, show that the reburn achieved a mean total fuel consumption of 75 percent for the three plots. In contrast with the initial burns where the proportion of duff consumed exceeded that for woody fuel, as a result of the reburn, 77 percent of the woody fuel was consumed while the duff was reduced by 63 percent.

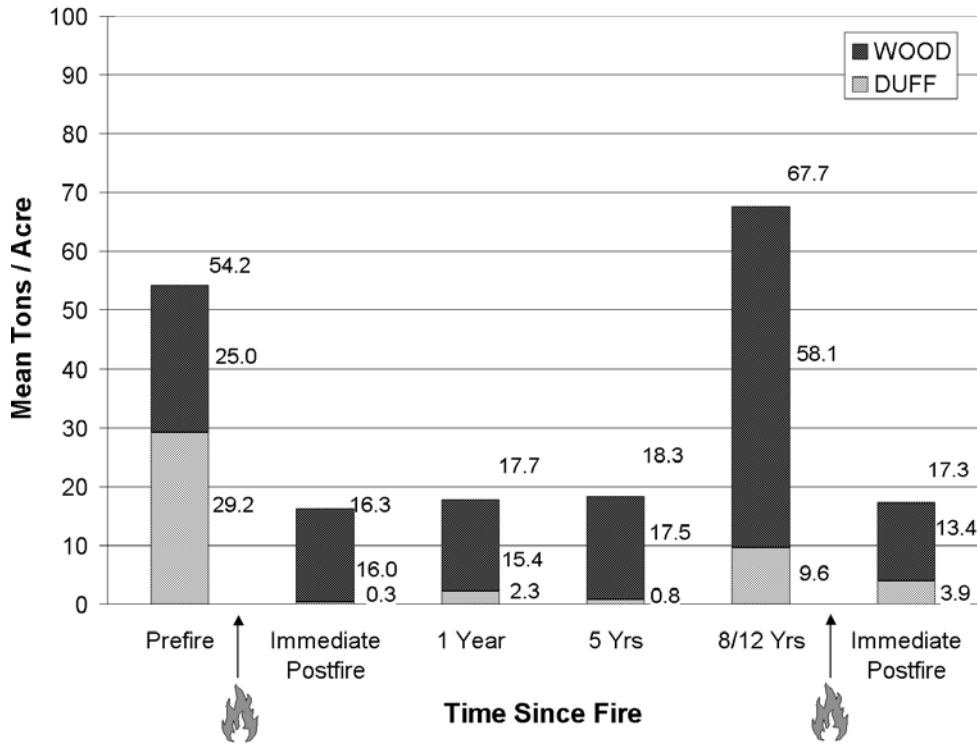


Figure 4 Fuel reduction and accumulation in reburns. Mean total fuel load +/- one standard error and mean wood and duff load before initial restoration burns, over time postfire, and immediately after reburning (n=3 plots) in the giant sequoia-mixed conifer forest.

Mean tree density immediately after the reburn was not reduced to the extent that it was 1-year after the initial burn (fig. 5). Mortality was lower after the reburn, compared to the initial fire, for all diameter classes except the smallest (<10 cm) in these plots (figs. 3, 5). Because tree mortality may not be apparent until 1-year after burning, mortality may yet increase in the reburned plots 1-year postfire. The <10 cm diameter class experienced 100 percent mortality as a result of the reburn. This mortality occurred in a dense patch of small trees located in one plot

only. Because of the small sample size (three plots) and high variability among plots, this mortality pattern cannot be generalized to all reburn areas. Also, it is important to note that these results apply to overstory trees only; tree seedlings (those trees <1.37 meters in height) are not included in these results. However, observations from throughout the two reburned areas (not just in permanent monitoring plots) indicate that some patches of regeneration are completely consumed, some survive completely, and still others are only partially burned.

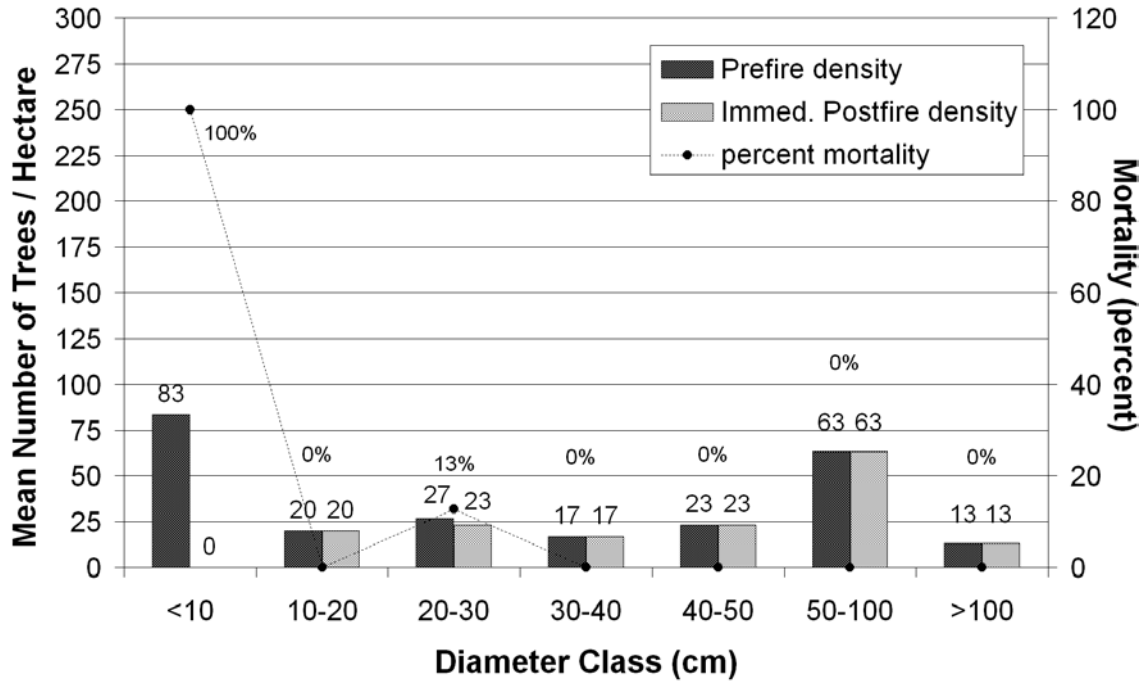


Figure 5 Tree density and mortality in reburns. Mean total tree density (all species combined) before and immediately after reburns with percent mortality by diameter class (n=3 plots).

The reburn results presented are for three plots in two separate fires only, therefore, generalization of the results to other areas and future repeated burns cannot be made. If, in future reburns, tree mortality levels off, contributions to forest floor fuel load will be minimized and fuel loads may return to more natural levels and accumulation rates.

Management Implications and Conclusions

As the park fire management program progresses from initial fuel reduction to the question of sustaining natural conditions, the park staff is questioning the meaning of restoration and perpetuation of natural systems. The park staff recognizes that restoration of fuel conditions will take more than one fire. Also, restoration of natural conditions implies more than simply restoration of fuel conditions; stand structure and composition are also important components of the natural system. The park staff is currently developing objectives for the prescribed fire program that will specifically address the structure and species composition of the giant sequoia-mixed conifer forest.

Standing dead trees killed by the initial or subsequent fires will, over time, fall to the forest floor and contribute to the fuel load. Prefire tree densities are such that mortality from the initial restoration burn, and from reburns, will continue to augment the fuel loads. However, as stand density reaches more natural levels (probably after two to three fires), tree mortality from future fires is not likely to contribute significantly to increased fuel load. After this point, fire may then be fully restored according to historic fire regimes, if appropriate, without major concern for the effects of unnaturally heavy fuel loads.

Because the number of areas that have been burned more than once is currently very limited, drawing conclusions about the timing and effects of repeated burns is not yet possible. However, many questions have been raised that more repeated burns and long-term monitoring of these reburns will help address. Once fuels are restored to more natural levels, some areas of the parks may then be returned to a natural fire regime where lightning ignitions are allowed to burn within the usual constraints of safety and environmental conditions.

Other areas, especially those located near developments and some park boundaries, may need to be managed under perpetual prescribed fire regimes. In these areas, the consequences of various fire return intervals must be determined (using models) and decisions about fire application frequency must be made. The effects of repeated fires on giant sequoia regeneration must also be well understood to ensure the perpetuation of the giant sequoia-mixed conifer forest. Long-term monitoring is critical for understanding the consequences of our land management actions and for providing feedback to managers. The results from this ongoing adaptive management program may be especially interesting to managers of other parks or wilderness areas where fire is considered the most appropriate means for the restoration and management of natural ecosystems.

Acknowledgments

Thanks to the many people over many years who contributed to the development and implementation of the Sequoia and Kings Canyon National Parks' long-term fire effects monitoring program.

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A Fire Protection Strategy for Giant Sequoia Groves in the Sequoia National Forest of California

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Abstract

The goals for National Forest management of giant sequoia groves (*Sequoiadendron giganteum* [Lindl.] Buchholz) are to protect, preserve, and restore them for the benefit and enjoyment of present and future generations. Sequoia National Forest in California initiated a collaborative stewardship pilot project with interested publics to formulate a fire protection strategy for giant sequoia groves. A small, relatively simple grove was chosen on which to develop a working model of this process. The resulting possible management practices were documented in a form suitable to initiate future management actions in compliance with the National Environmental Policy Act (NEPA). The collaborative group derived desired conditions, described existing conditions, and developed possible management practices that would lead to fire protection. The FARSITE fire simulation model was used to predict and illustrate fire spread and intensity under different ignition and weather scenarios. The collaborative group concluded that short term grove protection can be accomplished with traditional methods, but long term protection depends on landscape-scale ecosystem restoration; and since the groves are a part of the forest, if the forest is protected, so are the groves. The process used will serve as a prototype in developing options for fire protection, and for the broader goals of preservation and ecological restoration for other Sequoia National Forest giant sequoia groves.

Collaborative Stewardship

On his first day as Chief (January 6, 1997), Michael Dombeck sent a message to all Forest Service employees:

"We will care for the land and serve people by listening to all our constituents and by living within the limits of the land. I call this commitment to healthy ecosystems and working with people on the land collaborative stewardship.... Our task is not to dictate the course or the outcome (of debates on how National Forests should be managed). Rather, we need to be facilitators, the suppliers of knowledge and expertise, the educators and communicators who help people search for solutions."

To be effective, collaboration must occur long before any action is proposed. Traditional public involvement in the formal National Environmental Policy Act (NEPA, 1969) process, however, often begins with a proposal for action. Prompted by the Chief's message, the Sequoia

National Forest in California broke with tradition by initiating a pilot project designed to integrate public involvement into the planning process at the very beginning.

Enthusiastic public participation was assured when the Forest Service chose to start with a controversial subject: giant sequoia management (*Sequoiadendron giganteum* [Lindl.] Buchholz). The relationship between people and the big trees has been controversial ever since they gained public attention in 1852. The controversy began with the felling of the Calaveras Grove "discovery tree" in 1853. Subsequent logging elsewhere created a public outcry that led to acquisition of the Mariposa Grove by the State of California in 1864, and the establishment of Sequoia and Grant Grove National Parks in 1890. In this century the National Park Service created controversy with prescribed fires designed to reduce fuels that had accumulated as a result of fire suppression. The Forest Service intensified the controversy by logging in some of its groves. A Proclamation by President George Bush (Bush 1992) affirmed the public's goals to protect, preserve, and restore the groves, but did little to quell the ongoing debate on how these goals should be accomplished.

To keep the process manageable within a constrained time frame, the focus of the pilot project was narrowed to the single goal of grove protection. Because fire was a major agent of grove destruction as well as preservation, the focus was further narrowed to protection from fire. Candidate sites were limited to small, easily understood groves with simple topography and minimal ongoing public debate. Of several considered, Deer Creek Grove on the Hot Springs Ranger District was selected (fig. 1). The outermost trees in this grove are contained within an area of less than 50 acres, it lies within a single, small sub-watershed, and Deer Creek Grove has not been involved in recent logging or other controversial Forest Service actions.

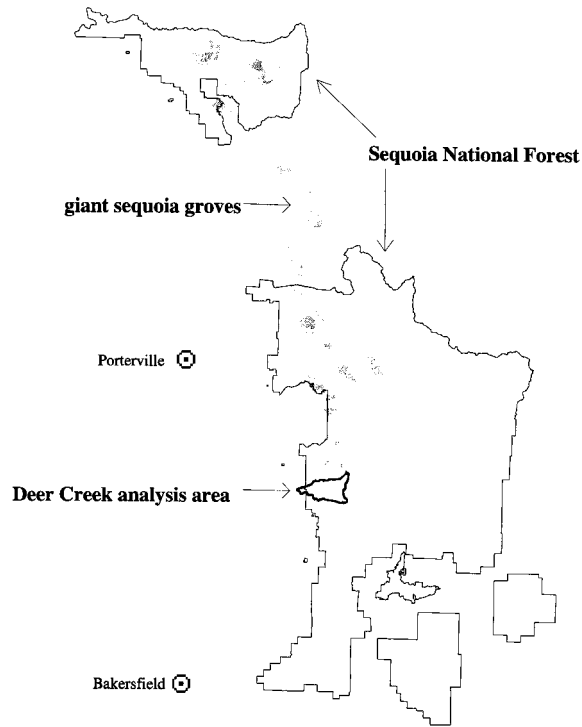


Fig. 1 -- The Deer Creek Grove on the Sequoia National Forest was selected for fire protection analysis.

Developing A Giant Sequoia Fire Protection Strategy

According to the Forest Plan implementation triangle (fig. 2) the "leftside" of the triangle was used as the framework for collaboration. The "leftside" analysis represents all the work that goes into planning before the NEPA process is initiated by an action proposal. It includes identifying management direction for a specific area, interpreting a desired condition from that direction, evaluating the existing condition, and developing possible management practices that could bring desired and existing conditions closer together if they are too widely separated. Any or all of the possible management practices then can become proposed actions that initiate the formal NEPA process. Public involvement on the "leftside" is not only valuable in formulating possible management practices, it also helps to anticipate and resolve issues that will be raised in the NEPA scoping process to follow.

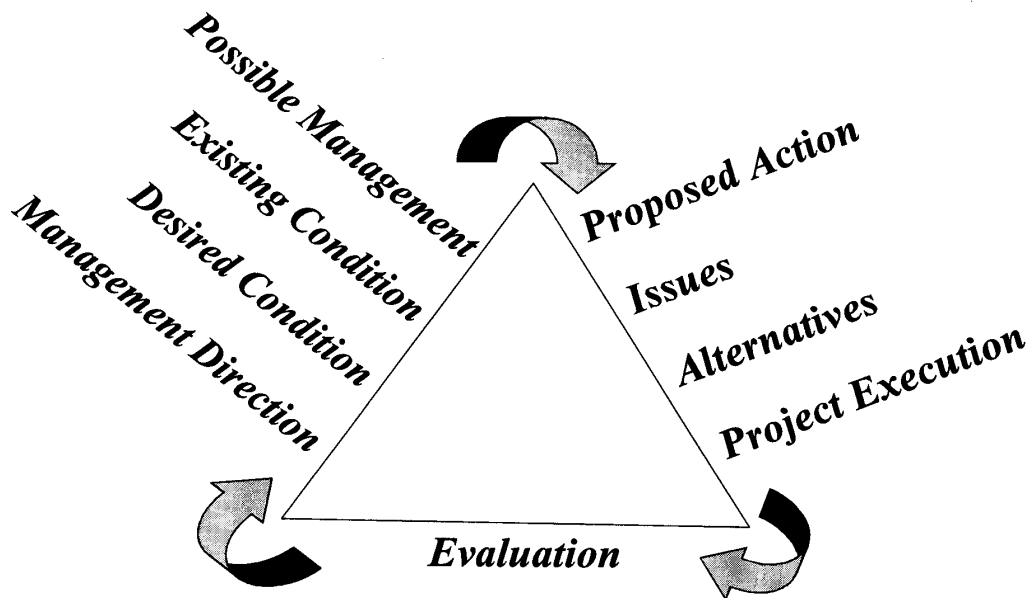


Fig. 2 -- The left side of the Forest Plan implementation triangle provided a framework for collaboration.

Because "leftside" analysis does not result in a management decision, public involvement procedures are not subject to NEPA and FACA (Federal Advisory Committee Act of 1972) regulations. Although all who wished to participate were welcome, invitations were sent only to those who were known to have a specific interest in the area chosen for analysis (e.g., local residents, timber industry, range permittees), or were already active participants on the subject of giant sequoia management (e.g., Sierra Club, Save-the-Redwoods League).

From Management Direction To Possible Management Practices

Management direction, the foundation of the "leftside" analysis rests, came from a variety of sources: the Forest Plan (USDA Forest Service 1988), a Mediated Settlement Agreement

(USDA Forest Service 1990), a Presidential Proclamation (Bush 1992), and the CASPO (California spotted owl) amendment to the Forest Plan (USDA Forest Service 1993). Management direction from these sources was compiled by the Forest Service and validated by a group of approximately 20 citizens who actively participated in the collaboration process.

The collaborative group then identified desired conditions that were important to the group and that were consistent with management direction. These conditions were described in simple statements such as:

- Fire protection features -- Fire protection features and fuel conditions provide adequate grove protection under most burning conditions.
- Ecological processes -- Ecological processes operate in a more or less natural way, especially within the grove area.
- Diversity -- The diversity in size, age, and species of the vegetation is sufficient to ensure long term sustainability and ecological resilience. Diversity in the grove area should mimic "natural" composition and structure.
- Fire prevention -- The Forest Service ensures that activities are conducted so that the chance of accidental fire is minimized and fire prevention education is available to and understood by forest users.
- Feasibility -- Planned grove protection activities are physically and financially feasible.
- Fire effects -- Fire-killed trees and charring on giant sequoias are considered by forest visitors as a natural part of the forest scene (when not of "catastrophic" proportions).
- Fire Suppression -- The fire suppression organization operates at the Most Efficient Level (MEL) as defined by the National Fire Management Analysis System (NFMAS).
- Fire Use -- Allow some unintentionally set fires to burn when beneficial effects are likely to outweigh non-beneficial ones.
- Grazing -- Full utilization of forage by grazing animals reduces fuel in and around the grove.
- Cooperation -- There is full cooperation on fire prevention and protection between the Forest Service, California Department of Forestry and Fire Protection (CDF), and private land owners.

Desired conditions dealing with recreation, wildlife, and other subjects were developed even though they did not deal with the objective of fire protection. This broader perspective is helpful because it reveals many of the concerns to be addressed later in the NEPA process.

After the Forest Service provided data, and conducted a field trip so that participants could understand existing conditions, the group focused on use of fire protection features and fuel management as a way to produce immediate and tangible results. The desired outcome was

described as keeping fires that do occur in the grove on the surface with a flame length less than 4 feet under most burning conditions. This allows direct suppression if necessary, and it allows most trees larger than 12 inches in diameter to survive; damage to most old-growth trees would be tolerable, and there should be only very occasional "torching" of the canopy. In addition, fuels of the forest floor (needle carpet and decomposing organic material at the soil surface) should burn with a duration and intensity such that the soil is not heated to extremes and basal girdling of larger trees is infrequent.

The District Fire Management Officer then was asked to develop a series of possible management practices designed to produce these outcomes under most burning conditions. He concluded that a logical approach was to design projects that would:

- Modify the existing fuelbreak so that it can be used as a prescribed fire control line in the short term, and a component of a broader defensible fuel profile zone strategy in the longer term.
- Connect the fuelbreak to other existing or planned fire protection features.
- Implement large scale fuel reduction by using prescribed fire, and mechanical, manual, or chemical methods.

This approach led to five different projects, covering approximately 1,300 acres, both within and adjacent to the grove (fig. 3). The projects all involve prescribed burning to reduce fuels, and various amounts of forest structure modification to influence fire behavior.

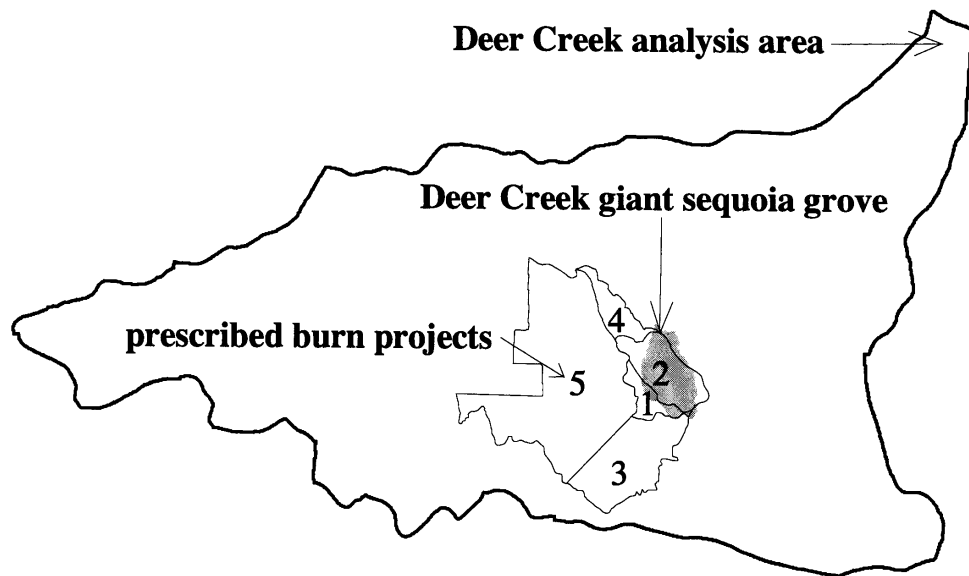


Fig. 3 -- Fuel reduction projects by means of prescribed burning were developed to provide protection for the Deer Creek Grove.

Validation with FARSITE Fire Simulation Model

The FARSITE fire simulation model (Finney and Ryan 1995) was run to evaluate the effectiveness of the possible treatments. The ignition point was chosen at a location where there is considerable ignition risk, and fire would spread up a southfacing slope with the prevailing wind and into the grove. Burning conditions were representative of a typical day in late September:

- temperature 98°F
- min. relative humidity 22 percent
- wind speed at eye level 7-8 mph
- 1-hour fuel moisture = 4 percent
- 10-hour fuel moisture = 5 percent
- 100-hour fuel moisture = 8 percent
- Live fuel moisture 72 percent

In the absence of suppression, and without any of the possible management practices in place, the fire advanced 1/2 mile upslope to the grove in just 1 hour (fig. 4). By this time it had spread to 44 acres. After 6 hours it had progressed downslope through approximately 70 percent of the grove, and had spread to a total of 2,500 acres. Fire spread through the grove was considerably slower than through the adjacent forest because the grove occupies a north aspect, the fire entered it from above, and the fuel types are different.

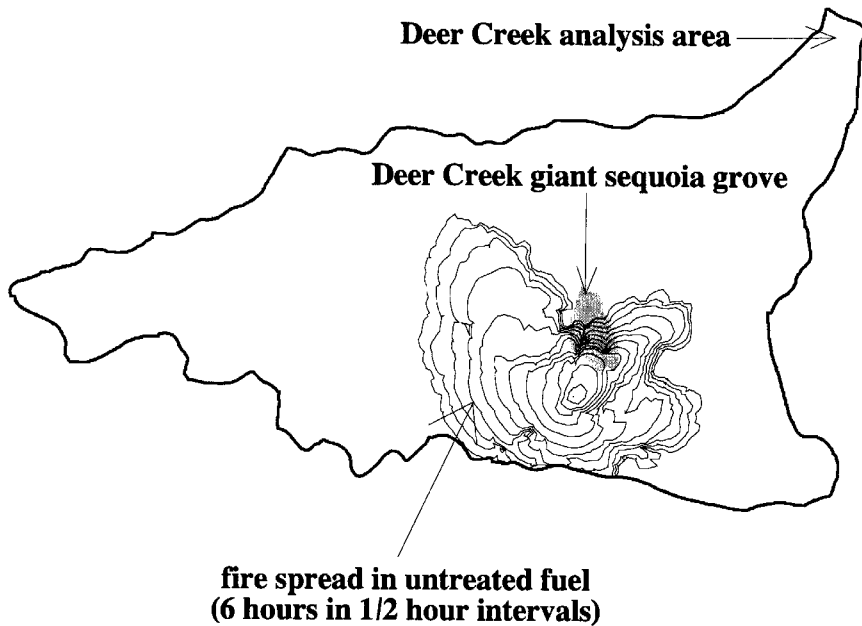


Fig. 4 -- Fire spread in untreated fuels.

With all five treatments in place (fig. 5), the fire reached the grove in approximately one and 1 1/2 hours, and progressed slowly through it. After 6 hours it had advanced through approximately 50 percent of the grove, and had spread to only 1,300 acres. There was a reduction in fire intensity within the grove itself.

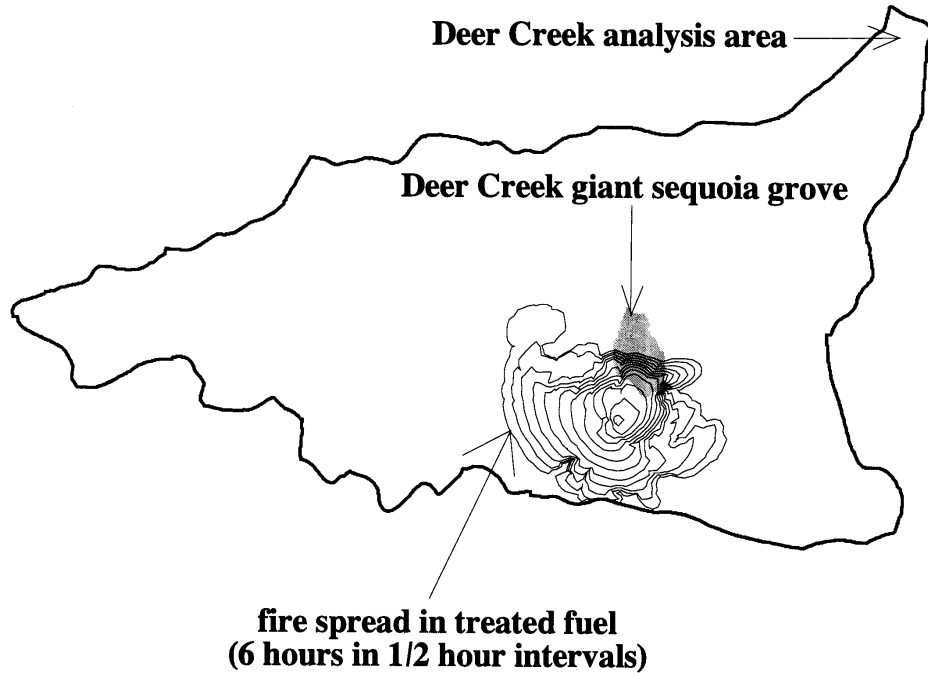


Fig. 5 -- Fire spread after fuels are treated by prescribed burning.

Experience with fires burning in similar fuel types and under similar burning conditions indicates that FARSITE reasonably predicts large scale fire behavior, both with and without fuel reducing treatments. However, the model is unable to deal with local anomalies (such as crown torching) that are expected in almost any fire, regardless of fuel and burning condition uniformity. This was the primary concern within the grove proper. Personal experience is still the best source of prediction at that level of detail.

Conclusions and Observations

The collaborative group worked toward a common goal by sharing responsibility. The Forest Service interpreted management direction and administrative rules, explained technical information, provided the leadership needed to stay on schedule, and encouraged personal interaction between individuals. Other participants offered opinions, expressed personal feelings, validated Forest Service interpretations, and offered interpretations of their own. The group worked in a mode of information sharing rather than consensus building.

The results of the collaborative effort showed that people will come together, work hard, value each other's opinions, and learn how to cooperate with each other on a common goal. But leadership is still needed to create the environment in which this can happen. In addition the

group was successful at turning possible management practices into proposals for action. Action always speaks louder than words.

Focusing on fire protection for a small, discrete portion of the forest leads naturally to larger landscape-scale protection for much of the surrounding area. If the forest is protected, so is the grove. Short term grove protection can probably be accomplished with traditional methods (prescribed burning, firefighting resources), but long term protection depends on landscape scale ecosystem restoration (Fullmer and others, 1996). The best protection in the long term is to maintain the grove, and its surroundings, in a condition so that natural processes (fire) can occur without catastrophic damage except under the most extreme burning conditions. This project is a first step in fulfilling the vision for giant sequoia management: "A learning community is created which serves to define when, where, and how the goals of protection, preservation, and restoration are implemented in giant sequoia groves. The community-of-interest implements the strategy it develops" (USDA Forest Service 1997).

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California's Urbanizing Wildlands and "The Fire of the Future"

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Abstract

In the early years of this century, the characteristics of two fire types - urban structure fires and wildland fires - began to hybridize due to the convergence of three unlikely factors: the cumulative impacts of artificially altered vegetation and fire regimes, the extension of municipal water systems beyond traditional city parameters, and the advent of the widely affordable family automobile. The resulting patterns of human settlement led to a new trend in destructive fires in which even relatively small and short-lived fires could overwhelm fire response capabilities and cause destruction of unprecedented magnitude. The worst conflagrations have occurred in areas where introduced tree species have increased fuel loadings in naturally fire-prone ecosystems. This paper presents recommendations for a new emphasis on fire loss prevention that is based on four non-traditional assumptions, and proposes a new fire paradigm with three strategies for its implementation.

Introduction

Interface fires, which combine characteristics of both urban structure fires and wildland fires, have become the fastest-growing source of fire value loss in North America. In California alone, more than half the homes lost to wildfire in the state's entire history have been destroyed since 1990. After the spectacular 1991 conflagration in the Oakland and Berkeley Hills, in which 2,500 homes burned to the ground in less than 12 hours, the news media seemed to discover the interface fire. Some went so far as to dub this fire "the fire of the future" (Cole et al., 1993).

Perhaps the best place to begin to understand the "fire of the future" is the most infamous day in American fire history: October 8, 1871. That was the day of the Great Chicago Fire, which began, as generations of American schoolchildren were taught, when Mrs. O'Leary's cow kicked over a lantern in the family barn. The fire raced through Chicago, then the fastest growing city in the nation. Before it was brought under control, 250 people lay dead and the city's core was wiped out. But few schoolchildren ever heard of another fire that occurred that same day, 300 miles to the north. The Great Peshtigo Fire, which started at virtually the same time as the Chicago Fire, was the most devastating wildfire in North American history. In a matter of hours this firestorm engulfed several hundred square miles - an area larger than the State of Delaware - and killed more than 1,200 residents of rural Wisconsin and Michigan.

The Great Chicago Fire has been historically known as an *urban structure fire*; Peshtigo was a *wildland fire*. In the early years of this century these two fire types began to hybridize, due to the convergence of three unlikely factors:

- Cumulative impacts of artificially altered vegetation and fire regimes.
- Extension of municipal water systems beyond traditional city parameters.
- Advent of the widely affordable family automobile.

The convergence of these three factors led to unprecedented patterns of human settlement in areas of increasingly unstable vegetation/fire complexes. The result was a new trend in destructive fires that manifested itself for the first time in Berkeley, California, on September 17, 1923. About noon that day, a grass fire began beneath high-tension lines in Wildcat Canyon just east of Berkeley. Pushed toward the city by hot, dry winds, the fire torched a grove of eucalyptus (*Eucalyptus globulus*) trees at the crest of a ridge, and sent a shower of burning leaves and bark onto the wood-shingle roofs of homes below (Biswell 1989). In less than 2 hours nearly 600 homes burned to the ground, a structure loss toll that would not be surpassed in the U.S. until 68 years later, when the remarkably similar 1991 Oakland-Berkeley Hills fire would burn four times as many homes to the ground just a few miles to the south.

This paper discusses the evolution of the urban-wildland interface during the 20th century, and the resulting increase in fires that are capable of totally overwhelming existing fire protection systems. The author proposes a shift from a traditional reactive wildfire paradigm to one that is proactive and emphasizes prefire management designed to minimize loss.

Origins of the Interface Fire Problem

As Charles Darwin wrote in *The Descent of Man*, "The discovery of fire is probably the greatest discovery ever made by man." Beyond a doubt, the domestication of fire about 400,000 years ago marks the moment that humans became the ecologically dominant species on earth (Gouldsblom 1992).

But as long as humans led nomadic existences as hunter-gatherers, they had much to gain and little to lose from fire. It was only when people began to come together and live in lasting settlements about 5,000 years ago that fire began to take on a socially threatening manifestation. Fire prevention and fire protection then became forms of community self-preservation. It might be argued that interface fires have existed as long as humans have built their habitations in close enough proximity to vegetation to allow fire to spread from one of these fuel sources to the other, across the *fire interface*, which was first defined by Butler (1976) as "any point where the fuel feeding a wildfire changes from natural (wildland) fuel to man-made (urban) fuel."

But the question might be asked, "why is the interface fire only now being labeled as a modern phenomenon - as the 'fire of the future'?" The answer lies in the alarming magnitude of recent interface fires, where they are occurring, their growing frequency, and the virtually instantaneous media coverage that has come to characterize major disasters.

California's "Synthetic Urban Forest"

The three most important environmental factors that determine wildfire behavior are weather, terrain, and fuel. The first two, while significant in every major California wildfire, have not changed appreciably in the past 150 years. On the other hand, fuel in the form of vegetation has changed dramatically in that time as a direct result of human activities.

Natural fire regimes have all but disappeared in California with the influx of more than 32 million people over the past 150 years. Certainly one reason for this has been our long-standing social attitude toward wildfire. By condemning all fire as bad and unwelcome, we have unwittingly allowed an unnatural and dangerous build-up of vegetation fuels to accumulate. Because the burning practices of indigenous Californians were eliminated during the 18th and 19th centuries, live and dead fuels have accumulated in many areas (Heady and Zinke 1978; Lewis 1973).

Perhaps the most important influence on vegetation fuels, however, has not been the subtraction of natural fire, but the addition of people and their vegetation to the naturally fire-prone ecosystems of California. On the surface, this may seem counterintuitive: conventional wisdom associates population growth with reduced vegetation cover. Usually when we think of urbanization encroaching into wildlands, we envision forest clearings, denuded hillsides, paved-over flatlands. But in fact California's population explosion over the past century has been accompanied by a huge *increase* in vegetation fuel loading in those areas where natural fire hazards are the greatest. The removal of natural fire played a major role in allowing fuel loads to increase over time. But the site-specific addition of water has also been a contributing factor.

The advent of municipal water delivery systems and the widely affordable family automobile changed forever the way our cities grew. The resulting suburbanization that began in earnest during the 1920's brought housing developments to previously uninhabited hillsides. This added unprecedented structural fuel loads and human ignition sources, and domestic water systems allowed the growth of unnatural urban forests in areas that previously sustained much lighter fuel loads. Stephen Pyne (1982) writes, "The transformation of grasslands, prairies, and savannas to forests is one of the most fundamental and widespread outcomes of European civilization." This is true on the steppes of Asia, the pampas plains of South America, and the savannas of Africa. But perhaps nowhere on earth has this vegetation change had as great an impact on fire hazards as in California's urbanizing wildlands, where fuel accumulations have reached unprecedented levels of conflagration potential due, in many areas, to urban forests of introduced, non-native trees planted concurrent with settlement.

Blue gum eucalyptus (*Eucalyptus globulus*) is of particular concern. No other species on earth contains as much volatile combustibility in a given area of land surface. Eucalyptus is estimated to have accounted for 70 percent of the total combustion energy produced by vegetation in the 1991 Oakland-Berkeley Hills fire (National Fire Protection Association), and fueled the 1923 Berkeley blaze, the 1970 Chatsworth fire in Los Angeles, and various other California interface fires.

The Most Explosive Ingredient: People

The thousands of homes lost to wildfire in the 1990's are stark reminders that fire is a dominant factor in the natural history of California. But the growing wildfire losses in California

may be due to demographics more than to the size or frequency of wildfires. Consider, for example, that 8 million people have been added to California's population in the past 20 years. That is a quarter of California's total population and more than the entire combined population of the States of Washington and Oregon.

Most of the new residential development resulting from this growth has been dispersed to California's residential "exurbs," a term used to describe "a suburb of a suburb, or a suburban-style community that is separated by open space from other metropolitan areas" (State of California 1991). This demographic shift to the exurbs means that increasing numbers of homes are being built in areas with some of the state's worst natural fire hazards. The interface fire problem is growing as fast as the population of the outlying areas of the Los Angeles Basin and San Diego County in the south and the inland San Francisco Bay Area exurbs in the north. The most explosive new potential for interface fires, however, may be along the entire length of the Sierra Nevada foothills and in the new extended metropolis of dozens of burgeoning regional centers like Redding, Santa Rosa, Santa Barbara, and Riverside. In many of these areas there is little land available for development that is *not* susceptible to wildfire.

Meanwhile, in the same period that California's population has grown by 8 million, fire department budgets have largely stagnated since property taxes were capped by the passage of Proposition 13 in 1978. California fire departments are hard-pressed to replace worn out engines and build new fire stations to keep pace with population growth and far-flung hillside development. And with the advent of telecommuting and advances in building technology, houses are being built in locations that would have been unthinkable a couple of decades ago.

By extending our metropolises into those areas at greatest risk to wildfire, and then adding our flammable building materials to the already-incendiary vegetation fuel load, we have ensured that even relatively small and short-lived fires can cause destruction of staggering magnitude. Unfortunately, the billion-dollar megafires of the past few years may be here to stay unless Californians adopt a new approach to addressing the state's fire problem in its urbanizing wildlands. The first step is to recognize that fire departments cannot solve the problem by themselves. If California's recent fire history has demonstrated anything, it is that even the most sophisticated fire departments can quickly become overwhelmed by wildland fire.

Overwhelming Fires

Only rarely do fires develop into uncontrollable firestorms. All fires, even huge conflagrations, begin from a point source such as a smoldering cigarette butt, a spark from a lawnmower, an arcing power line, or a bolt of lightning. But such point sources do not develop into wildfires unless an enormous number of coincidences of timing, weather, and fuel conditions occur. And fires, once ignited, rarely develop into problem fires because firefighters extinguish the vast majority of them while they are still small. Occasionally, however, a fire will resist these initial attack efforts. And when this happens, more often than not, it happens in wildlands that have become urbanized.

To understand why, it helps to look at how fire departments respond to fires. A typical urban fire originates in a structure. The responding fire department usually will operate with a stationary strategy due to the fixed nature of their water sources. In an urban fire, arriving firefighting resources will deploy in one geographical area. If the fire expands, more resources are requested to cover the additional exposures. Fire in vegetation, on the other hand, calls for a

wildland response, which is typified by a highly mobile strategy in which firefighting resources carry their own water or other retardant. On a wildland fire, if the primary control line fails, firefighters can fall back to a secondary line and exercise the option of "firing out" the intervening vegetation fuels.

Neither approach works well on interface fires, however, for two reasons. First, typically there aren't enough resources to cover all threatened exposures; and second, unprotected structures make it impossible to safely fire out vegetation fuels (Foote and Cole 1993). Furthermore, the situation can quickly deteriorate as wind-whipped firebrands generate exponential numbers of new point sources, igniting numerous structures simultaneously, sometimes for hours on end, while hundreds of fleeing residents clog the only roads that provide access to burning structures. Such scenarios have happened somewhere in California nearly every year since 1990. In every case, responding firefighters became hopelessly overwhelmed: they didn't have a fighting chance until residents were evacuated and winds let up.

Loss Reduction

The trend in interface fire losses in California indicates that traditional fire mitigation measures are not adequate. Perhaps what is needed is a new way of thinking about California's wildfire problem, and maybe more important, a new way of talking about it to the public. To begin to craft more successful strategies than in the past, we may need to develop a new wildfire paradigm—one that incorporates the lessons of past failures. A good place to start may be to revise Smokey's message from one of fire prevention to one of fire loss reduction.

The fire service's traditional emphasis on wildfire prevention is a recipe for failure. Every time a wildfire makes the news due to property loss or injury, the implicit message is that the fire department failed to prevent the fire. As long as that is the public perception, the fire service is going to be stuck in a reactive paradigm. And with the growing risk of interface fire in California, it is becoming true of more and more fires that by the time fire departments react, it may already be too late. Those who allow themselves to get stuck in the reactive paradigm exemplified by Smokey's admonition that "Only you can prevent wildfires" may find themselves increasingly tainted with failure.

What is needed is a shift from the traditional reactive wildfire paradigm to one that is proactive and emphasizes prefire management designed to minimize loss. For this message to be realistic and meaningful, it should be delivered in a context of at least four assumptions that are not widely understood, and may be somewhat controversial.

Vegetation Fires are Inevitable

It is simply not possible to prevent all fires in California ecosystems, many of which were fire-dependent even before we added 32 million people to the native population. Wind-driven vegetation fires are as natural to California as hurricanes are to Florida and tornadoes to Kansas. They cannot be prevented any more than it is possible to prevent wind or rain. Instead of obsessing on preventing these fires, we would do better to focus on the more realistic objective of removing ourselves from harm's way.

Life and Property Will Likely be Exposed to Fire

California has the most effective initial attack wildland firefighting system ever devised. But in the path of a wildfire in which many structures are threatened, residents are likely to be on their own when it matters most—during that exceedingly short window of time when any firefighting can be effective. Why? Because such fires move unpredictably and more rapidly than fire engines, and because roads become choked with fleeing residents. When dozens of homes are burning simultaneously in hilly terrain, the reality is there are many more emergencies than responders.

Some Structures are not Worth the Risk

The controversial issue of “structural triage” has huge implications for homeowners and insurers, but the fact remains that the biggest mansion in Malibu is not worth a single firefighter’s life. California has the world’s most experienced wildland firefighters, and they know that homes lacking defensible space are no place to be in a conflagration. There may be dozens of homes threatened for each firefighter responding to an interface fire; it is imperative that they be able to concentrate their efforts only where they can work safely, and only on homes that have a reasonable chance of surviving.

Government Alone Cannot Solve the Problem

Fire and land management agencies need to do a better job of promoting the message that mitigating the interface fire problem is a shared responsibility. Those who profit from and enjoy the amenities of building and living in California’s urbanizing wildlands must be willing to take primary responsibility for mitigating the fire hazard that “comes with the territory.” Not only interface residents, but also land use planners and developers, insurance companies, realtors, and lenders must be partners in developing proactive solutions and mitigations.

Three Strategies for a New Fire Paradigm

Traditional fire prevention and suppression tactics have proven inadequate for preventing the “fire of the future.” What may be needed is nothing less than a transformation in the institutional arrangements that have allowed fire hazards in our urbanizing wildlands to build to explosive levels. As long as the institutions that plan, finance, and provide insurance for development in urbanizing wildlands continue practices that allow, and sometimes even subsidize, vulnerable residential development in areas subject to predictable and avoidable fire hazards, Californians will face the increasing prospect of overwhelming wildfires.

Unfortunately, the public does not appreciate fire departments’ limitations in responding to such fires. Although government cannot mitigate the hazard alone, it can take the lead in promoting at least three major strategies.

Minimizing the Potential for Fuel Coupling

At the interface, two distinct and non-compatible fire environments meet: the structure (most commonly a house) where fire must be controlled at all times; and the wildland, where fire

occurs naturally (Butler 1976). Minimizing the potential for fires to burn from one of these environments to the other has been the essence of interface fire mitigation for at least 75 years. After the 1923 Berkeley Fire, for example, the National Board of Fire Underwriters (1923) recognized the hazards posed by wood shake roofs and siding, and while they didn't use current fire safe terminology, they certainly recognized the importance of mitigating the fuels on the urban side of the interface. Similar admonitions can be found in every after-action report following every interface structure-loss disaster, and yet planners, lenders, and insurers continue to tolerate construction practices that are not resistant to wildfire. Likewise, it is no revelation that vegetation fuels on the wildland side of the interface must be mitigated to minimize fuel coupling between man-made and vegetation fuels. In many urbanizing areas the focus needs to be on reducing unnaturally high fuel loads caused by introduced pyrophytes. Defensible space needs to be viewed not only as a zone from which firefighters can defend life and property, but as the interface resident's first, and perhaps only, line of defense against advancing wildfire.

Establishing a Standardized Community Prefire Planning Process

Wildfire hazards must first be identified and mapped so that mitigation projects can be developed and prioritized. Because mitigation projects will be competing for limited implementation funds, it is important that a standardized process be used to evaluate hazards and propose the most appropriate and cost effective mitigations. The full spectrum of the affected community must be engaged in the process: the private as well as the public sector, and most important, citizens and residents. Such stakeholder involvement can be facilitated through the use of geographic information systems (GIS) using integrated databases, high-speed portable workstations, and large screen displays so that alternatives and questions can be explored immediately in group settings (Cornett 1994).

Building Powerful Guiding Coalitions

None of these strategies will be accomplished without effective leadership. But the interface fire problem does not occur in a single jurisdiction, nor is it the responsibility of a single entity (such as government). It is a social problem that requires a multi-entity approach. For such a multi-entity model to work, however, strong leadership coalitions and unprecedented partnerships will be required. This leadership must be representative of all the major affected entities: private citizens, fire service and land management agencies, land use planners, developers, insurance providers, lenders, public utilities, and others.

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An Ecological Comparison of Fire and Fire Surrogates for Reducing Wildfire Hazard and Improving Forest Health: A Research Proposal

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Abstract

Current coniferous forests in many areas of California and elsewhere in the western U.S. are denser and more spatially uniform, have more small trees and fewer large trees, and have greater quantities of fuel than their presettlement counterparts. Widespread treatments are needed to restore ecological integrity and reduce the high risk of destructive, uncharacteristically severe fires in these forests. Among possible treatments, however, the appropriate balance among cuttings, mechanical fuel treatments, and prescribed fire is often unclear. For improved decision making, resource managers need much better information about the consequences of alternative management practices involving fire and mechanical/manual “fire surrogates.” Land managers and researchers, working collaboratively, need to design and implement long-term interdisciplinary studies to quantify those consequences. We propose here the outline of such a design. Suggested treatments are: (1) untreated control; (2) prescribed fire only, with periodic reburns; (3) initial cutting, followed by prescribed fire; only fire used periodically thereafter; (4) initial and periodic cutting, each time followed by prescribed fire; fire alone also could be used one or more times between cutting intervals; and (5) initial and periodic cutting, each time followed by residue removal and/or mechanical fuel treatment; no use of prescribed fire. Non-control treatments would be guided by one or two desired future conditions. Treatments should be replicated at least 3 times at a research site. Each treatment plot should be at least 25 to 35 acres in size. A number of disciplines should be involved to study a wide variety of responses to the treatments. Results related to treatment costs and implementability, and short-term ecological effects, should be available relatively quickly. However, many answers would come only from longer-term research. Discussions have been initiated with potential management partners concerning possibilities for conducting such studies in the southern Sierra Nevada, the southern Cascades/northern Sierra Nevada, and the Klamath Mountains. Additional study areas are desirable.

Introduction

Current coniferous forests in many areas of California and other parts of the west are denser and more spatially uniform, have more small trees and fewer large trees, and have greater quantities of forest fuels than their presettlement counterparts (Bonnicksen and Stone 1982, Chang 1996, Parker 1984, Parsons and DeBenedetti 1979, Weatherspoon and Skinner 1996). Causes include fire exclusion, past grazing and timber harvests, and changes in climate (Skinner

and Chang 1996). The results include a general deterioration in ecosystem integrity and sustainability and a considerably increased probability of large, high-severity wildfires. These conditions are prevalent in short-interval fire-adapted forest ecosystems throughout much of the western United States (Agee 1993, Mutch and Cook 1996). The report of the Sierra Nevada Ecosystem Project (SNEP) highlighted these problems and explained the need for large-scale and strategically-located thinning (especially of small trees), fuel treatment, and use of prescribed fire (SNEP 1996, Weatherspoon and Skinner 1996). Testimony before the California State Legislature (Skinner 1997) emphasized these problems to State lawmakers. A recent speech by Interior Secretary Babbitt (1997) pointed out that similar problems and the need for similar solutions are now being acknowledged nationally by high-level policymakers.

The need for large increases in the use of restorative management practices is clear (e.g., Hardy and Arno 1996). Less clear, however, is the appropriate balance among cuttings, mechanical fuel treatments, and prescribed fire (SNEP 1996, Weatherspoon 1996). Economics and practicability in light of current stand and landscape conditions are important considerations. However, to restore and maintain forest ecosystem integrity, we also need to understand more about the ecological consequences and tradeoffs of alternative management practices. The frequent, low - to moderate - severity fires that characterized presettlement disturbance regimes in most of our forests (Skinner and Chang 1996) affected not only overall forest structure, composition, and fuel levels, but also a wide range of other ecosystem components and processes (Chang 1996). What components or processes are changed or lost, and with what effects, if fire "surrogates" such as cuttings and mechanical fuel treatments are used instead of fire, or in combination with fire? Currently, information necessary to answer such key questions is largely anecdotal or absent.

Land managers, researchers, and other interested parties, working collaboratively, need to design and implement long-term research to learn the consequences of producing and maintaining one or more desired stand conditions using (1) cuttings and mechanical fuel treatments alone (i.e., without fire), (2) fire alone (via multiple prescribed burns), and (3) combinations of cuttings, mechanical fuel treatments, and prescribed fire. Untreated controls would also be necessary. Only in this way will it be possible to determine which ecosystem functions of fire can be emulated satisfactorily by other means, which may be irreplaceable, and the implications for management.

Discussions have been initiated with potential management partners and other stakeholders concerning possibilities for conducting such research in the southern Sierra Nevada, the southern Cascades/northern Sierra Nevada, and the Klamath Mountains. The level of interest has been high. We believe that the subject of the proposed study outlined in this paper is of sufficient importance and wide applicability to warrant a regional or west-wide study with a number of installations and a common design. This design, to which our proposal might contribute, could greatly enhance development of broadly applicable models of ecosystem responses to fire and fire surrogate treatments.

Objectives

The proposed research should address three broad objectives:

1. Assess the ecological consequences of alternative fire and fire surrogate treatments for improving forest health and reducing wildfire hazard in mixed-conifer and other short-interval fire-adapted coniferous forests.
2. Within the first 5 years of the study, collect baseline data, carry out cutting/mechanical and prescribed fire treatments, document short-term responses to treatments, and report results.
3. Over the life of the study, conduct interdisciplinary research to quantify a wide spectrum of ecosystem responses to specified management treatments (including appropriate controls), develop and validate models of ecosystem structure and function, develop and successively refine recommendations for ecosystem management in relevant forested areas, and report results.

Research Approach

Management activities in forested ecosystems usually manifest themselves most directly through (1) changes in vegetation structure and/or composition, (2) disturbances to soil, forest floor, and woody residues, and (3) the spatial and temporal distributions of these items. These changes result in a wide array of effects on other ecosystem components and processes, including soil biota, nutrient cycling, wildlife communities, and watershed properties. Various combinations of manipulative activities—cutting trees or other vegetation, using prescribed fire, and mechanically treating residues or scarifying the soil—will therefore comprise the experimental treatments in the proposed research. Treatment combinations will include those that address widely-shared concerns about forest health and wildfire hazard -- e.g., thinning and fuel treatment; those that deal with environmental concerns; and those most operationally practical. Consistent with the long-term focus of the study, treatments will be repeated periodically to represent real management approaches.

The basic study design outlined in the following sections is a good place to begin. However, this basic design may need to be modified to fit the particular forests chosen for study and to meet the needs and interests of the participants and other anticipated stakeholders in the most useful way.

Fire/Fire-Surrogate Treatments

The following suite of five fire/fire-surrogate (FFS) treatments is proposed:

1. Untreated control.
2. Use of prescribed fire only, with periodic reburns.
3. Initial cutting, followed by prescribed fire; only fire used periodically thereafter.
4. Initial and periodic cutting (at intervals appropriate to the forest type and site -- e.g., 20 years), each time followed by prescribed fire; fire alone also could be used one or more times between cutting intervals.
5. Initial and periodic cutting (at the same intervals as in 4), each time followed by residue removal and/or mechanical fuel treatment; no use of prescribed fire.

These five treatments should span a useful range both in terms of realistic management options and anticipated ecological effects. FFS treatment 3, the treatment with perhaps the least obvious management utility, is intended to expedite achievement of desired stand (tree-based) structure and composition, using a single initial cutting, in an area in which restoration and maintenance of natural processes (including use of prescribed fire) are emphasized.

After initial prescribed burns in FFS treatments 2, 3, and 4, subsequent burns will be conducted at irregular intervals, with times determined by the best available information on distribution of presettlement fire intervals on the kinds of sites represented in the study. It seems likely that important elements of ecosystem diversity were promoted historically by natural variability in fire intervals (Agee 1993, Skinner and Chang 1996).

Desired Future Conditions

The non-control FFS treatments (treatments 2 through 5) would be guided by one or two desired future conditions (DFCs) or target stand conditions. Table 1 shows the overall design for one versus two DFCs, with each "3" indicating three replications (for example) of a given treatment combination. The nature of the FFS cuttings and prescribed burns might differ considerably between two different DFCs. If this proposal becomes part of the basis for a regional or west-wide study, significant advantages could accrue from adopting one DFC for implementation at all study installations (at least for a given forest type). A second DFC then could be designed to be responsive to more localized considerations, such as forest and site conditions, management objectives, and public desires.

We recommend considering for DFC #1 a stand condition characterized by a mosaic of small even-aged groups or patches. Silvicultural cuttings that would best lead toward this condition would be small group (1/4 to 2 acres) selection along with thinning in the "matrix" of other age classes between the group regeneration cuttings. Six to 10 age classes covering a group rotation length of 200 to 300 years could be considered. For purposes of the proposed study, some benefits of this DFC and associated silvicultural method include:

1. Best silvicultural approximation of general structural effects of dominant presettlement fire regime (frequent low - to moderate - severity fires) (Weatherspoon 1996) applicable to forests addressed in this proposal.
2. Development and maintenance of a continuous and substantial large-tree component throughout the treated stands
3. Improvement of forest health and reduction of wildfire hazard by reducing stand density, increasing height to live crown, and developing a stand structure characterized more by horizontal separation of size classes and less by multiple vertical canopy layers. (Treatment of surface fuels, which will be a component of each non-control treatment, is a key part of fire hazard reduction.)
4. Opportunity to measure response variables within a wide range of age classes (seral stages) at any given time.

Table 1. Fire/fire-surrogate treatment matrix for three (3) replications of one or two desired future conditions (DFCs).

		FFS#1	FFS#2	FFS#3	FFS#4	FFS#5
1 DFC	DFC#1	3	3	3	3	3
	DFC#2					
2 DFCs	DFC#1		3	3	3	3
	DFC#2	3				3

A possibility for DFC #2 might be a two-storied stand that also would maintain large trees throughout the stand, would allow for regeneration of shade-intolerant tree species, and would be approximated silviculturally using retention shelterwood cuttings (Weatherspoon 1996). Another alternative is to have DFCs #1 and #2 be generally similar in stand structure but differ significantly in stand density.

Given the same starting point of stand and fuel conditions, moving toward different DFCs using FFS treatment 2 (fire only) clearly will be a much less precise process than silvicultural cuttings and will require a number of burns. Some desired changes in stand structure—e.g., “thinning” relatively large trees without doing excessive damage to the overall stand—may not be feasible. However, skilled and innovative use of prescriptions, firing techniques, and other methods such as stage burning should, over several successive burns, permit considerable progress toward DFCs using prescribed fire alone.

Other Considerations

Assuming three replications of each treatment (probably in a randomized block design), this design would result in 15 treatment plots if one DFC is used, and 27 plots if two DFCs are used ([table 1](#)). To accommodate inherent spatial variability in the DFCs and allow for repeated entries, each plot probably needs to be at least 25 to 35 acres in size. This plot size would be adequate for relatively localized response variables such as vegetation, soil, and some fire and fuel attributes. It also should be satisfactory for measuring responses of smaller-ranging animal species. In contrast, wider-ranging wildlife species, fisheries and other watershed-level responses, and other landscape-level concerns could be studied at this scale only indirectly -- e.g., via habitat attributes and modeling approaches. It may be desirable in some locations to augment these relatively small, replicated plots with a subset of key treatments implemented on a much larger scale and in an adaptive management-type mode in collaboration with land managers. These large treatment areas could provide useful information concerning operational-scale economics and some indications about larger-scale ecosystem responses (especially if linked to the smaller plots via appropriate models).

In order for results to be broadly applicable within the forest types studied, treatment plots generally should be located in widely-distributed stand conditions, which usually will be characterized by previous timber harvests. In some cases, however, it may be desirable to include late-successional forests as part of the study. Participants would need to discuss the most appropriate locations of the experimental blocks in terms of more specific current stand conditions, aspects, slope classes, slope position (including whether to extend treatments into riparian zones), and other site conditions.

The proposed research is designed to be open-ended in terms of scientific disciplines and associated response variables that can be accommodated. Clearly, the greater the number and diversity of investigators involved, the greater the range of questions related to ecosystem structure and function that can be addressed, and the greater the opportunities for interdisciplinary synergy. Desired cooperating disciplines include, but are not limited to, entomology, fire ecology, forest genetics, geography, microbiology, micrometeorology, plant ecology, plant pathology, silviculture, soil science, and wildlife biology. To the extent possible, baseline or pretreatment data for each discipline should be collected. The design of the study, however, permits new research to be initiated after treatments are in place - even several years thereafter - and still yield valid results.

A significant component of the study necessarily will involve identifying and testing appropriate response variables or measures to assess important differences between fire and fire surrogate treatments. These measures then could form much of the basis for management monitoring of operational treatments to improve forest health and reduce wildfire hazard.

Spatiotemporal analyses of data at various scales, along with exploration of cross-disciplinary relationships, will be enabled and encouraged by several attributes of the study: relatively large plot sizes, spatial referencing of all data to a grid of permanent sample points to be established in each treatment plot, acquisition of high-resolution digital orthophotography of the study area, and incorporation of all data into a GIS-based data base.

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The National Park Service Fire Effects Monitoring Program in California – Lessons Learned Over the Last Eight Years

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Abstract

The National Park Service developed a Fire Monitoring Handbook, which contains a standardized protocol for the monitoring and documentation of prescribed fire behavior and effects. The handbook provides a formal system that: documents burning conditions and fire behavior; insures that fires remain within prescribed ranges; verifies completion of burn objectives; and follows long-term trends. This information can help managers in the refinement of prescriptions when they do not achieve their objectives or undesirable trends occur, and to identify research needs.

This paper focuses on the lessons learned, and the resultant changes to this monitoring program. We hope that these lessons will help managers who intend to establish, or currently manage a prescribed fire monitoring program.

Introduction

One can find a myriad of reasons to monitor the effects of prescribed fire, whether they be legal, moral, or driven by agency policy. In addition, monitoring of any management activity is a pivotal part of the adaptive management process (Rolling 1978; Ringold, et al. 1996). A monitoring program also allows you to share your good work with the public and other agencies. All managers should not be asking if they should monitor, but can they afford not to monitor?

Program Goals

The goals of our program are to: record basic information for all fires; document immediate post-fire effects of prescribed burns; share information between land managers; follow trends in plant communities where fire research has been conducted, and identify future research needs.

Program Structure

The National Park Service developed a Fire Monitoring Handbook, which contains a standardized protocol for the monitoring and documentation of prescribed fire behavior and effects. The handbook defines levels of monitoring activity, which relate to fire management objectives and strategies. At each successive level, monitoring is more extensive and complex.

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The first level covers reporting basic information for all fires. The next level calls for monitoring of short-term effects, and the final level consists of monitoring long-term change. The levels are cumulative; requirements include all levels below the highest specified. In California, we require monitoring at all levels for prescribed burns. The handbook describes monitoring procedures and required frequencies for each level.

The first level provides a basic overview of the fire event, and is essential to all types of fire. It includes: data on ambient conditions, and fire and smoke characteristics. We use these data to predict fire behavior and to identify potential problems.

The second level requires collecting information on fuel reduction and/or vegetative change within one to two years after a fire. This permits a quantitative evaluation of whether management achieved a stated objective such as to reduce dead and downed fuels by 60 percent or to remove 95 percent of the invading shrubs from a grassland.

The third level involves collecting information on trends, or change over time, in a managed ecosystem. Once a manager detects an unexpected and/or undesirable trend, they can establish a research program and/or provide an appropriate management response. An example of where this type of monitoring would have helped is in the effects of the National Park Service's total fire suppression policy until 1968. Park Service management did not formally recognize unknown and undesired effects for about 90 years, and only after considerable and often irreversible damage had been done. If a systematic process of monitoring and evaluation had been present during this time, the full suppression period may have been short-lived. Current fire management strategies also have potential to cause undesired change. Consequently, land managers should strongly consider long-term change monitoring for all types of fire management strategies, including fire suppression.

There are three types of plots or transects used. The variables for each type of plot are cumulative. Grassland transects monitor the following vegetative variables: frequency relative cover, and burn severity. Brush plots include the above plus: brush density by species and by age. Forest plots include the above plus: tree density, tree diameter, dead and downed fuels, scorch height, and crown scorch. This represents the recommended amount of monitoring for all parks within California. Many parks have chosen to monitor additional variables. We monitor all of our plots preburn, during the burn, immediately postburn, 1 year, 2 years, 5 years, 10 years, and 20 years after the burn unless the area is reburned.

We have divided the workload for this program in California amongst four regional teams. We have two mobile crews that rove between small and medium sized parks. The other two crews work solely within the two largest parks in California.

How Did We Get Here?

A Prescribed and Natural Fire Monitoring Task Force developed the Fire Monitoring Handbook in 1989. This task force consisted of resource management specialists and park scientists with a fire background. In 1989, the Western Region of the National Park Service published the first edition of the handbook, and established several pilot programs (NPS 1989). In 1990, we required all parks in the region with a prescribed fire program to have a fire monitoring program. We have continued to revise and update the handbook with field participation and peer review (NPS 1991a & 1992). We look forward to another revision in the Spring of 1998.

Lessons Learned

We will use some of the lessons learned that I am sharing here in our next revision of our manual. Some of the lessons that we have learned relate to how we work with the people that actually collect the data. I think this is especially important when you are making several return visits to your plots.

Program Recommendations

This section relates to recommendations that concern the creation and management of a large scale monitoring program, though all land managers can probably find some useful information here.

Try to provide a career ladder and other incentives for people to stick with their job for at least several years. To that end we have created a career path that can take an employee from a basic seasonal data collector to a permanent team leader. From the team leader position, the employee is then able to choose from a wide variety of career choices. Following this change we noted a higher level of data quality.

Provide quality training to all the people that are performing these tasks. We have created three training courses in association with this program. Classes exist to teach: how to read plots; how to monitor fire behavior and weather; and how to set up and manage a monitoring program. Establish an oversight committee. We created a committee that represents all the regions in the country where the National Park Service uses prescribed fire. We also included a wide range of job responsibilities from resource and fire managers, to researchers. This committee serves as a clearinghouse for all major programmatic decisions, and serves as the final layer of quality control.

Create an area-wide position. My position acts as a conduit for all data, data quality management, and procedural questions; facilitates training, and shares ideas and problems with users throughout the area. This greatly enhances quality control, and maintains long-term consistency as this position provides a connection for monitors, managers and their replacements.

Establish monitoring teams whose sole focus is monitoring. We created several monitoring teams, who establish and monitor all the plots for a group of parks. When we initially established the monitoring program, some of the monitors had many collateral duties. If these monitors were part of a fire organization, monitoring became the lowest priority whenever a wildfire or prescribed natural fire occurred. The present situation fosters monitoring specialists, increases the ability for an area-wide manager to monitor quality control, and increases standardization among parks.

Our California teams are set up as follows, the two roving teams are: the Northern California team that does all the monitoring for: Lassen Volcanic National Park, Lava Beds National Monument, Redwood National Park, and Whiskeytown National Recreation Area; and the Central and Southern California team that covers: Channel Islands National Park, Golden Gate National Recreation Area, Joshua Tree National Park, Lake Mead National Recreation Area, Pinnacles National Monument, Point Reyes National Seashore, and Santa Monica National Recreation Area. The two large park crews are stationed at Yosemite National Park and Sequoia & Kings Canyon National Parks.

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We consult all monitors and managers working with this program for their input into every revision of the Fire Monitoring Handbook. This process involves people at all levels of the program, which maintains a certain investment in the program as a whole.

Create an annual monitoring report. With or without a change in personnel, we have found it beneficial for monitors and managers to record the following: what the monitors did that year, next year's anticipated workload, what mistakes they made, changes that were necessary, suggestions for improvements in methods, initial data analyses (which also serves as an additional data quality check), interpretation of those analyses, management implications of potential results, and management's reaction to those results.

One vital link in any successful monitoring program is excellent communication between resource & fire managers & researchers. Where communication is poor or non-existent the monitoring program suffers. We address this by trying to insure that managers work together in designing, managing, and analyzing the data from the monitoring program. In addition by staying in touch with others that are doing similar work, so that we can share others' lessons method modifications, and insights, e.g., this paper.

Software Recommendations

Data management is a critical portion of any monitoring program. Sound data quality procedures are the key to insuring that managers have high quality data. When working with data one must collect, transfer, and store these data accurately, and keep it secure from loss or damage.

We enter all of our data into IBM compatible personal computers using the Fire Monitoring Handbook software—FMH.EXE. The data entry and analysis program uses dBASE database files, but is a stand alone package that does not require any other software to run other than DOS. The software program is available on a single 360K diskette. A software manual (NPS 1991b) is available as a companion document to the handbook

Design a software program that is user-friendly. We designed the data entry screens to mimic standard data sheets. The addition of pull down menus, specific help, and extensive error checking makes FMH.EXE powerful and easy for computer novices to use. After we enter the data, analysis routines calculate all the minimum variables, and some additional variables. For further analyses, software users can export these data to any statistical package that can use dBASE files.

We have tried to stay current with all of our software users by developing software that is compatible with the operating system that the majority of users use. For example, we will not lean too heavily on the power of the Internet, or Windows-based operating systems until the majority of our users have committed to these systems.

The programmer should have one person who is very familiar with current protocols and monitor use patterns to assist with program design. Both people should also have a modicum of understanding of each other's field of expertise to facilitate communication. This way the software package becomes something that is usable to users with a broad range of computer experience.

We have created a handbook that is user friendly for both the manager and the field technician. Having a handbook allows people to build and manage a standardized monitoring program, or provides them with a reference so that they can create a program from scratch.

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We allow room to change protocols, with a mind's eye on the value of retaining certain things for data consistency. We realized that an overlap of methodology calibrates between the new and the old data.

We address manual ambiguities, by having the editor interface with a broad range of users, in a broad range of vegetation types. This past year we canvassed some 60 users (amateur & veteran, student & professor). We took their comments to our committee, who decided how to respond to these comments.

A key here is that not all monitoring protocols are driven by the handbook. They come from measurable fire management objectives. When the handbook does not have the suitable protocol to match an objective we can supplement the protocols. After all, the handbook only provides a recommended minimum level of monitoring, which does not cover every possible management need. An example of additional monitoring might include wildlife monitoring, or a specific methodology for monitoring annual plant species.

We allow for multiple scales of observation, but still require fixed plot sizes. We now allow managers to have plots of any size, and to some extent shape, to compensate for the varying spatial distributions of tree, shrub and herb species.

A goal is to get as many people as possible to use the same method, so as to maximize the amount of compatible data. Every national park in California uses this methodology. A total of forty-eight parks within the National Park Service have established fire monitoring programs based on the fire monitoring handbook. Several others have expressed interest, and are seeking funding.

Monitoring programs based on the fire monitoring handbook have been established in several Fish and Wildlife refuges in Iowa, Minnesota, New Jersey, New Mexico, Texas, Wisconsin, and Florida; US Forest Service areas in California, Illinois, Michigan, Minnesota, Vermont, and Washington; many Texas State parks; a few California State parks; and Department of Natural Resources areas in Minnesota and Missouri. The Bureau of Indian Affairs supports a growing program and provides training support.

We realized that we needed to stress to monitors that the time of year is not as important as the phenology of the plot, which can change from year to year, due to many factors such as drought.

Although we have very clear hindsight, our advice would be to consider all aspects of your monitoring program, from the initial phases to how managers will use the data and analyses try to think of everything up front.

We permanently mark our plots, and make them very easy to relocate. This is a critical element of any long-term monitoring program. We GPS our plot locations whenever possible and provide additional data in case a monitor cannot use a GPS device for some reason.

Another goal is to make sure that you collect the highest quality information the first time. This comes down to providing standardized training and higher high quality people from the very beginning. This is very important because all future data collection and analysis rest upon the quality of data from the initial plot establishment. We found that we had low data quality and high plot quantity in the initial phase of our program. After review this data, we decided to remove several of the initial plots.

Lastly, even though the average fire return interval for most fires in California is more than ten years, we found that programmatically we needed to address fire frequency. We have made certain adjustments to our datasheets and to the software to make it easier to track the long-term effects of the fire regime created by fire management, not just an initial burn.

Statistical Considerations

Setting clear, measurable objectives is an extremely critical step for a monitoring program (Hellawell 1991; Schroeder and Keller 1990). Many of our fire programs have objectives that are vague and unmeasurable. If we want to use monitoring to measure success, we must measure our results against a measurable goal or standard. Objectives must specify a standard, desired state, threshold value, or trend, relative to one or more of the components within the plant association being burned. The objective must also specify where and by when the manager hopes to meet this objective.

Managers must make some additional decisions when they compare measurements between the same place over two or more time periods. When a manager analyzes his monitoring results, the most critical type of statistical errors they can make is to miss an actual change that occurred due management practices (TNC, 1996). This is critical, because failing to respond when a true change actually occurred may lead to serious management problems, e.g., increases in non-native plant populations. Statistical power is the complement of this type of error. Thus, it is very important for managers to set power levels for all of their critical variables that they monitor.

We also realized the importance of the relationship between statistical power and the size of the change that you want to be able to detect. Managers must decide how large of a change will be biologically meaningful. Deciding what amount of change is biologically meaningful is difficult for many reasons. However, managers can change this amount once monitoring information demonstrates the size and rate of population fluctuations. We began to address both of these issues by changing the way we calculate our minimum sample size.

We choose to abandon stratified random sampling in favor of restricted random sampling. We made this decision because when using stratified random sampling there are often areas left unsampled, or areas where we installed plots close together (spatial autocorrelation).

Summary

Even though our needs differ throughout the State we can all benefit by sharing the lessons that we learn. One way that we share our experiences is by sharing data. I certainly do not propose that all land management agencies in California use the National Park Service monitoring program, because all the information that we require may or may not be beneficial for every agency. I propose that we all work towards a common ground of information. Lastly, I hope that managers from other agencies would consider the lessons from this paper. Managers can then apply these to any monitoring endeavors that their agency will support.

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The QLG Defensible Fuelbreak Strategy

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Abstract

According to the Quincy Library Group (QLG), very large areas of National Forest land urgently need fuel treatment, but neither the scale and pace nor current methods have any chance of meeting that need. The brush disposal (BD) program has failed to treat large accumulations of activity fuels, and natural fuel treatment (NFT) is insufficient in scale to address the 70-year buildup of fuels resulting from fire suppression policies, and it is overly dependent on prescribed fire. As originally proposed, the QLG Defensible Fuelbreak Strategy had three elements: (1) An initial 4 years of very high priority; (2) Fuel treatment in strips approximately 1/4-mile wide that included a road; and (3) Such treatment at a rate of 50,000 acres per year in the QLG area. Four years would be sufficient to establish a network of fuelbreaks that would enclose untreated areas of about 10,000 acres each. After the first 4 years, treatment would continue, but shift to area treatments within the enclosures. As represented in the “QLG Bill” (HR-858, S-1028), the fuelbreaks are called “defensible fuel profile zones,” the treatment rate is 40 to 60 thousand acres per year, and the initial term is 5 years. The QLG fuelbreak strategy is not separate from other fuel management; it is simply the first stage of whatever fuel treatment program is done. If that fuel treatment program is adequate, fuelbreaks are the logical first step. If that treatment program is not adequate, the fuelbreaks won't make it so, but they would still be the logical way to initiate even a partial fuel reduction effort.

Strategy Development

The Quincy Library Group Community Stability Proposal of 1993 suggested three ecosystem management strategies for immediate implementation on National Forest (NF) land in the Quincy Library Group (QLG) area (Lassen NF, Plumas NF, and Sierraville Ranger District of the Tahoe NF): (1) Silviculture based on group selection and individual tree selection; (2) Fire and fuels objectives recommended in The California Spotted Owl: A Technical Assessment of its Current Status (CASPO Report); and (3) Riparian habitat and watershed restoration. Recognizing that strategies (1) and (3) could not be achieved and sustained without success in strategy (2), QLG put considerable effort into developing a fuel reduction program that would give both quick progress and long term effectiveness against the threat of large, high intensity wildfire.

According to the Quincy Library Group (QLG), the central problem was that very large areas of National Forest land urgently needed fuel treatment, but neither the scale and pace nor current methods have any chance of meeting that need. For various reasons the Forest Service brush disposal (BD) program has failed to treat large accumulations of activity fuels, and natural fuel treatment (NFT) is insufficient in scale to address the 70-year buildup of fuels resulting from

fire suppression policies, and it is overly dependent on prescribed fire, which could not safely be used in the areas most needing fuel reduction treatment.

In the QLG area, at least 1.5 million acres needed fuel reduction treatment. At the recent rate of less than 10,000 acres per year, one treatment cycle would take more than 150 years. On the other hand, it wasn't feasible to treat the whole area in as little as 10 years. A compromise rate, 30 years of treatment at 50,000 acres per year, was considered both feasible and adequate. But the adequacy of a 30-year treatment cycle is conditional: it depends on using a pattern of treatment that will protect not only the acres treated, but provide significant early protection to the areas not yet treated.

As a result of this analysis, QLG developed its Defensible Fuelbreak Strategy in 1994. This strategy had three elements: (1) An initial four years of very high priority; (2) Fuel treatment in strips approximately 1/4-mile wide that included a road; and (3) Such treatment at a rate of 50,000 acres per year. Four years would be sufficient to establish a network of fuelbreaks that would enclose untreated areas of about 10,000 acres each. After the first 4 years, treatment would continue at the same rate, but shift to area treatments within the enclosures. As represented in the "QLG Bill" (HR-858, S-1028), the fuelbreaks were called defensible fuel profile zones (DFPZs), the treatment rate was 40 to 60 thousand acres per year, and the initial term was 5 years.

The initial suggestion of quarter mile width was intended to provide a treated area wide enough to bring a crown fire to ground, to reduce the intensity of ground fire so that safe and effective defense is feasible, and to permit retention of some clumping and other characteristics felt necessary for wildlife and other considerations. An included road (or its functional equivalent) would provide rapid access, efficient operating space, and safe retreat if necessary. The fuelbreak concept and the quarter mile width have been evaluated, and to some extent validated, by modeling that was reported in the Sierra Nevada Ecosystem Project (SNEP) Report.

According to the SNEP report, in computer simulations of fire effects with and without fuelbreaks,

“...the DFPZs reduce the extent of [severe] fire by up to 1/3 over fifty years.”
(Johnson and others 1997).

Another section of the SNEP report analyzes alternative strategies for fuel reduction. Goal 1: Reduce substantially the area and average size burned by large high-severity wildfires. Multiple benefits of DFPZs may include: (1) reducing severity of wildfires within treated areas, (2) providing broad zones within which firefighters can conduct suppression operations more safely and more efficiently, (3) effectively breaking up the continuity of hazardous fuels across a landscape, (4) providing “anchor” lines to facilitate subsequent areawide fuel treatments, and (5) providing various nonfire benefits. We are aware of no other strategy with as great a potential in the short term to progress reasonably rapidly toward achieving goal 1. (Weatherspoon and Skinner 1996)

Reply to Objections

Two objections have been raised regarding the QLG Defensible Fuelbreak Strategy. First, because it is untested its effectiveness is unknown. QLG's reply is that the QLG Bill will provide that test. It would establish fuelbreaks on a large enough scale that actual field tests of fuelbreak effectiveness would be expected to occur several times within the first decade.

Second, it is claimed the fuelbreaks would require specialized maintenance. QLG's reply is that fuelbreaks are not expected to be much different from the desired future condition of most of the forest. Except for removing snags and hazard trees along the road for fire-fighter safety, the fuelbreaks would be thinned to meet the forest-wide CASPO fire and fuel objectives. In any case, the same maintenance would be required of any thinned area in the forest, in order to sustain its fire resistance and fire resilience. As the initial fuelbreak construction and area fuel reductions proceed, increased use of prescribed fire for treatment and maintenance is feasible and should be used. The fuelbreak strategy is not separate from other fuel management; it is simply the first stage of a comprehensive fuel treatment program. If a fuel treatment program is adequate, fuelbreaks are the logical first step. If a treatment program is not adequate, then fuelbreaks won't make it so, but they would still be the logical way to initiate even a partial fuel reduction effort.

Further Analysis

The Quincy Library Group was instrumental in securing funding for a study known as the Technical Fuels Report (TFR) (USDA Forest Service 1995). QLG views the TFR as a good first step, but it is not a complete interdisciplinary analysis of the defensible fuelbreak concept, nor does it provide the prescriptions and authority needed for full implementation of the fuelbreak network. One provision of the QLG Bill would require the National Forests in the QLG area to provide an Environmental Impact Statement (EIS) on the QLG pilot project, and this EIS is expected to build on the TFR and establish a solid foundation for fuelbreak implementation in the QLG area. Until an EIS or equivalent process is complete for the area to be treated, QLG strongly cautions against using the Technical Fuels Report beyond its proper scope. It is preliminary information, not authority for implementation.

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Effects of Prescribed Fire on Live Trees and Snags in Eastside Pine Forests in California

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Abstract

Snags are important to forests because they contribute to the development, maintenance, and productivity of soils and provide habitat for an array of life forms. Historically, fire has played an important role in shaping the composition and structure of many forests in the western United States and fire is now being reintroduced to restore the natural process. However, the effect of fire on the snag resource is not well known and responses may differ depending on the length of time between fires. Preliminary data from two fires in eastside pine forests, burning after a long fire-free interval, suggest that fire-killed trees deteriorate at faster rates than trees dying from other causes and fires remove many of the existing snags. Of 14 trees dying after a prescribed burn in 1990, eight lost large portions of their tops by 1997. In an unburned plot, only six of 21 trees dying in that period lost large portions of their tops. Eight trees on the burned plot lost more than 10 percent of their bark, whereas none of the trees on the unburned plot lost even 10 percent of their bark. In an area burned in 1995, 39 of 71 snags survived the burn but some were heavily scorched or incurred other damage from the fire. These results suggest that fire may have a great effect on the characteristics and numbers of snags in eastside pine forests. However, additional studies are necessary to determine if these results are typical of a more frequent fire regimes.

Introduction

Standing dead trees (snags) are an important component of a functioning forest as they contribute nutrients to the soil, provide habitat for a variety of fungi, and provide habitat and food sources for a myriad of invertebrate and vertebrate species (Balda 1975, Laudenslayer 1997, Maser and others 1988). The number of snags in a forest varies spatially and temporally as a consequence of diverse patterns of snag creation and loss. Creation of new snags depends on spatial and temporal patterns of the agents that cause tree mortality including insects, disease and fire. Spatial and temporal patterns of snag loss and rates of deterioration are also important characteristics of snags and may be related to the cause of tree mortality as well as tree species, size (diameter), soil characteristics, and topographic location.

Although much research has been devoted to gaining a better understanding of the value of snags to forest wildlife, especially birds, little research has been done to evaluate the characteristics and deterioration rates of snags created by different mortality agents. Fire, which historically has played an important role in a functioning forest, may be an important cause of tree mortality and snag loss. The lack of knowledge about the effects of fire on trees and snags is of concern because fire is now being reintroduced into forests after long fire-free periods (e.g., Agee 1993; Kilgore 1973a, 1973b; Kilgore and Briggs 1982; Skinner and Chang 1996). This

paper provides preliminary results on the effects of prescribed fire, such as tree mortality, deterioration of trees dying after the fire, as well as snag persistence after a long period without fire.

Materials and Methods

The study area is located just north of Butte Lake in Lassen Volcanic National Park, Lassen County, California. Topography of the study area is variable and includes relatively flat areas interspersed with short, steep slopes. The forest is dominated by yellow pines (*Pinus ponderosa* and *P. jeffreyi*) with smaller numbers of white fir (*Abies concolor*), red fir (*A. magnifica*), lodgepole pine (*P. contorta*), and incense cedar (*Calocedrus decurrens*). Mean basal area approximates 26 sq. m/ha with much of the basal area present in trees with diameters at breast height (dbh) greater than 80 cm. Few grasses, forbs, shrubs, or sapling trees are present and the soil is covered by 10 to 25 cm of volcanic ash. Thickness of the forest floor (organic material deposited on the mineral soil) surrounding trees is quite variable with thickness generally increasing with tree diameter. For trees with diameters greater than 80 cm, litter depth adjacent to the trees varies from 9 cm to 38 cm and litter depth 1 m away from the trees varies from 5 cm to 21 cm.

In 1988, two 500 m long by 100 m wide study plots were randomly located in the eastside pine forest north of Butte Lake. On each plot, all existing dead trees were mapped, individually marked, and dbh, heights, percent of bark remaining, number of nesting cavities, were measured. Each year since 1988 as part of an ongoing study, all existing snags were examined to determine if they had changed substantially (e.g., lost height, bark, limbs, or added new nest cavities) and all new snags were mapped and measured.

Prescribed burning is being conducted in Lassen Volcanic National Park to reduce the fuel loading. In late June 1990, one ha of one plot was prescribed burned and in September 1995, the remaining four ha were burned. The other, parallel plot, was not prescribed burned.

Yellow pines dying between June 1990 and summer 1994 on the portion of the plot burned in 1990 and the entire unburned plot were selected to compare deterioration rates. Criteria to determine tree death were conservative: foliage had to be at least fading before a tree was judged as dead. Trees dying after 1994 were not included in the deterioration study because death was probably not directly related to the consequences of fire and there was insufficient time to evaluate deterioration. Deterioration characteristics (measured by loss of tree height) and loss of bark of all snags from time of death through 1997 on both plots were compared. Deteriorated trees were those losing at least 10 percent of their bole, whereas trees losing less than 10 percent of their bole were considered intact. Trees losing bark were grouped into trees losing more than 10 percent and trees losing less than 10 percent. Because all of the trees dying after fire had a diameter greater than 46 cm, only snags in the unburned plot with diameters greater than 46 cm were compared.

The condition of all yellow pine snags existing on the unburned section of the plot was evaluated after the September 1995 prescribed fire. Trees were classified as intact (not substantially affected by the fire), charred (snag relatively intact but light scorching to deep charring), and consumed (most or all of the snag consumed by the fire). Responses of snags to the prescribed fire were further described using the amount of bark remaining on the snag (< or > 50 percent) and the diameter of the snag (< or > 60 cm).

Results

Mortality and Deterioration

After the June 1990 prescribed fire, all 14 yellow pines >46 cm in diameter in the 1 ha burned plot died between 1992 and 1994. In the 5 ha unburned plot, 21 yellow pines >46 cm died between 1991 and 1994 (table 1).

Table 1. Time for loss of tops (>10 percent) to occur in yellow pine snags by death year cohorts on a 1 ha plot burned in 1990 and a 5 ha unburned plot in an eastside pine forest, Lassen Volcanic National Park.

Plots	No. Snags			No. Deteriorated snags					
	Year	Cohort	Intact	1992	1993	1994	1995	1996	1997
Burned (1 ha)	1991	0	0	0	0	0	0	0	0
	1992	3	2	0	0	0	0	1	0
	1993	9	3	0	0	0	3	2	1
	1994	2	1	0	0	0	0	1	0
Unburned (5 ha)	1991	1	0	0	1	0	0	0	0
	1992	0	0	0	0	0	0	0	0
	1993	8	4	0	0	0	2	2	0
	1994	12	11	0	0	0	0	1	0

Trees dying after the 1990 burn deteriorated more quickly than those on the unburned plot dying from agents not directly related to fire (e.g., bark beetles). Large cracks often developed in the wood and more than half of the trees in the burned plot lost large portions of their tops, whereas about one-third of the trees in the unburned plot lost large portions of their tops by 1997 (fig. 1). On both plots, it took approximately 2 years after death for snags to begin losing their tops (table 1). Bark on all snags in the burned plot loosened quickly, but little fell from the snags until the 1997 assessment by which time large portions of bark had sloughed off of eight of the trees (fig. 1).

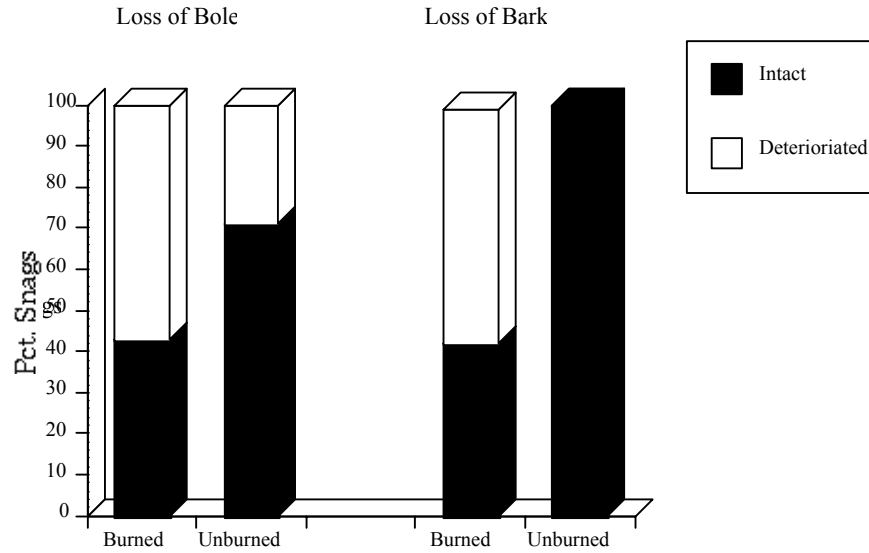


Figure 1. Loss of tops of boles and bark by 1997 in yellow pine snags (intact <10 percent loss; deteriorated >10 percent loss) with diameters >46 cm dying between 1990 and 1994 on a 1 ha plot burned in 1990 and a 5 ha unburned plot in an eastside pine forest, Lassen Volcanic National Park.

Loss of Existing Snags

After the 1995 fire, snags generally survived relatively intact or were mostly or completely consumed (fig. 2). Fifty-nine percent of the 71 snags on the 1995 burned plot (4 ha) were either scorched or charred (10 snags) or largely or completely burned (32 snags). More than half of the snags with <50 percent bark survived the fire relatively intact, whereas less than 40 percent of the snags with >50 percent bark survived the fire relatively intact.

Effects of Prescribed Fire on Existing Snag:

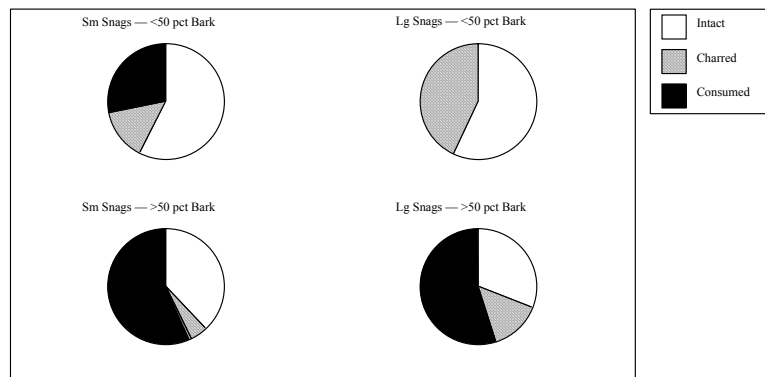


Figure 2. Response of existing yellow pine snags to prescribed fire on a 4 ha plot burned in 1995 in an eastside pine forest, Lassen Volcanic National Park. Snags are grouped by the diameters of the snags (sm. snags are <60 cm and lg. snags are >60 cm in diameter) and by the amount of bark on the snag before the fire (< or > 50 percent). Intact snags were not substantially affected by the fire, charred snags incurred light scorching to deep charring, and consumed snags were mostly consumed by the fire.

Discussion

Mortality and Deterioration

All of the large diameter trees (>46 cm diameter) within the area burned in June 1990 died within 4 years. Mortality of these large diameter trees was incomplete in other areas of the burn. Mortality of smaller diameter trees (<46 cm diameter) also was incomplete. The portion of the study area where the mortality of the large diameter trees was complete was on a relatively short, steep slope which probably contributed to the high death rate.

Tree mortality after fire is often delayed from 2 to 5 years (Swezy and Agee 1991), which is reflected in this study. The first death of a large tree was detected 2 years after the burn, with the majority of the mortality occurring 3 years after the fire. All 14 of the trees with diameters >46 cm on the plot had died by 1994 -- within 5 years of the burn.

Tree mortality after fire varies greatly depending on variables such as bark thickness, fuel loadings, fire temperature, and length of time maximum temperatures persist (Ryan 1990, Sackett and Haase 1996). After prescribed fires in Idaho, Montana, Oregon, and Washington, tree mortality ranged from 0 to 97 percent and mortality varied among the tree species examined. Mortality ranged from 87 percent for western hemlock (*Tsuga heterophylla*) and Englemann spruce (*Picea engelmannii*) to 15 percent for western larch (*Larix occidentalis*), with mortality for Douglas fir (*Pseudotsuga menziesii*), western red cedar (*Thuja plicata*), lodgepole pine (*Pinus contorta*), and subalpine fir (*Abies lasiocarpa*) falling between those extreme values (Reinhardt and Ryan 1989, Ryan and Reinhardt 1988).

Mortality of trees also varies with the time of the fire. Swezy and Agee (1991) conclude that mortality of old ponderosa pine trees in their study area was as much as three times higher from early season burns in June (37.6 percent) and July (31.6 percent) compared with mortality from burns later in the season in September (12.0 percent).

Rates of Deterioration

Rates of deterioration of trees dying after fire have not been well studied. Kimmey (1955) has summarized the general pattern of deterioration. In the third year after fire, smaller diameter (as high as 30 cm in diameter) fire-killed ponderosa and Jeffrey pines begin to break up at a variety of heights. In the fourth and fifth years, tops of additional trees including large trees begin to break out and some entire trees come down. Dahms (1949) indicates that by 10 years after a fire, more than half of the ponderosa pine snags were down and after 22 years, 78 percent had fallen.

In a paper on fall rates of fire-killed ponderosa pines, Harrington (1996) reported that trees began to fall 3 years after the burn and 60-70 percent of the trees fell within 7 years of the fire. A fallen tree in Harrington's study is one where a maximum of 0.3 m stub remained after falling. In the results of this study, none of the trees fell as in Harrington's study; a substantial amount of bole remained of even the shortest stub (about 5 m). The time since the burn for the top to break away from the first tree was 5 years, substantially longer than Harrington showed. These differences may be attributable to environmental characteristics of the study areas (southwestern Colorado versus northern California), tree diameters (ranging from small to large versus >46 cm in diameter), and tree species (ponderosa pine versus ponderosa and Jeffrey pine).

Bark beetle-killed ponderosa pines also start falling shortly after death, starting in the first year. Keen (1955) found that the rate of fall in the first 5 years after death was relatively slow but accelerated rapidly between the 5th and 15th years; soil characteristics and tree diameter both influence falling rates. In contrast to Harrington's (1996) study, by 7 years after death, Keen (1955) found 50-60 percent of the trees had fallen, less than the 60-70 percent recorded by Harrington (1996) in 7 years after the fire. Because there is often a lag time between the timing of the fire and tree death, the disparity between Keen's and Harrington's results is probably higher.

Loss of Existing Snags

Loss of existing snags to a prescribed fire in a southern Arizona ponderosa pine forest was influenced greatly by snag diameter. More than half of the snags >50 cm in diameter (56 percent) were consumed by the fire and 51 percent of the snags between 30 and 50 cm (Horton and Mannan 1988). The results for this study are quite similar to the Arizona results, despite the differences in diameters classified as small versus large snags; 44 percent of the snags >60 cm in diameter and 46 percent of the snags <60 cm in diameter were consumed by the fire.

Implications

Deterioration of yellow pines dying after a fire appears to occur at a faster rate than those killed by other causes and the characteristics of the decaying snags may differ. Further, after a fire, many of the existing snags have been consumed and new snags created. These patterns suggest that the snag environment in a forest with fire may differ substantially from a forest without fire. Different decay agents may be active and the resulting snags may provide a different suite of habitat characteristics to species who depend on snags for foraging, cover, and reproduction. The large loss of snags to prescribed fire suggests that a fire affected landscape would have few snags than one without fire. If fires are relatively frequent, the snag resource may be dominated by relatively young, presumable hard snags. These results are from forests without fires for long periods; the responses of snags under a more frequent fire regime may be quite different. These conclusions should be considered as hypotheses to be tested in future experiments, and additional study of the relationships of fire to tree mortality, decay, and snag demise is necessary to better understand the role of fire in forests.

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The Use of Prescribed Fire in Wetland Restoration at Mono Lake Tufa State Reserve

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Abstract

Experimental burns were established to begin the process of fire cycle restoration. The restoration of natural fire cycles in the wetlands of Mono Lake in California is expected to create open freshwater ponds that are preferred by many waterfowl taxa. The time of year when the burn is conducted affects the wildlife value of the burned area. Research in other wetlands of the Great Basin Ecological Province indicates autumn and winter burns are preferable to other seasons. Burn plots were delineated in two separate compartments lake-fringing wetlands at Simon Springs. The autumn burn areas totaled approximately 12 acres. The lake edge plot was burned on November 7, 1995, and inland plot was burned on November 8. Both compartments contained similar semiterrestrial (wetland) and terrestrial environments. Deeper ponds contained cattail (*Typha*) dominated communities; shallower ponds contained sedge (*Juncus*) and bulrush (*Scirpus*) communities. Some sedge and saltgrass communities were found in terrestrial environments. All these communities were closed in structure, except desert saltgrass (*Distichlis spicata* (L.) Greene), which was open to closed canopy as a function of soil moisture. Rabbit brush (*Chrysothamnus nauseosus* (Pallas) Britton) open scrub/open desert saltgrass association dominated tufa ridges. A second experimental burn was conducted on February 13, 1997, on an adjacent lake infringing wetlands dominated by cattails. Even though much of this burn was conducted over ice, emergent cattails burned quite well. However, sedges and rushes burned in a mosaic pattern. Open water areas were also created where vegetation was consumed. These areas are expected to remain open for longer periods than open areas created by the autumn burn. The burns were conducted within prescription; however, since wind conditions were at the low end of prescription, the fire did not carry as well as expected and strip burning was necessary. Cattail burned with high intensity, with flame lengths up to 3 m and produced near-black smoke. The plants burned off at, or within a few centimeters above, water level. Bulrushes did not burn well; they smoldered or did not burn at all. Higher winds may have produced better ignition. Sedges generally burned with fair intensity, with up to 1 m flame height. Desert saltgrass burned with low intensity, but with complete ignitions where stands were closed. Open stands of saltgrass did not burn. Rabbit brush flamed up with high intensity. When in close proximity to tufa towers, 6 m flame heights were not uncommon, and the high heat scorched the towers and glazed the outer surface with a blackened, glass-like coating.

Introduction

Ten years, to the day, after the Mono Lake National Scenic Area was established, on September 28, 1994, the California State Water Resources Control Board (SWRCB) ruled in favor of the Public Trust Doctrine and against further extraction of water from the Mono Basin in California. Until such time that the lake level reaches 6,392 ft. average elevation, water cannot be exported from the basin by Los Angeles Department of Water and Power (LADWP). This landmark decision was based upon a 16-year battle by environmental groups and a lengthy environmental review process that included 43 days of hearings by the Board. In the SWRCB's "Mono Lake Basin Water Right Decision 1631," LADWP is ordered to submit a waterfowl habitat restoration plan with recommendations on waterfowl habitat restoration measures and describing how any restored waterfowl areas will be managed on an ongoing basis. The plan was to focus on restoration measures in lake-fringing wetland areas.

To accomplish the planning and implementation phases of ecosystem restoration, LADWP established the Mono Lake Waterfowl Habitat Restoration Technical Advisory Group (TAG). The TAG participated in the choosing of consultants to write the plan, provided technical support and direction to the consultants, reviewed the plan, and helped implement actions called for in the plan. The TAG was made up of representatives of Federal, State, and local agencies, as well as The Mono Lake Committee, Caltrout, and the Audubon Society. LADWP presented plans to the SWRCB on November 1, 1995.

The TAG held several meetings over the year. The group consensus was that restoring the natural role of fire in the wetlands will enhance its value for seasonal waterfowl use. The use of prescribed burns in lake-fringing wetlands is likely to be the most natural way to enhance these systems for waterfowl use. Much of the otherwise open fresh water is clogged with debris from dead herbaceous vegetation.

This paper discusses the experimental burn project implemented by the California Department of Parks and Recreation (DPR) to help answer questions about timing and frequency of fire necessary to meet wetland ecosystem restoration objectives; the project is based on recommendations of the TAG and scientists hired by the LADWP to study the waterfowl.

Study Area

The area of the experimental burns is near Simon's Springs where 15 percent of the waterfowl in the Mono Basin historically occurred. At the 1940 "point of reference," the area consisted of 496 acres of marsh, 2 acres of wet meadow, 200 acres of alkali meadow, 3 acres of wetland scrub, and 164 acres of dry meadow edaphotopes. The experimental burn site includes small examples of most vegetation formation types associated with lake fringing wetlands. The 80-acre test site is within the relicted lands of Mono Lake Tufa State Reserve.

Simon Springs are on the southeastern shoreline of Mono Lake, located immediately west of the Simon Springs Fault at a point just south of the north boundary of Section 7, T1N R28E. The project site is along the fault rift from the 1995 lake level to around 6,390 ft (all below the 1940 natural lake level of 6,417 ft).

Implementation of Mandates at Mono Lake Tufa State Reserve

Ecosystem management in state reserves is to be directed toward the preservation of native ecological associations (Section 5019.65 of the California Public Resource Code). Such associations include all living things, in a dynamic balance that occurred before the Eurasian invasion of California. California Indians such as the Kuzedika modified the basin landscape primarily by the use of fire. Thus, ecosystem management objectives in Mono Lake Tufa State Reserve try to mimic Kuzedika modifications of their environment. DPR is mandated to preserve or restore the natural ecological balance that has been maintained for thousands of years during the Holocene epoch (last 10,000 years) of modern climatic regimes.

Stine (1996) has found that around 1650 A.D. Mono Lake attained a high level at 6,423 ft elevation; then cool, dryer conditions lowered the lake level to 6,394 ft by 1860. Relatively warm, wet conditions have characterized the last 145 years. Before 1860, terrestrial and wetland ecosystems were subject to frequent fire under natural conditions in the Basin. With the current climatic conditions becoming more like the "medieval warm period" which peaked around 1200 A.D., ecosystem management should be directed toward what would have evolved under current climatic conditions, without Eurasian influence, rather than toward what was present at Eurasian contact.

The Natural Role of Fire in the Mono Lake Basin

Lightning ignitions tend to be more prevalent at higher elevations on the west side of Mono Basin. Lightning-set fires are more common in the summer; they usually creep down from the higher elevations of the Sierra Nevada. Under natural conditions lightning fires are generally confined to areas between major streams. One lightning fire occurred in the early 1980's about a mile southwest of Simon Spring and it burned about 1,000 acres of sagebrush scrub.

Fire was one of the earliest human tools. California Indians used fire in a multitude of plant communities. The post-glacial California vegetation has evolved under a frequent fire regime that included both lightning and human ignitions. Restoration of natural fire cycles is best determined by studying fire scars and analyzing ash layers in soil profiles and sediments. Historical accounts are also researched.

According to Schumacher (1969), evidence of human occupation of the Mono Basin/Owens Valley area dates back to between 10,000 and 20,000 B.P. A human migration occurred from the east and northeast during this time frame. Lake Lahontan, a deep freshwater lake covering 8,000 square miles was present until about 10,000 years ago. It was surrounded by glacier-covered mountain peaks and the lake had numerous tule marshes. The lakeshore and fishery supported Paleo American Indian populations. About 7,000 years ago the climate began to changed to a dryer and warmer regime. During ancient mesic to dry times, the Pinto people occupied the western Great Basin region. It is believed that these people left the region when the climate became arid about 5,000 years ago. Archeological evidence, including petroglyphs and stone points and blades, indicate that the Basin has been occupied for at least 5,500 years (Fletcher 1987).

For the last 3,000 years the Paiute have occupied the region. The Mono Lake Paiute occupied the Mono Basin area, and the Owens River Paiute lived primarily in the Lower Owens

River area. To the west of the Basin lived the Sierra Miwok. The Mono Lake Paiute or Kuzedika practiced what has been termed a "desert culture strategy," which depended upon flexibility of movement for most of the year, with groups congregating only during winter. The family was the primary settlement unit. The Kuzedika were limited by their environment; population was restricted by the occasional years of scarcity and famine, possibly not more than 200 lived in the basin at Eurasian contact.

During the spring and early summer, the Kuzedika lived along streams draining from the Sierra Nevada. There, they gathered seeds, berries, bulbs, and grasses, and hunted for game. The east slope of the Sierra Nevada provided wild onions, lily bulbs and mule deer. Throughout late spring and summer, meadows and sagebrush shrub savanna provided seeds of a variety of bunchgrasses including ashy wild rye (*Leymus cinereus* (Scribner & Merr.) A. Love), Indian ricegrass (*Achnatherum hymenoides* (Roemer & Schultes) Barkworth), western wheatgrass (*Pascopyrum smithii* (Rydb.) A. Love) and desert needlegrass (*Achnatherum speciosum* (Trin. & Rupr.) Barkworth) (Hickman 1993). When summer came, insects were collected. Alkali fly larvae (*Ephydra riparia* Fallen.) dislodged by wind driven waves frequently formed extensive windrows of larva around portions of the Mono Lake shoreline. The protein-rich insect resources were so important to the Mono Lake Paiute that they called themselves Kuzedika, which means "fly larvae eaters." Other Paiute groups and the Washoe to the north often joined them in the harvest. Another major food source was Pandora moth larvae (*Coloradia pandora* Blake), which were collected from stands of Jeffrey pine (*Pinus jeffreyi* Frev. & Balf.). These were collected in alternate years beginning in early July. Other insect foods included ant eggs, crickets and the larvae of wasps and bees. Groups of men climbed high into the Sierra to hunt mule deer and bighorn sheep. Berries and fruits such as desert peach (*Prunus andersonii* A.Gray), Mexican elderberry (*Sambucus mexicana* C. Presl), and buffalo berry (*Shepherdia argentea* Nutt.) were collected. In late summer and early autumn the Kuzedika held rabbit drives around the lake flats. The drives required the participation of many people, some to hold the long nets into which the rabbits were driven, others to light fires in the sagebrush scrub, which forced the rabbits into the nets. In a similar, way pronghorn were also driven into extensive fences.

In the autumn, pine nuts were collected, mainly from singleleaf pinyon pine (*Pinus monophylla* Torrey & Fremont). These were stored for use as the winter staple; however, the crop was not reliable and sometimes failed completely. When food stores were low, the Kuzedika sought refuge with relatives to the east and south or with the Miwok of Yosemite Valley. Gentle winters were spent on the east shore or in the pine groves north of the Lake.

The Kuzedika moved in a sequence established over thousands of years, from one favored locality to another according to the availability of food. Their routes of travel were well defined and the basin was honeycombed with trails linking seasonal homes.

Freshwater marshes provided many plant taxa used by the Kuzedika. One of the most valuable genera was *Scirpus* used for making mats, boats, baskets, rugs, blankets, duck decoys, skirts, and as a food. Common cattail (*Typha latifolia* L.) was used for fastening tules together in boat construction and dome-shaped houses were covered with cattail mats; cattail tubers were eaten (Anderson 1993). From its aquatic roots to its flowering tip, it was used by the California Indians. The roots, the root shoots, the tips of the new leaves, the inner layers of the stalk, the green bloom spikes, the pollen, and the seeds are all edible.

In the spring the inner leaves of cattail were pulled out of the plant and eaten raw. In the summer the green bloom spikes appear. They were cut off and the papery husk peeled off, then

the spikes were boiled and eaten like corn on the cob. A little later in the summer the bright yellow pollen forms; it can be shaken or rubbed off and used for baking. The rhizomes or roots form an interconnecting maze in the muddy marsh bottom; larger roots were collected by yanking up the entire plant with hands below the base of the plant (Niethammer 1974).

The seeds of cattail and Indian ricegrass had to be flash-burned to remove unwanted chaff. Some groups preferred to process hard-shelled seeds such as Indian ricegrass and alkali bulrush (*Scirpus robustus* Pursh) with specialized tools, such as the flat surface of the metate and a flat stone muller (Fowler 1986).

Scirpus areas were burned to remove the old growth, and stimulate the production of long straight, new tules. Burning cleared out reed-choked marshes, reducing the density and creating an edge effect. Burning allowed for space for waterfowl movement, for nesting sites, and for increased species diversity. Willows (*Salix* spp.) and sedges (*Carex* spp.) were used for basketry 1 year after burning. Periodic autumn burning was widespread for indigenous peoples of the region; fires were set on an annual basis in October and November (Anderson 1993). These fires did not necessarily burn all areas; rather, fire would creep through areas of fuel accumulation but missed areas where fuel was not sufficient. Thus, a mosaic of pyric successional communities occurred, some burning every year, others burning perhaps every 5 years.

Although there is no record of wetland burning by the Kuzedika, burning by Kumeyaay to the south is documented: "In marshy areas, cattails and reeds were regularly burned to improve their qualities as sources of both food and materials for technical purposes (e.g., they supplied house thatching, boat reeds, and a cane stalk which was used for arrow shafts). They, along with basket grasses, were spot burned every three years; in addition, the root areas were dug around and heavy root clumps were divided--often for the purposes of establishing the plant elsewhere." (Shipeck 1993 p.383). Irrigation and planting occurred in Owens Valley, the Walker River drainage, and probably Pahrump Valley and Ash Meadows in southwestern Nevada. This irrigation created wetlands for the production of blue dicks (*Dichelostemma capitatum* Alph. Wood) and yellow nut-grass (*Cyperus esculentus* L.). The tubers of these plants were used as food; cultivated seed plants included lovegrass (*Eragrostis mexicana* ssp. *virescens*) Koch & E. Sanchez), slender wheat grass (*Elymus trachycaulus* ssp. *trachycaulus* (Link) Shinn.), ashy wild rye, sunflower (*Helianthus nuttallii*? Torrey & A. Gray), pitseed goosefoot (*Chenopodium berlandieri* Moq.), and western yellow cress (*Rorippa curvisiliqua* (Hook.) Britton) (Lawton and others 1993). Although not mentioned in historical accounts, fire was undoubtedly part of this wild plant cropping system. Sowing of wild seeds in all parts of north-central Nevada was reported (Steward 1938). The brush in basins in the hills near winter villages was burned and *Mentzeia* spp. and *Chenopodium* spp. seeds were broadcasted by all village members.

When John Muir visited Mono Basin in 1869, he encountered Kuzedika women harvesting wildrye (probably ashy wild rye) in their traditional way: "Five miles below the foot of Morane Lake, just where the lateral moraines lose themselves in the plain, there was a field of wild rye, growing in magnificent waving bunches six to eight feet high, bearing heads from six to twelve inches long. Rubbing out some of the grains, I found them about five eighths of an inch long, dark-colored, and sweet. Indian women were gathering it in baskets, bending down large handfuls, beating it out, and fanning it in the wind. They were quite picturesque, coming through the rye, as one caught glimpses of them here and there in winding lanes and openings, with splendid tufts arching above their heads, while their incessant chat and laughter showered their heedless joy.

Like the rye-field, I found the so-called desert of Mono blooming in a high state of natural cultivation with wildrose, cherry, poppies and bush-composite. I observed their gestures and various expressions of their corollas, inquiring how they could be so fresh and beautiful out in this volcanic desert. This told as happy a life as any plant-company I ever met, and seemed to enjoy the hot sand and wind." (Muir, 1988 p.75-76). Muir also noted that "sage-brush country" was beyond the east side of Mono Lake. Today, basin sagebrush has replaced Muir's happy plant-company. Wildrye is now confined to small stands in seep-meadows and along stream banks.

Mono Basin Prescribed Fire Plan

DPR has conducted small experimental burns in lake-fringing wetlands at Simon Springs. The first test burns were conducted November 7-8, 1995. The second test burn was conducted on February 13, 1997. The burns were financed through DPR's Resource Management Program. Test burns were to provide baseline information important to the formulation of the LADWP's Mono Basin Waterfowl Habitat Restoration.

The proposed Mono Lake Basin Prescribed Fire Plan is a multi-agency plan. It is a cooperative effort of the major landowners in the Basin. The fire plan is to be implemented in two phases: the experimental phase and the routine burn phase.

The experimental phase will last another 3 to 5 years. This phase will provide a better understanding of the positive and negative effects of burning on waterfowl and other wildlife in the Basin. This phase will include burns at different times of the year and in different types of ecosystems, i.e. lake-fringing wetlands, riparian and meadow systems, etc. This phase will include monitoring of vegetation, associated wildlife and include seasonal aerial photographic flights. Prescribed burn crews from DPR, the USDA Forest Service and probably the California Department of Forestry and Fire Protection will participate.

Costs per acre burned will decrease through time, but the costs of monitoring should remain about the same, as much larger areas will be monitored but in a less intense manner. Annual monitoring will replace seasonal monitoring. Prescribed fire on 300 to 400 acres per year is anticipated.

Ecological Baseline and Monitoring

Vegetation

The site is dominated by herbaceous vegetation, with scattered rabbit brush shrubs occurring only on the tufa ridges that surround the site. Semiterrestrial or wetland vegetation consists of a mosaic of graminoid types. Stands of common cattail are surrounded by stands of Nevada rush (*Juncus nevadensis* S. Watson), three square (*Scirpus americanus* Pers.), Nevada bulrush (*Scirpus nevadensis* S. Watson), and to a lesser extent, stands of sedges (*Carex diandra* Schrank and *C. nebrascensis* Dewey). Associated with the wetland ecotopes are various meadow or grassland environments. Wet meadow ecotopes include stands of tufted hairgrass (*Deschampsia cespitosa* (L.) Beauv. ssp. *cespitosa*). Baltic rush (*Juncus balticus* Willd.) often dominates mesic meadow ecotopes, and desert saltgrass is found on xeric meadow edaphotopes.

The wetland and meadow ecotopes support a scattering of uncommon taxa among the dominants; these include *Cryptantha circumsissa* (Hook. & Arn.) I.M. Johnston, *Puccinellia lemmonii* (Vasey) Scribner, *Descurainia pinnata* ssp. *halictorum* (Cockerell) Detl., *Erigeron pumilus* Nutt. var. *intermedius* Cronq., *Epilobium adenocaulon* var. *parishii*, *Solidago spectabilis* (D. Eaton) A. Gray, *Eriogonum ampullaceum* J. Howell, and *Castilleja minor* (A. Gray) A. Gray ssp. *minor*. Sensitive taxa, such as Utah monkeyflower (*Mimulus glabratus* Gray ssp. *utahensis* Penn.), may occur in the wetlands along the shoreline. Mono Lake lupine (*Lupinus duranii* Eastw.) and Mono Lake milk-vetch (*Astragalus monoensis* Barneby var. *monoensis*) may occur on the tufa ridges; however, these taxa have not been observed on or near the burn plots.

A vegetation map of the Simon Springs wetlands was outlined on aerial photographs before experimental burns. False color infrared prints of 9-by-9 inches were used for interpretation of vegetation.

Permanent Vegetation and Waterfowl Transects

Four permanent transect lines were established in the summer 1995. These transects bisected the burn plots in high, medium, and low elevations. The vegetation monitoring protocol used the point-intercept method (100 m, 100 point transects), following procedures outlined in the National Park Service Western Regional Fire Monitoring Handbook (with the exception of transect length and point distance). This method records taxa and their height occurring at regular, predetermined intervals along the transect. Ecological attributes that can be quantified from this method include species composition, frequency of occurrence, height, and cover. At least six transect lines will be placed across additional burn plots to cover all vegetation formation types on the site. Ends of transects are marked by fence posts (metal T posts) and will be photographed from each end before the prescribed burn and seasonally during the course of the experimental phase. Each transect line extends beyond the perimeter of the burn for at least 150 meters. Each end contains a control transect; each transect line will be divided into at least two transects in the burn site and two transects on either side of the burn site. Transect locations were picked to represent various vegetation formation types within the burn site.

Point-count bird population monitoring is planned along the same transects by using the protocols of Ralph and others (1995).

Prescribed Burn Results: November 7-8, 1995

The primary objective of the experimental burn was to begin the process of fire cycle restoration. The restoration of natural fire cycles in the lake-fringing wetlands of Mono Lake are expected to restore conditions of open freshwater ponds that are preferred by many waterfowl taxa. The time of year that the burn is conducted is important to the wildlife value of the burned area. Research in other wetlands of the Great Basin Ecological Province indicates autumn and winter burns are preferable to other seasons. Photo documentation of the transects, fire behavior, and the general area is in progress. Video documentation of the initial prescribed burn was also accomplished.

Burn plots were delineated in two separate compartments in the lake-fringing wetlands Simon Springs. The burn area was approximately 12 acres. One plot at the lake edge was burned on November 7 and one plot inland, surrounded by tufa ridges was burned on November 8. Both compartments contained similar semiterrestrial (wetland) and terrestrial environments. Deeper

ponds contained cattail dominated communities; shallower ponds contained sedge, and bulrush communities. Some sedge and saltgrass communities were found in terrestrial environments. All these communities were closed in structure, except saltgrass which may be open to closed canopy as a function of soil moisture. Rabbit brush open scrub/open desert saltgrass association dominated tufa ridges.

The prescribed burns were conducted within prescription; however, since wind speed was at the low end of prescription, fire did not carry as well as expected and strip burning was necessary. Cattail burned with high intensity with flame lengths up to 3 m and produced near-black smoke. The plants burned off at, or within a few centimeters, of the water level. Bulrushes did not burn well: they smoldered or did not burn at all; higher winds would have produced better ignition. Sedges generally burned with fair to good intensities with up to 1 m flame height. Desert saltgrass burned with low intensity but with complete ignitions where stands were closed. Open stands of saltgrass did not burn. Rabbit brush flamed up with high intensity. When in close proximity to tufa towers, 6 m flame heights were not uncommon and the high heat scorched the towers and glazed the outer surface with a blackened, glass-like surface. This darkened surface coating was still apparent after 2 years. General vegetation was sampled just before the burn and again on November 8, 1995. Photo documentation of the transects was done before the burn and at varying periods after the burn.

Observations on April 1, 1996 found snipe, red-winged blackbirds, shovelers and Canada geese using the burn area adjacent to the rising lakeshore. By May, much of the open water had regrowth of cattail, up to 0.5 m tall. A winter burn would be more likely to create open water for the spring season, as regrowth may be retarded. All of the burn plots were green with new vigorous growth, while unburned areas were still brown and not yet producing new growth. Waterfowl were using the area; however, massive numbers had not yet arrived at Mono Lake. On September 6 there were few little signs of the burn, except the thatch was gone and small areas of open water remained. Mallards were using the area in October 1996.

General vegetation patterns were not expected to change during post-burn; however, an increase in productivity and biodiversity was expected in the burn plots. Nutrient releases from years of thatch build up stimulated increased plant growth after the burn. Such biomass increase is not expected once a near natural fire cycle has been re-established. Western yellow cress became established in some cattail stands that were opened up by the autumn burn.

Prescribed Burn Results: February 13, 1997

Although there was little physical evidence of a prescribed burn by mid-summer 1997, fresh open water had been created along the lakeshore. Moderate numbers of waterfowl have been observed using the burn area where open water occurred, this area provided additional open water habitat over the adjacent control. On July 24, 1997, we noted several large families of mallards in the open water of the winter burn plot.

Conclusions

The restoration of pre-diversion lake levels is the most important element in the restoration of waterfowl habitat in the Mono Basin. Restoration of natural fire cycles appears to be beneficial to waterfowl. Further experimental burns are needed in order to determine the best

fire regime for maintaining wetland systems that are beneficial to migratory waterfowl. Repetitive burns at frequent intervals may be necessary. Burns planned for 1997/98 will re-burn portions of the autumn 1995 and winter 1997 burns. A prescribed fire program can be accomplished without buying the water rights necessary for proposed alternative management strategies, and results of prescribed fire can be accomplished quickly. Monitoring is the only scientifically sound way to measure success and failure and to steer the course of future restoration efforts.

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Altered Fire Regimes and Changes in Stream Channel Morphology in the Sierra Nevada

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Abstract

Many have asserted that current fires burn much larger contiguous areas at higher intensities, resulting in a larger proportion of the burned area experiencing severe fire effects. Watershed scientists and aquatic ecologists have speculated that of all disturbances high intensity wildfires over large contiguous areas may pose the highest threat to stream systems and aquatic habitats. Significant changes in stream channel form occur when variables that influence channel morphology are outside of a normal or acceptable range of variation. Under the natural disturbance regime of the Sierra Nevada, variation in the timing and location of erosion-triggering fires and storms results in episodic delivery of sediment and large wood to channels that cause stream channels to alternate between periods of aggradation and degradation. The shift in fire regimes in the mixed conifer zone of the Sierra Nevada has shifted the disturbance regime from a “pulse” disturbance regime to a “press” disturbance regime. Sediment delivery to streams is lower during the period of fire exclusion, and post-fire sediment delivery increases substantially, perhaps by one or more orders of magnitude. During the fire exclusion period, the frequency of large wood in channels decreases and pool frequency and volumes decrease. Post-fire large wood frequency increases, but the response of pool volumes is different in headwater and alluvial streams.

Introduction

Increases in biomass (both living and dead), coupled with efficient suppression of low and moderate intensity fires, has led to an increase in general fire severity (McKelvey and others 1996). Many have asserted that current fires burn much larger contiguous areas at higher intensities, resulting in a larger proportion of the burned area experiencing severe fire effects. There is no direct data to support these assertions, but as with the observations of increased fuel loadings, such a conclusion is consistent with information available from fire history studies and other sources (McKelvey and others 1996). Watershed scientists and aquatic ecologists have speculated that high intensity wildfires over large contiguous areas may present the greatest potential for long-term effects on stream systems and aquatic habitats (Minshall and Brock 1991).

This paper discusses how the shift in fire regime characteristics of the mixed conifer zone of the Sierra Nevada from frequent, low to moderate intensity fires to less frequent, high intensity fires affects sediment regimes, the frequency of large wood in channels, and the morphology of headwater and alluvial stream channels.

Stream Channel Morphology

Stream channel morphology is directly influenced by eight major variables including channel width and depth, flow velocity and discharge, bed slope, roughness of channel materials, sediment load and sediment size (Leopold and others 1964). A change in any one of these variables can initiate a series of channel adjustments that can cause a change in other variables, resulting in an alteration of channel pattern and aquatic habitat types. Significant changes in channel form occur when variables that influence channel morphology are outside of a normal or acceptable range of variation.

The physical and biological driving variables that initiate channel adjustments are changes in streamflow magnitude and/or timing, sediment supply and/or size, direct disturbance, and vegetation changes. Streams do not always change instantaneously under a geomorphic “threshold.” Rather, streams evolve over time to accommodate changes in the driving variables. The rate and direction of channel adjustment is a function of the nature, magnitude, and frequency of the change in the driving variable, location of the change in the drainage network, and the stream type involved. Some streams change very rapidly or exhibit a smaller “lag time” between the disturbance in the watershed and the channel adjustment, while other streams exhibit longer lag times.

Fire Effects and Fire Regimes

Several generalizations can be made about the response of the channel adjustment driving variables to fire. The removal of vegetation by fire leads to temporarily reduced evapotranspiration, increased overland flow, and greater peak and total discharges (Tiedemann and others 1979). Conversely, fire suppression during this century has created forests with greater density of vegetation than in the past (Chang 1996, Skinner and Chang 1996, Weatherspoon 1996) and should increase evapotranspiration, while decreasing overland flow, and peak and total discharges. Although these changes are difficult to quantify, transpiration in forests where live biomass production has not been regulated by the killing or volatilization of vegetation by fire should be at or near maximum (Kattelman 1996).

Under intense burns, all surface litter may be removed, making soils highly susceptible to erosion (DeBano 1979). In the eastern Sierra Nevada near Reno, Nevada, a single storm produced about $600 \text{ m}^3/\text{km}^2$ ($1.3 \text{ AF}/\text{mi}^2$) of sediment from a burned watershed, while an adjacent unburned area yielded only a trace of sediment (Copeland 1965). Fires reduce the soil-binding capacity of roots. When intense rainstorms saturate soils during periods of low root strength, elevated landsliding into channels and debris flows may result (Reeves and others 1995). The potential for increased sediment discharges caused by mass wasting are highest from 5 to 13 years after a fire (Burroughs and Thomas 1997, Ziemer 1981).

Direct disturbances to stream channels by fire include the consumption or alteration of woody debris that store sediments and control the bed slope of channels. After a fire in northwestern California, much of the large woody debris in inner gorge/gully channels was consumed. Smith and Wright (1988) estimated that $400\text{-}500 \text{ m}^3$ of sediment stored in the channels would mobilize and scour the channels. Consumption of streambank vegetation reduces the resistance of the banks to lateral migration of the channel. In a channel where all streamside vegetation was killed by a fire, channel cross-sectional increased by about 20 percent

in the 4 years after the fire, but returned to post-fire (pre-runoff event) cross sectional area 6 years after the fire (Roby and Azuma 1995).

A simulation model developed by Benda (1994) for the Central Oregon Coast Range indicates that under a natural disturbance regime, variation in the timing and location of erosion-triggering fires and storms results in episodic delivery of materials that cause stream channels to alternate between periods of aggradation and degradation. Meyer and others (1992) found cycles of aggradation and degradation associated with wildfires and hillslope failures in a Wyoming stream like those of the Central Oregon Coast Range. Reeves and others (1995) hypothesized that the natural disturbance regime of the Central Oregon Coast Range is described by the frequency, size, and spatial distribution of wildfires and landslides, and that the regime has been responsible for developing a range of channel conditions within and among watersheds. In the mixed conifer zone of the Sierra Nevada the natural disturbance hypothesis proposed by Reeves and others (1995) is applicable, but, the influence of landslides may not be as great (Seidelman and others 1986).

Resilience of an ecosystem is the degree to which the system can be disturbed and still return to a domain of undisturbed processes and interactions (Holling 1973). If a disturbance exceeds the resilience of the system, the domain may shift and the system will develop new conditions or states that had not been previously been exhibited. Yount and Niemi (1990), modifying the definition of Bender and others (1984), distinguished “pulse” disturbances from “press” disturbances. A pulse disturbance allows an ecosystem to remain within its normal bounds or domain and to recover to the conditions that were present before the disturbance. A press disturbance forces an ecosystem to a different domain or set of conditions. The shift in fire regimes in the mixed conifer zone of the Sierra Nevada has shifted the disturbance regime from a pulse disturbance regime to a press disturbance regime.

The Sierra Nevada: Changes in Fire Regimes and Stream Channel Morphology

The mixed conifer zone is the primary middle-elevation zone of the Sierran forest ranging from about 760 to 1,400 m (2,500 to 4,600 ft) in the north, and from 915 to 3,050 m (3,000 to 10,000 ft) in the south (Eyre 1980). The natural fire regime of this zone is characterized by short-interval, low intensity surface fires (Chang 1996). Fires burn regularly and frequently and, as such, rarely allow organic fuels to accumulate to a point where higher intensity fires may develop (van Wagtendonk 1972). It is generally agreed that fires in the mixed conifer zone have become less frequent and generally more severe since about 1850 (Skinner and Chang 1996, Swetnam 1993).

Under the natural pulse fire regime of the mixed conifer zone of the Sierra Nevada, the morphology of headwater streams was likely influenced by episodic delivery of sediment and wood to stream channels. For example, streams in headwater areas may have experienced large sediment deposits infrequently because lower intensity more frequent fires produced mosaic vegetation age classes and fire effects. Alluvial channels in the middle elevations of watersheds experienced cycles of sediment accumulation and flushing as fire generated sediment was transported into them and then out of them.

Under the current press fire regime, sediment delivery to headwater streams is lower during the period of fire exclusion. Post-fire sediment delivery increases substantially, perhaps by one or more orders of magnitude. However, headwater streams are most likely not

experiencing a press response--a shift to another domain or set of conditions--in channel aggradation because headwater streams generally have sufficient power to transport the increased sediment delivered after fires. The frequency of large wood in channels is most likely exhibiting a press response both during the period of fire exclusion and after fire occurrences. During the fire exclusion period, the frequency of large wood in channels is much lower than would be expected under a natural fire regime. During this period, the frequency and volume of pools is less than what would be expected under a natural fire regime. This state occurs because woody debris plays an important role in creating pools in streams. The number of pools are positively correlated with the frequency of large wood in low-gradient stream channels (Grette 1985), and when large wood is removed from stream channels, the frequency and volume of pools decreases (Bisson and Sedell 1984).

Middle-elevation alluvial stream channel sediment regimes and frequency of large wood in channels are experiencing a press response to the current fire regime. The cycle of sediment flushing has been extended because sediment inputs from fires are less frequent. This flushing of sediment results in higher rates of channel degradation and greater cross-sectional area during the fire exclusion period. Post-fire sediment inputs are higher compared to what would be expected under a natural fire regime but channels are able to store sediments because of increased cross-sectional area produced by the extended channel degradation period. Large wood in channels is exhibiting the same press response described for headwater streams. During the fire exclusion period, the frequency of large wood in channels decreases and pool frequency and volumes decrease. The channel response to the post-fire increase in the frequency of large wood in alluvial channels is different from the response in the headwater streams because pool volumes may not be increased. Headwater streams have sufficient power to transport sediment, thus, the volume of pools created by large wood inputs from fires is maintained. The sediment that is flushed from the headwater streams, is transported to the alluvial streams which generally have a lower stream power compared to the headwater streams and consequently a lower potential to transport increased sediment loads. As a result, pool volumes in alluvial streams decrease as sediment is transported from headwater streams into alluvial streams.

Summary

Under the natural fire regime of the mixed conifer zone of the Sierra Nevada, the stream channel morphology of headwater streams was influenced by episodic delivery of sediment and wood, and large deposits of sediment and wood in the channel were infrequent. Alluvial channels in the middle elevations of watersheds experienced cycles of sediment accumulation and flushing as fire generated sediment was transported into them and then out of them.

The current fire regime of the mixed conifer zone of the Sierra Nevada, which is characterized by longer periods of fire exclusion and fires that burn much larger contiguous areas at higher intensities, may initiate changes in delivery of sediment and wood to channels that shift stream channel morphology characteristics to a different domain or set of conditions. In headwater streams the frequency of wood in channels during the fire exclusion period is much lower than would be expected under a natural fire regime, resulting in a decrease of pool frequency and volumes. Middle elevation alluvial stream channels are responding to the current fire regime and its effects on the sediment regime by exhibiting higher rates of channel degradation and greater cross-sectional area during the fire exclusion period. The alluvial

channel response to the delivery of sediment and wood after fires is different than the response of headwater streams because of the inherent difference in stream power between headwater and alluvial streams. Alluvial streams do not have the power to transport the increased sediment load generated by fires, resulting in decreased pool volumes.

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Effects of Fire and Emergency Seeding on Hillslope Erosion in Southern California Chaparral

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Abstract

Catastrophic wildfires can set the stage for massive postfire erosion and sedimentation in southern California chaparral ecosystems with the onset of heavy winter rainstorms. As a mitigation measure, land managers have typically used grass seeding as a standard emergency rehabilitation technique. However, the effectiveness of grass seeding as a watershed protection practice remains uncertain. To address this problem, we conducted field experiments on southern California chaparral-covered hillsides involving burning and seeding to quantify the magnitude of postfire hillslope erosion and the effect of annual ryegrass (*Lolium multiflorum*) for erosion control. After fires in chaparral, there is a dramatic increase in both dry season and wet season sediment production, resulting in hillslope erosion up to 100 times greater than prefire amounts. Hillslope erosion generally takes 2 to 4 years to return to prefire levels, after which it may actually dip below the baseline. After a wildfire, the erosion response of a recently burned site was similar to that after the original prescribed fire, but lower in amplitude than a previously unburned companion site. Seeding with annual ryegrass may reduce postfire hillslope erosion on some sites in southern California chaparral ecosystems, but only after erosion has dropped to baseline levels.

Introduction

Chaparral in California is a shrub-dominated plant community that covers about 11 percent of the state (Barbour and Major 1988). Chaparral appears to be adapted to periodic burning, and fire may be necessary for ecosystem perpetuation (Barro and Conard 1991). However, these same fires may render the postburn landscape susceptible to massive erosion, flooding, and sedimentation. Many of these brushfields occur at the urban/wildland interface, where burgeoning population centers in the lowland valleys have encroached on adjacent foothills and steep mountain fronts. Consequently, the societal impacts of wildfire and accelerated erosion in chaparral are disproportionately large relative to its area.

The general patterns of postfire erosion on chaparral hillslopes have been well-documented (Rice 1974, Wells 1981, Wells 1986, Wells 1987). Fires remove the protective vegetation and organic litter from the hillsides and can destabilize surface soils on steep slopes. During and immediately after a fire, surface erosion increases by raveling or gravity sliding, as organic barriers are incinerated (liberating trapped sediment) and soil structure in the upper horizons is disrupted. With the onset of the rainy season, surface erosion again increases, as the

denuded hillsides are exposed to raindrop impact and associated surface runoff. Moreover, the production of a fire-induced, near-surface water repellent soil layer (DeBano 1981) alters hillslope hydrology by restricting soil water infiltration. This can generate extensive overland flow capable of eroding considerable quantities of soil material. Erosion generally remains elevated for several years after a fire, gradually decreasing over time as the area revegetates, and watershed erosion returns to prefire levels within 5 to 10 years (Rowe and others 1949).

The potential for extensive damage and expensive cleanup costs associated with accelerated erosion and flooding in fire-prone chaparral ecosystems is enormous. Land managers and protection agencies have undertaken a variety of postfire emergency rehabilitation measures to protect downstream life and property. Although many possible options for erosion control are available (USDA Forest Service 1992), conventional wisdom maintains that it is most cost-effective and realistic to attempt to reduce erosion at the hillside source areas (Rice and others 1965).

Seeding treatments seek to rapidly establish a dense ground cover on burned hillslopes that will hold the soil in place until the area revegetates. By 1950 annual ryegrass (*Lolium multiflorum*) had become the species of choice for postfire seeding in chaparral ecosystems: it germinated quickly; produced an extensive root system; was inexpensive and readily available; and could be easily applied to large areas from the air (Barro and Conard 1987).

Although a variety of postfire rehabilitation strategies have been employed over the years, the effectiveness of the treatments has not been adequately monitored. Most projects were evaluated qualitatively or subjectively, perhaps with a photo series to document the degree of postfire ground cover. Rigorous quantification of hillslope erosion has been lacking (Barro and Conard 1987). The few studies that have measured surface erosion and compared postfire treatment effects suffered from inadequate sample sizes (Blankenbaker and Ryan 1985) or were confounded by factors such as severe animal disturbance (Taskey and others 1989) or extremely low precipitation in the first postfire winter (Rice and others 1965).

Another difficulty of working in chaparral ecosystems is the huge spatial and temporal variability in hillslope erosion response (Wells 1981, Wohlgemuth 1986). Thus, the results of individual sites from single years may reflect local site characteristics and/or postfire weather patterns rather than general fire responses or treatment effects.

This paper discusses burning and seeding field experiments to investigate postfire hillslope erosion and the effect of annual ryegrass for emergency watershed protection on chaparral sites in southern California.

Field Studies

Our experimental design initially called for the establishment of three study sites in each of four regions within coastal central and southern California (Peninsular Ranges, central Transverse Ranges, western Transverse Ranges, and southern Coast Ranges; [fig. 1](#)). All sites were located in areas that were targeted for burning by Federal, State, or county agencies as part of fuel hazard reduction programs. Unfortunately, only one site in each geographic area was burned and the four study sites burned in three different years: Belmar in 1988, Bedford and Vierra in 1990, and Buckhorn in 1994 ([fig. 1](#)). However, the Belmar site and a previously unburned companion site burned in a wildfire in 1993, yielding results from a total of five different fires. Physical site characteristics of the five burn sites have been previously described

(Wohlgemuth and others [In press]). Despite the implementation problems, this project, using identical methodologies over a wide variety of sites and conditions, represents the definitive hillslope erosion and seeding study to date in chaparral ecosystems.

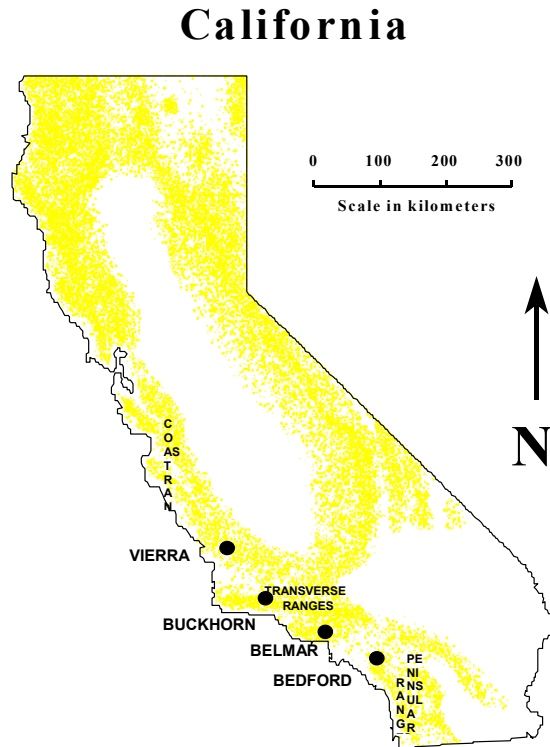


Figure 1. Chaparral study sites of postfire hillslope erosion in the coastal central and southern California mountains.

We established 70 erosion plots in mature, mixed chaparral at each site. Each erosion plot consisted of a set of five sheet metal sediment traps with a 30-cm aperture (Wells and Wohlgemuth 1987). These unbordered plots were situated at midslope positions, with the potential contributing area extending to the hillslope crest. We measured both wet and dry season hillslope erosion for 1 to 4 years before burning. At each site, 10 of the 70 plots were established outside the firelines to serve as unburned controls. The rest were burned in high intensity prescribed fires intended to mimic wildfire conditions. Partially burned plots were discarded, reducing the number of usable burn plots from the original 60 to as few as 36 and as many as 57. Half of the burn plots were randomly selected for seeding with annual ryegrass. Seed was applied in the late fall with hand-spreaders at a rate of 9 kg/ha (about 475 seeds per square meter), comparable to aerial seeding operations (Barro and Conard 1987). Sticky paper was deployed to check the application rate. Eroded material was collected from the traps, then transported to the laboratory where it was dried and weighed. Postfire erosion was measured with decreasing frequency for up to 5 years at each site, and erosion data were aggregated into wet and dry season collection periods, based on the rainfall patterns. Differences in erosion resulting from the seeding at a site were evaluated using a two-sample randomization technique (Manly 1991).

This study is unique in its combination of several design features. First, by physically capturing soil and sediment in collector traps, we were able to measure hillslope erosion directly, rather than relying on ocular estimates or indirect techniques such as erosion pins (Haigh 1977) or erosion bridges (Ranger and Frank 1978). Second, by using a large sample size, we were able to overcome the large spatial variability inherent in hillslope erosion that has undermined previous studies. Third, by using prescribed burns to simulate wildfires, sites were established before burning, enabling us to measure prefire erosion then capture the complete postfire erosion record for the exact same location, rather than using uncalibrated controls. Fourth, by establishing sites over a large geographic area and in different years, we were able to quantify erosion response over a wide variety of conditions. Fifth, one of our sites fortuitously burned in a wildfire 5 years after the original prescribed fire, enabling us to quantify the effects on hillslope erosion of a recent reburn.

Results and Discussion

Erosion data from the control plots were used in conjunction with the prefire data from the burned plots to calculate a baseline level of erosion for each sample location. This baseline is an estimate of the amount of erosion over time that would have been produced by a plot if it had not been burned. The baseline erosion varies over time, generally increasing in response to greater rainfall, but the magnitude of the fluctuations is very small compared to the change in erosion after fire. Postfire erosion was compared to the calculated baseline to quantify the effects of both the fire and the grass seeding on hillslope sediment movement. A generalized pattern of erosion response was determined on the basis of data from our study sites (Wohlgemuth and others [In press]; fig. 2).

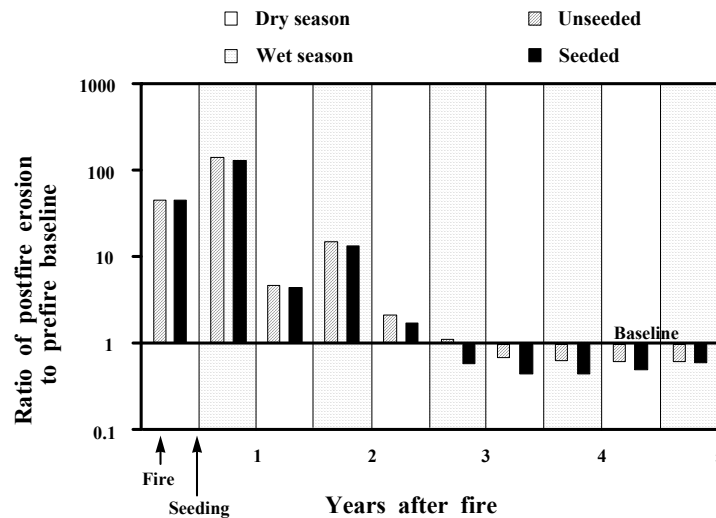


Figure 2. Generalized pattern of postfire hillslope erosion and the influence of ryegrass seeding in chaparral. The values shown are indicative only and do not represent an actual site. The horizontal line is the baseline (prefire) erosion. The ratio of postfire erosion to baseline erosion is plotted on a logarithmic scale.

Erosion increased dramatically after the fire at each site, confirming the observations of previous investigators (Rice 1974, Wells 1981). Accelerated erosion in the form of dry ravel starts during and immediately after the fire as the surface material on the hillslopes adjusts to a new equilibrium state. A second pulse of accelerated erosion is generated with the onset of the winter rains, as the hillslopes adjust to another equilibrium state governed by surface runoff. Generally, surface erosion in the first postfire winter is more pronounced in wet years (or years with very high intensity rains) than during normal or sub-normal rainfall years. In the case of drought years, dry season erosion can actually exceed surface transport during the wet season (Wohlgemuth and others [In press]).

Accelerated postfire surface erosion eventually recovers to prefire levels, as hillslope sediment supply is depleted and the site revegetates. On our sites, when postfire vegetation cover was sparse, recovery took as long as 4 years. However, recovery occurred in as little as 2 years on other sites where vegetation regrowth was rapid (Wohlgemuth and others [In press]). Three to 5 years after the fire, measured erosion actually dropped below the calculated baseline, similar to the pattern observed by Wells (1981).

Seeding with ryegrass to reduce erosion produced mixed results. On two of the sites (Belmar and Buckhorn), there was no treatment difference in surface erosion. On the other sites (Bedford and Vierra), significantly more ($p < 0.05$) postfire hillslope erosion was generated on the unseeded plots than the seeded plots for several of the seasonal collection periods (Wohlgemuth and others [In press]). However, this difference was not achieved until erosion was at, or below, the baseline levels (fig. 2).

The wildfire at the Belmar sites provided a valuable opportunity to compare a variety of burn responses for essentially identical site characteristics. The 1993 wildfire burned under much more severe weather conditions than did the original 1988 prescribed burn. Consequently, the reburn site burned with higher fire intensity than it did in the prescribed burn, while the previously unburned vegetation was completely consumed. Both sites had elevated erosion levels in the first postfire winter rains, but while the reburn erosion response was comparable to the original prescribed fire, the previously unburned site was an order of magnitude greater (Wohlgemuth and others [In press]). Recovery to preburn erosion levels was almost immediate on the reburn site, while erosion on the previously unburned site remained elevated. It is unclear to what degree these measured erosion responses reflect the relative importance of the fire characteristics, the vegetation regrowth, or the depletion of hillslope sediment supply.

Conclusions

In southern California chaparral-covered uplands, hillslope erosion is inevitable. Fire increases the background hillslope erosion by one to two orders of magnitude. Much of the postfire erosion occurs in the dry season on these steep hillsides, although accelerated erosion by gravity processes immediately after the fire is superseded by hydrologic processes with the onset of winter rains. Hillslope recovery to preburn erosion levels is remarkably rapid, occurring within 2-4 years after the fire. Grass seeding as a postfire emergency rehabilitation measure does little to reduce erosion until it has already dropped to baseline levels. Thus, it is unrealistic to expect that seeding can ever be more than a partial solution to the management problems associated with accelerated postfire erosion.

Each of these study locations was unique in terms of the combination of site characteristics, fire characteristics, and postfire rainfall that governed vegetation regrowth, erosion response, and seeding treatment effectiveness. Although we have been able to make some qualitative comparisons and note general trends, more study sites with better replication will be necessary before postfire hillslope erosion patterns are thoroughly explained.

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Predicting Postfire Survival in Coulter Pine and Gray Pine After Wildfire in Central California

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Abstract

Factors related to the survival of Coulter pine (*Pinus coulteri* D. Don) and gray pine (*P. sabiniana* Dougl. ex Dougl.) 3 years after a September wildfire were evaluated for a site on the central coast of California. Data for 146 Coulter pine and 117 gray pine were analyzed with logistic regression models to estimate postfire survival in relationship to tree and fire-damage variables. Probability of survival for both species decreased with the increasing percentage of crown scorching and increasing height of bole bark char. Crown scorch was the most important variable for predicting survival of these species, but it was augmented by the bole-damage variable. Survival of gray pine was higher than that of Coulter pine for comparable values of both variables.

Introduction

Coulter pine (*Pinus coulteri* D. Don) and gray pine (*Pinus sabiniana* Dougl. ex Dougl.) are both widely distributed in California. Gray pine inhabits a broad range of vegetation types and environments from riparian areas to granitic and serpentinite outcrops (Graves 1932, Griffin 1965), but it most commonly co-occurs with blue oak as small open stands or as scattered trees in the foothill regions bordering the Great Valleys of California (Sawyer and Keeler-Wolf 1995). Coulter pine occupies coastal mountains from Contra Costa County and south through central and southern California and into Mexico (Griffin and Critchfield 1972). Like gray pine, it also grows in a wide variety of vegetation types including chaparral (Wilson and Vogl 1965), mixed evergreen woodlands and lower coniferous forests (Minnich 1980, Sawyer and Keeler-Wolf 1995).

Fire is an important disturbance factor throughout the ranges of both species, but because neither species is of commercial value, comparatively little quantitative information is known about their fire ecologies, especially their tolerance of fire-caused damage. Gray pine has been described as "easily killed" by fire (Graves 1932). Lawrence (1966) found that 83 percent of gray pine in a "moderately severe" fire died, and only the largest individuals with thickest bark survived.

In Contra Costa County, Vale (1979) noted that 3 percent of Coulter pines in a woodland survived a "hot ground fire" and observed that the trunks of killed individuals were charred high into the canopy. In a different, nearby woodland stand subjected to "less intense heat," 17 percent of the trees survived and all of those exceeded 40 cm stem diameter at 1.4 m (DBH). In contrast, Coulter pines associated with chaparral are typically subject to crown fire that results in tree death (Borchert 1985, Vale 1979). However, even in chaparral, small patches may burn at low intensity leaving trees with only partially burned canopies (Borchert, pers. observation).

This study developed models for predicting the effects of fire-caused damage on the survival of Coulter and gray pine, which managers can use to identify hazard and salvage trees.

Study Area

In late September 1993, the Marre Fire burned 17,490 ha of private land and Los Padres National Forest in the vicinity of Figueroa Mountain and Zaca Peak, located 40 km northwest of Santa Barbara, California. In February 1994, 5 months after the fire, we sampled nine sites dominated or co-dominated by Coulter pine between the elevations of 790 m and 1,220 m. Vegetation types included Coulter pine chaparral (*Arctostaphylos glandulosa* Eastw., *Quercus wislizenii* var. *frutecens* A. DC.), Coulter pine-coast live oak (*Q. agrifolia* Nee) forest, Coulter pine-canyon live oak (*Q. chrysolepis* Liebm.) forest, and Coulter pine-California annual grassland. Gray pine was sampled at four sites, mostly in blue oak (*Q. douglasii* Hook. & Arn.)-gray pine woodland and in coast live oak-gray pine forests. Sites ranged in elevation from 730 m to 1,160 m.

Methods

At nine sites, 117 Coulter pines were sampled. Depending on the size of the stand, from 3 to 26 trees were sampled in 5 DBH classes (<20 cm, 21-40 cm, 41-60, 61-80 cm, and >81 cm) that displayed a range of crown scorching (0-100 percent). At four sites, 146 gray pines were sampled in a similar manner. The number of trees per stand ranged from 22 to 36. We avoided sampling trees with broken tops or those that had all the needles consumed.

Five months after the fire, we recorded the following attributes for each tree: DBH, tree height, a visual estimate of the percentage of the prefire (foliage and buds) crown killed by the fire, and maximum height of the bole bark char. A wide range of fire severities and tree sizes were represented in the data for each species (table 1). Bark thickness was taken from a random sample of 39 unburned trees of each species covering a range of bole diameters. Samples were taken with a bark punch at DBH on the upslope side of the tree. We visually estimated the percentage green crown for each tree at 12, 27 and 36 months after the fire. A tree was presumed dead if green canopy was not visible after two consecutive visits.

Table 1. Tree characteristics used to develop the logistic regression models for survival of Coulter pine and gray pine. Status is for trees 36 months after the wildfire.

Species	Status	N ¹	DBH (cm)	SD ²	Height (m)	SD	Crown scorch (%)	SD
Coulter pine	Live	46	36.9	16.2	16.7	5.7	51.5	27.3
	Dead	71	37.8	23.5	18.5	8.5	84.1	21.2
Gray pine	Live	90	31.4	22.7	13.0	8.2	51.6	26.9
	Dead	56	39.9	26.5	17.9	10.3	83.7	26.6

¹ Sample size. ² Mean ± one standard deviation.

Species	Status	N	Bole bark char (m)	SD	Relative char height (m)	SD
Coulter pine	Live	46	2.7	2.0	0.16	0.001
	Dead	71	5.8	4.9	0.28	0.16
Gray pine	Live	90	3.7	3.3	0.27	0.12
	Dead	56	7.8	5.6	0.42	0.20

Data Analysis

The probability of postfire tree survival was modeled by using an equation for logistic regression analysis:

$$P(s)=[1+e(\beta_0+\beta_1X_1,\dots,\beta_nX_n)]^{-1}$$

in which P(s) is the probability of survival, β is the regression coefficient, and X is the independent variable.

The logistic function has been used in numerous studies to estimate postfire survival in conifers (Finney and Martin 1993, Greene and Shilling 1987, Harmon 1984, Harrington 1993, Peterson and Arbaugh 1986, Peterson and Arbaugh 1989, Regelbrugge and Conard 1993, Ryan and others 1988, Ryan and Reinhardt 1988), and it is particularly effective for analyzing data with a binary dependent variable, in this case whether the tree was alive or dead 36 months after the fire. We used DBH, tree height, and percentage crown scorch 5 months after the fire, height of the bole bark char, and relative char (height of the bole bark char divided by tree height) as independent variables to estimate postfire survival of each species. Because bark thickness was not measured for all the sampled trees, it was not used as an independent variable in the models. NCSS (1996) and Statistica (1995) software were used to analyze the data.

Results

The best survival model for each species used percentage crown scorch and height of bole bark char as predictor variables in the two-variable model (table 2). The model likelihood ratio χ^2 was highly significant (P<0.001) for each species and the coefficients for percentage crown scorch and height of the bole bark char also were significant (P<0.001). Height of bole bark char and percentage crown scorch were not significantly correlated (r=0.17, p=0.07) for Coulter pine and only weakly (r=0.25, p<0.05) correlated for gray pine.

Table 2. Logistic regression models for predicting tree survival after a September wildfire for Coulter pine and gray pine. Parameter estimates that differ from zero at $\alpha=0.05$ are indicated by * and those differing from zero at $\alpha=0.01$ are indicated by **.

Two-variable model			$P(s)=[1+e(\beta_0+\beta_1X_1+\beta_2X_2)]^{-1}$		
Species	β_0	β_1	β_2	LRS ¹	P(<) ²
Coulter pine	5.8889**	-0.0773**	-0.4203**	54.6	0.0001
Gray pine	4.3850**	-0.0409**	-0.2079*	59.5	0.0001

Three-variable model				$P(s)=[1+e(\beta_0+\beta_1X_1+\beta_2X_2+\beta_3X_3)]^{-1}$	
β_0	β_1	β_2	β_3	LRS ¹	P(<) ²
3.6791**	-0.0455**	-0.2301**	1.1436	126.24	0.0001
χ^2 values for each variable		41.42**	49.52**	24.59**	12.06**

P(s)= predicted probability of tree survival

X_1 = percentage crown scorch

X_2 = height of the bole bark char

X_3 = dummy variable for pine species

β_i = model coefficients estimated from the data

e = the base of the natural logarithm

¹ LSR= likelihood ratio statistic, a χ^2 statistic for assessing model goodness of fit.

² Statistical significance of LSR.

When species data for percentage crown scorch and height of bole bark char were pooled and species was coded as a dummy variable (Coulter pine=1, gray pine=0), the fit of the model significantly improved over the two-variable model (table 2). The model likelihood ratio χ^2 was highly significant as were the regression coefficients and χ^2 values for the three independent variables (table 2). Based on χ^2 values, percentage crown scorch was greater than bole bark char and bole bark char was greater than species in importance in the model. Eighty-two percent of the trees were correctly classified by using the three-variable model when trees with survival probabilities of <0.50 were considered dead and those >0.51 were considered alive.

The survival probability of both species decreases as percentage crown scorch and height of bole bark char increase. Gray pine has a higher survivorship than Coulter pine for nearly all values of crown scorch (fig. 1), especially for crown scorch values from 60 to 90 percent. Similarly, over the range (1-12 m) of bark char heights, survival probability of gray pine averaged more than 20 percent higher than that of Coulter pine (fig. 2).

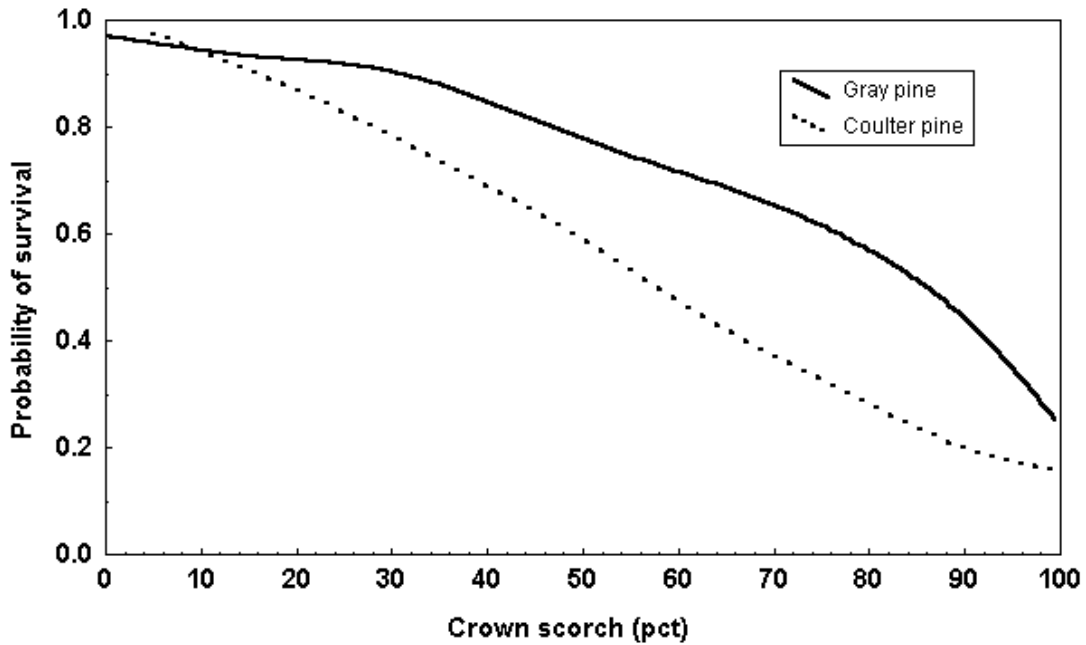


Figure 1. Least squares regressions of pine survival and percentage crown scorch for gray pine and Coulter pine based on the three-variable model.

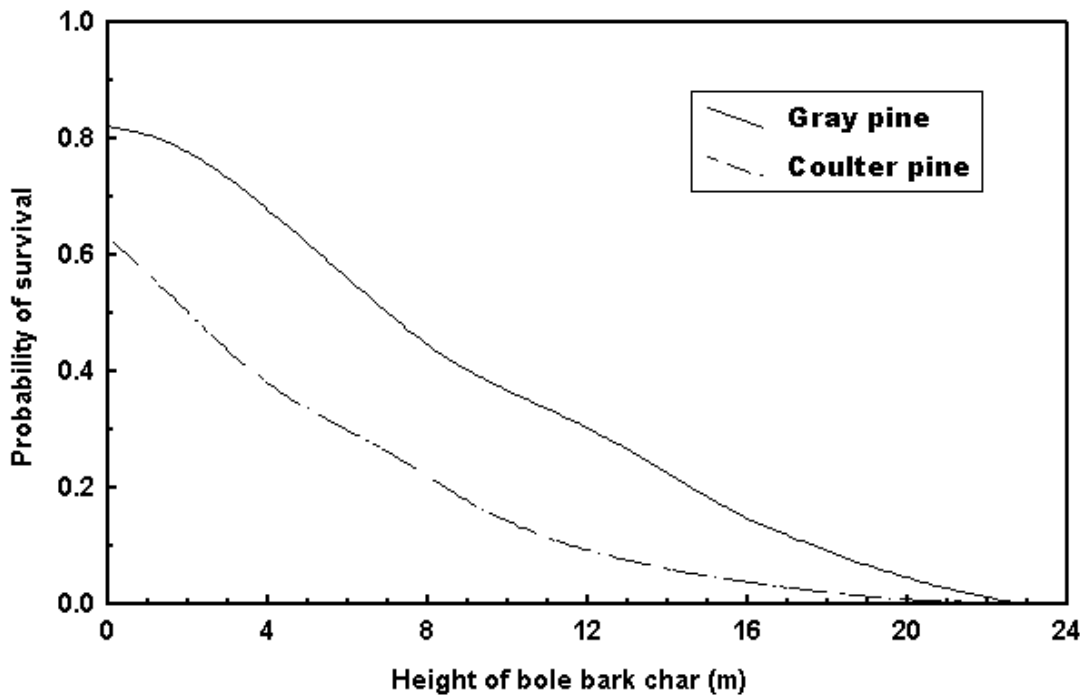


Figure 2. Least squares regressions of pine survival and height of bole bark char for gray pine and Coulter pine based on the three-variable model.

There was an unexpected difference in the crown recovery of the canopies in the two species 12 months after the fire (fig. 3). Coulter pine showed an average increase of 19 percent between 5 and 12 months after the fire. In marked contrast, gray pine showed an average decrease of 20

percent in the green canopy in the same period (table 3). Nevertheless, 27 months after the fire, average percent green canopy of gray pine had rebounded to the level recorded 5 months after the fire (fig. 3).

Table 3. Change in percentage green canopy of Coulter pine and gray pine between sampling dates 5 and 27 months after the fire.

Species	Unchanged N ¹	Increase N	Mean % Increase	SD ²	Decrease N	Mean pct Decrease	SD
Coulter pine	37	44	27	19	36	20	19
Gray pine	38	16	11	9	92	28	21

¹ Sample size. ² ± One standard deviation of mean percentage increase or decrease.

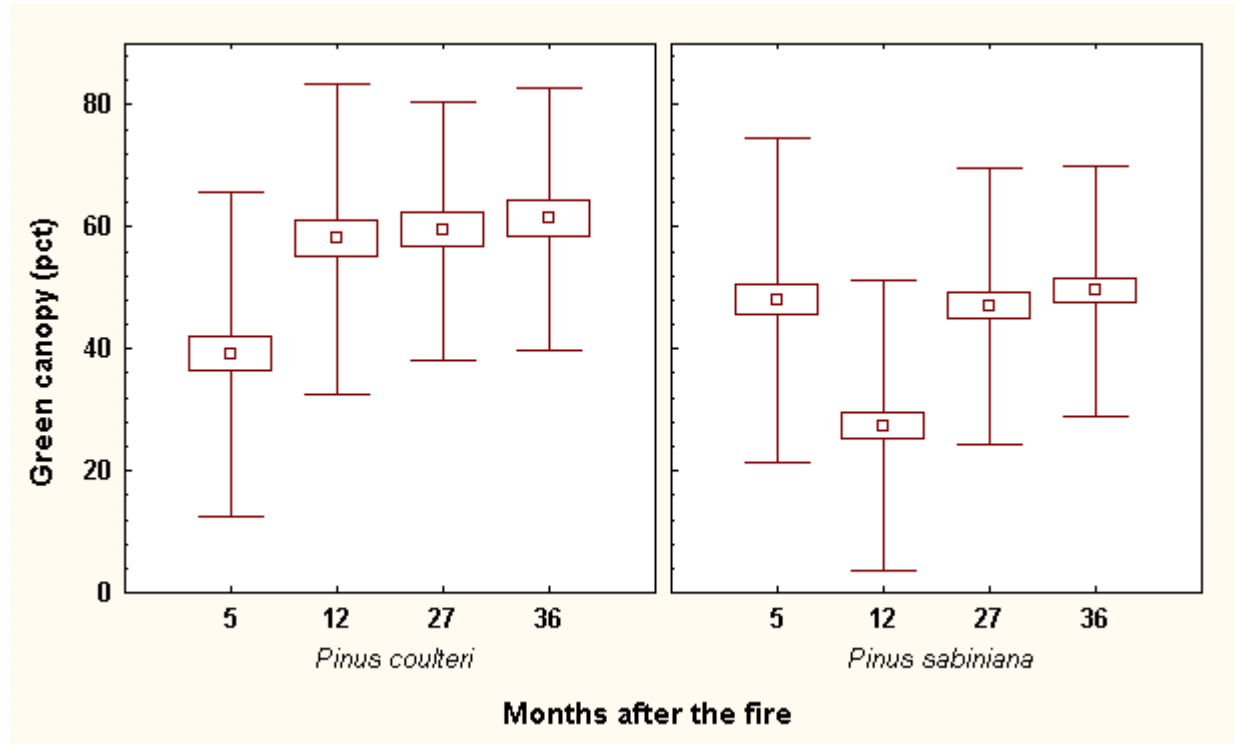


Figure 3. Postfire green canopy for gray pine (a) and Coulter pine (b). The box is ± one standard error of the mean and the whiskers are one standard deviation of the mean.

Regressions of bark thickness and DBH (fig. 4) indicate that the two species were not significantly different in bark thickness across a range of bole diameters.

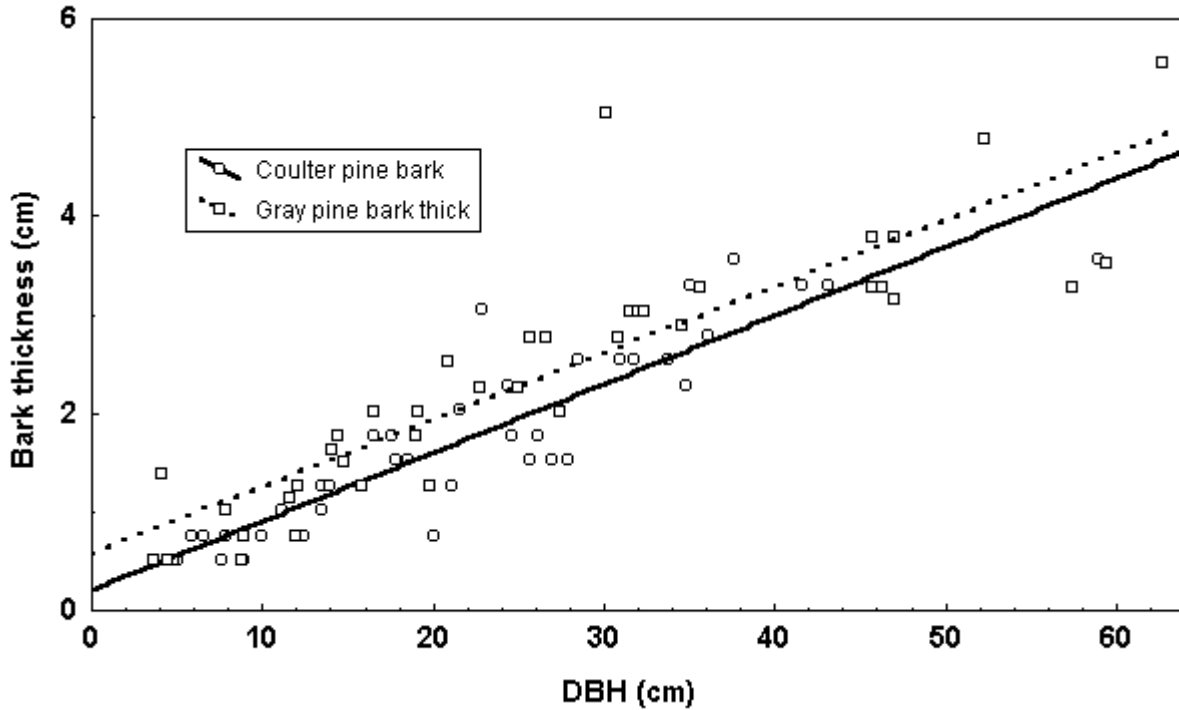


Figure 4. Linear regressions of bark thickness versus DBH for the two species. The equation for gray pine is: $\text{bark thickness} = 0.21 + 0.07 * \text{DBH}$ and for Coulter pine it is: $\text{bark thickness} = 0.58 + 0.07 * \text{DBH}$.

Discussion

Crown scorch was the most important variable for predicting postfire survival of these two species. As expected, tree survival decreased with increasing crown scorch, an outcome that has been documented in numerous postfire survival studies of conifers (Dieterich 1979, Finney and Martin 1993, Harrington 1987, Peterson and Arbaugh 1986, Ryan and others 1988, Ryan and Reinhardt 1988, Storey and Merkel 1960, Wagener 1961, Waldrop and Lear 1984, Wyant and others 1986). Scorching kills needles but has its greatest impact on the canopy when it kills terminal buds and twigs (Wagener 1961). Loss of living canopy reduces the ability of the tree to sustain non-photosynthetic tissues such as roots and cambium, to replace lost foliage, and to maintain chemical defenses against insects and pathogens (Peterson and Arbaugh 1986, Ryan and others 1993). Several studies have determined that the percentage of the crown volume scorched after wildfire was correlated with a reduction in radial growth (Johansen and Wade 1987, Peterson and others 1991) and increased susceptibility to beetle infestations (Furniss 1965).

After this fire, gray pine survived higher levels of crown scorch than Coulter pine. In other studies, Wyant and others (1986) found that Douglas-fir (*Pseudotsuga menziesii* (Mirabel) Franco) was more susceptible to crown damage than ponderosa pine (*P. ponderosa* Dougl. ex Law.). In addition, several Mediterranean pines also show very different mortality patterns in relationship to crown kill (Ryan and others 1993).

A survey of the literature suggests that mortality in pine species from crown scorch tends to fall into two groups: those that show a threshold of scorching beyond which mortality increases dramatically, and a group in which mortality increases more or less continuously with increasing

crown scorching. Numerous studies suggest that ponderosa pine (Harrington 1993) falls in the threshold crown-scorch group, although the scorch threshold varies in different studies. Pignon pine (*Pinus pinea* L.) and maritime pine (*P. pinaster* Ait.) also appear to have well defined scorching thresholds (Ryan and others 1993). On the other hand, for gray pine and Coulter pine, Aleppo pine (*P. halepensis* Mill.) (Ryan and others 1993) and lodgepole pine (*P. contorta* Dougl. ex Loud.) (Peterson and Arbaugh 1986) mortality tends to increase monotonically in relationship to crown scorch.

Mortality of both species in this study increased with increasing height of the bole bark char, although this variable was not so important as crown scorch. Gray pine survival was higher than that of Coulter pine for nearly all comparable values of bark char. Storey and Merkel (1960) found no differences in mortality of longleaf pine (*P. palustris* Mill.) and slash pine (*P. elliottii* var. *elliottii* Engelm.) in relationship to bark charring (percentage of the tree charred), but basal scorch was more likely to kill lodgepole pine than Douglas-fir because of lodgepole pine's thinner bark (Peterson and Arbaugh 1989). In the Sierra Nevada incense cedar (*Calocedrus decurrens* (Torr.) Florin) was more resistant to bole charring than ponderosa pine (Reggelbrugge and Conard 1993), even though incense cedar has thinner bark than ponderosa pine.

Damage to the bole ranks second to crown scorch as the variable best explaining fire-caused mortality in many conifers, and in some studies it has proven to be the most important variable (Ryan and Reinhardt 1988). Heat released from the flaming front or smoldering combustion at the base of the tree can kill all or part of the cambium, either weakening the tree or killing it outright. A few researchers have measured cambium kill directly (Harrington 1987, Peterson and Arbaugh 1989, Ryan and others 1988), but most have selected variables likely to be correlated with cambium death, such as bark-char ratio (Peterson and Arbaugh 1986, Peterson and Arbaugh 1989), height of the bole bark char (Regelbrugge and Conard 1993, Storey and Merkel 1960, Waldrop and Van Lear 1984), relative char (height of the bole bark char divided by tree height) (Regelbrugge and Conard 1993, Wyant and others 1986), and bark thickness (Greene and Shilling 1987, Harmon 1984, Ryan and Reinhardt 1988, Ryan and others 1993).

The difference in survival between Coulter pine and gray pine does not appear to be related to bark thickness because they do not differ in this characteristic. In fact, both species have relatively thick bark compared to other conifers (Ryan and others 1993). Rather, the difference may be due to qualitative differences in the insulating capacity of the bark (Hare 1965) or perhaps a difference in their ability to withstand the effects of partial girdling (Wagener 1961).

By the first growing season after the fire, most dead needles have been shed. New needles grow from lightly damaged buds and twigs, and the amount of green canopy in many trees increases from immediate postfire levels (Wagener 1961). For Coulter pine, any increase in green canopy was complete 1 year after the fire. Response of gray pine was unusual and very different from that of Coulter pine. Full recovery of live canopy in gray pine was not complete until 27 months after the fire (fig.3). Between 5 and 12 months postfire, the green canopy of gray pine declined by an average of 20 percent, but 27 months after the fire, it had rebounded to early postfire levels. Whatever the cause, use of percentage crown scorch 12 months after the fire in the regression models resulted in poorer predictions of gray pine survival than values recorded 5 or 27 months postfire.

These models are preliminary and need to be tested for other sites and other fires. Moreover, they are not likely to be applicable for spring and early summer fires when developing buds are more likely to be killed (Harrington 1993). Lastly, the model's predictive ability may be further improved by the inclusion of insect damage and root kill as independent variables.

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Response of French Broom to Fire

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French broom (*Genista monspessulana*) is an aggressive invader of grasslands and mixed evergreen forests, especially in central and northern California. Prolific seed production in concert with absence of natural seed predators ensures that large numbers of seeds are deposited underneath these shrubs. Seed longevity and dormancy result in the accumulation of a considerable seed bank, making this pest plant very difficult to eradicate. Both mortality and germination of seeds occur with fire, the only means known to deplete the seed bank. We studied seed bank depletion and site alteration in broom stands in relation to burning. Pre- and post-burn sampling was done in relatively young and old stands of broom in which fuel was added, removed, or left undisturbed. Comparisons were made with an adjacent unburned control stand. We found that a single fire produces high seedling densities and promotes broom spread. Control will require repeat burning. In old stands, however, we found a persistent seed bank that will only be exhausted by repeat burning to prevent new seed input until the seed bank is depleted by germination and mortality. Germinants that emerged in the second and third years were not numerous. Addition of fuel in old stands did not improve seed bank depletion and it resulted in much lower native species cover compared to leaving broom slash where it fell. In contrast, if stands are burned at a young enough age, with supplemental fuel, the seed bank can be more rapidly exhausted. We also found nitrogen enrichment by broom may persist after fire. Thus, site restoration may be even more difficult than previously realized, and species with greater nitrogen demands will be favored in soils once occupied by the roots of broom.

Introduction

The current worldwide epidemic of introduced plant invasions involves many plants well adapted to fire (D'Antonio and Vitousek 1992). In order to predict the spread of these species and understand the ecological consequences of their invasions, it is imperative to consider how fire affects pest plants, as well as the invaded community. Wildfires may increase the spread of pests, but fire may also be used to help control them. In fact, species with persistent seed banks may be impossible to control without using fire.

French broom, a garden escape from the Mediterranean region, is the most widespread of five closely-related, nitrogen-fixing, leguminous pest plants in California, ranging along the coast from Del Norte County southward to San Diego County (Hoshovsky 1988). It is also found in the Sierran foothills. French broom is an aggressive invader of grasslands, mixed evergreen forests and mesic chaparral (Howell 1970). It forms dense, almost impenetrable 2 to 4 m tall thickets that choke out shorter vegetation and decimate local native plant (alpha) diversity (table 1). Broom is rarely used by native animals or attacked by diseases. Badly infested areas, therefore, have greatly reduced overall biological diversity.

Table 1. Comparison of native species diversity and plant cover other than broom in 12 old-growth broom plots versus 12 adjacent uninfested grassland.¹

	no broom		broom	
	Species present	native cover	Species present	native cover
Mean	11.7	15.1	3.1	5.1
S.E.	0.8	5.0	0.3	1.7
¹ Plots were ½ x ½ m. ¹ Plots were ½ x ½ m.				

Parker and Kersnar (1989) found an average of 10,000 dormant broom seeds m² in the litter and soil under mature French broom stands in Marin County. Like other legume seeds, dormancy of this species is enforced by a hard coat that prevents imbibition. Parker and Kersnar (1989) found that about 40 percent of French broom seeds can germinate readily with sufficient moisture, while Adams and Simmons (1991) report a figure of 18 percent. Heat of 50 to 100 °C doubled germination but mortality ensued at about 125 °C (Parker and Kersnar 1989). Hand scarification produced almost 100 percent germination. Longevity of French broom seeds is not known but seeds of Scotch broom (*Cytisus scoparius*) remain viable for at least 80 years if properly stored (Turner 1933). Many legume seeds are known to have much greater longevity (Baker 1989).

A persistent seed bank is a common trait among many difficult-to-control introduced species (Cavers and Benoit 1989), and reducing this seed bank is the chief obstacle to controlling French broom. It is necessary to determine the conditions for stimulating germination of the greatest number of seeds to achieve exhaustion of the seed bank (Parker and Kersnar 1989). In the case of French broom, a sizeable seed bank may remain dormant in the soil indefinitely in the absence of fire or other treatments that break dormancy. With no other treatment practicable, control of the pest may be impossible without fire or disturbance treatments.

Once established, there are two obvious mechanisms whereby French broom alters the invaded habitat. First, it causes changes in community composition by displacing preexisting vegetation. Second, as a nitrogen-fixing plant, French broom can enrich N levels in the soil. Nitrogen-fixation has not been studied in French broom. Scotch broom can fix N throughout the year in regions with mild winters (Wheeler and others 1979).

Fire may also be useful for helping return native vegetation to broom infested areas. Fire has been documented to promote native species in California grasslands, in part because seeds of the latter are sensitive to heating (Ahmed 1983). In addition, a portion of the total N pool stored in aboveground biomass and litter will be lost to the atmosphere when a site burns (Conrad and DeBano 1978), which could eliminate N-enrichment. N-enrichment favors introduced species to natives (Huenneke and others 1990).

Broom invasion is a serious problem on the lands of the Marin Municipal Water District in Marin County, California. The District has been conducting prescribed burns in infested areas since 1980. This paper will discuss studies we have performed in relation to these burns to determine

whether broom will expand its range with fire, how the seed bank may be depleted with fire, and the effects of fire on community composition in broom stands. We also describe alteration of soil N by broom invasion, and the effect of fire on this.

Methods and Materials

Study site

Research was conducted on the eastern side of the Marin Municipal Water District Watershed lands in Marin County, California, at Bon Tempe Meadows (latitude 37° 58', longitude 122° 35', elevation 200 m). The climate is Mediterranean, and the mean annual precipitation is about 120 cm. Monthly average maximum temperature ranges from 13 °C in December to 25 °C in the summer.

The meadow is underlain by sandstone and shale of the Franciscan Assemblage and is almost entirely within the Blucher-Cole complex (2 to 5 percent slope) soil mapping unit (USDA Soil Conservation Service 1985). These soils are very deep clay loams to silt loams. Permeability is moderate to low. Soils are subject to very brief periods of flooding. In the area where plots were located, slopes are 0 to 10 percent with a south aspect.

Meadow vegetation consists of grassland with patches of French broom. Individuals or clumps of coyote bush (*Baccharis pilularis*) and live oak (*Quercus agrifolia*) are also common. Grassland consists of a matrix of native coastal prairie (Holland 1986), and grassland dominated by exotic species. Native grassland is composed of fairly dense to dense tussocks of needlegrass (*Nassella pulchra*) and oatgrass (*Danthonia californica*). Non-native grassland consists of two types. In wetter, low-lying areas, the robust perennials velvet grass (*Holcus lanatus*) and vernal grass (*Anthoxanthum odoratum*) occur. In dry, loamy soil, rattlesnake grass (*Briza maxima*) is dense. Scattered with it are the annuals wild oats (*Avena barbata*), quaking grass (*Briza minor*), and *Aira caryophylla*.

Experimental Design

We located a total of 20, 5 by 5 m plots in the meadow in August, 1995. Allocation of plots to burn treatments is presented in [table 2](#). In addition to the 20 treatment plots, three plots were established nearby in the uninvaded grassland. Just outside the burn area, three plots were located in old broom stands and two plots in the uninvaded grassland. Young stands had an average of 185, 1 to 2 m tall broom plants/m², the oldest estimated to be about 5 years old based on rings visible on cut stumps. There was 75 to 100 percent cover of grass and thatch. Old stands had an average of 88 broom plants/m² and were estimated to be about 15 years old. Associated vegetation averaged 5 percent cover and was mainly poison oak (*Toxicodendron diversilobum*) and grassland remnants.

Table 2. Sampling in burn treatments. Plots are 5 x 5 m areas at locations where broom was not cut, and/or where cut slash was left. Where slash was concentrated or removed, sites were 2.5 x 2.5 m in size (see Methods).

	No. plots	No. subplots
Young broom		
Uncut	1	4
Slash left	3	12
Slash increased by factor of 4	3	12
Slash removed	3	12
Old broom		
Uncut	1	4
Slash left	3	9
Slash increased by a factor of 4	3	12
Slash removed	3	12

Within each 5 by 5 m plot, we located four 0.25 m² permanent subplots (one randomly located in each quadrant of the main plot) in which we monitored broom seedling density and percent cover of all species that were present both before and after burning. Six transects also were established extending 40 m from the edge of the plots. Broom expansion/contraction after fire was measured by counting all broom seedlings in the 40 contiguous 1 m² plots comprising the transect.

Before burning in October 1995, broom was cut near soil level and allowed to thoroughly dry. Slash was left in place in the 5 by 5 m plots, hereafter referred to as slash plots. In addition, fuel-added and fuel-removed treatments were established in 5 by 5 m areas 1 m away on one side of these plots. In fuel-added plots, fuel load was quadrupled by taking all broom cut from the entire 5 by 5 m area and placing it into a 2.5 by 2.5 m area near the plot center. A 2.5 by 2.5 m area where fuel was removed was also identified. Four 0.25 m² plots were located in the center of the fuel-added and fuel-removed areas, and vegetation sampling was conducted there.

Burns were carried out in mid-October in both 1995 and 1996. Flame lengths, rates of spread, and duration of flaming combustion were monitored at plot locations. Depth of ground char in each 0.25 m² plot was visually characterized (Ryan and Noste 1985).

Soil Analyses

We also collected four randomly located soil cores (5 cm diameter by 10 cm depth) in the 5 by 5 m plots before and immediately after fire for analysis of N availability. Cores were kept on ice. Later they were homogenized and rocks and roots > 2 mm were removed. One 20 g subsample from each plot was extracted in 2 M KCl, while a second was subjected to incubation to determine anaerobically mineralizable N. At the end of incubation, subsamples were extracted with 2 M KCl. All extracts were shaken for 0.5 hr., then filtered through Whatman #1 filters that were pre-leached with double deionized water. All solutions were analyzed colorimetrically for NH_4^+ and NO_3^- using a Lachat flow-injection autoanalyzer.

After fire, five of the same soil cores were taken at random locations from within fuel-added and fuel-removed plots. Cores were homogenized and a 1 L aliquot of soil was passed through a variety of sieves to remove particles smaller than French broom seeds. The distinctive seeds of French broom were then retrieved from the remaining mix. These were inspected under a microscope and classified as alive (white, undamaged embryo) or dead (darkened and/or damaged embryo). A subsample of 150 live seeds was spread on wet paper outdoors to evaluate germination. The dense hard seeds of broom within the soil may be damaged by soil heating but are not consumed as a result of the aboveground vegetation burning. Because seeds in the litter layer would be expected to be consumed by combustion, these methods estimate the post-fire seed bank in the soil.

Before the 1996 burn, ten 2 by 2 m plots were located within a 0.5 ha area that had been old-growth broom. Soil in these plots down to 20 cm was overturned and thoroughly mixed. Paired control plots were located adjacent to the treated ones, and vegetation sampling followed at all locations. There was no combustion in these plots during the second fire.

Data Analysis

Due to spatial constraints, the number of plots within each treatment was unbalanced. Young and old stands were analyzed separately. There were only three sampling locations within each type. This greatly limited the use of inferential statistics without violating independence assumptions. We focus on before and after comparisons at the same locations.

The effect of broom and burning on soil nitrogen availability was investigated by using ANOVA. The main effects were broom and burn; each date was analyzed separately with a Bonferroni adjustment for multiple tests.

Results and Discussion

Burn Characteristics

Temperatures and relative humidities ranged from 25 to 28 °C and 30 to 35 percent when plots were burned both years. Despite these high temperatures and low humidities, the uncut old broom stand did not burn either year, and the young uncut stand had spotty combustion. The soil surface was characterized as unburned in these plots. Under conditions where prescribed burns typically are conducted, it can be expected that combustion of live, standing broom will be difficult without artificially increasing fuels.

In young slash stands, flame lengths were 0.5-1.5 m both years. Rate of spread was somewhat slower but residence time somewhat greater than in grassland. Ninety to 100 percent of the soil surface in this treatment was characterized as having light ground char (Ryan and Noste 1985); the remainder had moderate char. Young, fuel-added plots were classified as having 100 percent moderate ground char (first burn only). These plots had residence times of 4 to 5 minutes for flaming combustion and flame lengths of 3 to 4 m.

Old broom, slash plots had up to 15 cm of broom slash that produced 0.5 to 2.5 m flame lengths that lasted 2 to 4 minutes. Soils were classified as having moderate ground char over 80 percent of their surface and deep ground char over the remainder. In fuel-added plots, residence time of flaming combustion was 4 to 6 minutes, and smoldering combustion continued long after. All plots were characterized as having deep ground char. All plots from fuel-removed areas were characterized as having light ground char. Fuel present at these sites and in year two consisted mostly of broom seedlings with sparse grass. Combustion was light, and the soil surface in these areas was characterized as 90 percent unburned and 10 percent lightly burned.

Broom Expansion

Three out of five broom patches expanded by an average of 6 m into adjacent grassland after the first fire. One of two unburned patches expanded 1 m over a 1 year period. Survival of isolated seedlings was also better in burned areas than in grassland (Odion, unpublished data); therefore, a single burn likely promotes broom expansion. Broom is now much more extensive in areas burned once by the Water District during the 1980's than before that time. This is consistent with most other research, which indicates that disturbance generally facilitates invasion by exotic species (DeFerrari and Naiman 1994).

After the second fire, broom seedlings that established in the grassland were killed, but seedlings again germinated beyond the original extent of three broom patches. This extension averaged 2.25 m. Thus, even though seed populations diminished with distance away from broom stands (Parker and Kersnar 1989), there were sufficient numbers to support a population expansion after two consecutive fires and no seed input.

Response of Seed Banks to Burning

Seed populations in old growth broom stands ranged from 4,300 to 14,000/m² at six locations, which is within the range found by Parker and Kersnar (1987); however, the average number we found (8,600, S.D. 3,900) was slightly lower. Parker and Kersnar (1987) found considerable seed at depths where heat would be insufficient to break dormancy, even with severe fires. In our fuel-added plots, 53 percent of seeds (159/305) had white, undamaged embryos. Of the 156 seeds undamaged by fire tested, 82 germinated; the remainder failed to imbibe and appeared dormant but not dead. Thus, undamaged seed densities we measured appear to be a reasonable estimate of living seed and about 2,000 to 7,000 seeds/m² remained after fire in fuel-added plots. Where fuel was removed, the effect of reduced heating was evident; 85 percent of seeds were undamaged and only 131 of the 356 tested germinated.

Greater mortality with the addition of fuel, however, manifested far fewer seedlings (478/m²; [table 3](#)) compared to the slash plots (1649/m²). After the second fire, slash plots again had more seedlings (368/m²) compared to fuel-added plots ([table 3](#)). Thus, in slash plots, increased germination resulted in similar seed bank depletion as where fuel was added. Seed populations

remained greatest in fuel removal plots, where initial germination in the field was lower, as predicted from lab results. During a third growing season with no fire, germination was greater in these plots (table 3). Only a small proportion seedlings survived to become established seedlings. After two burns and three growing seasons, there was an average of 22.4/m² 1 to 3 year old broom plants established in fuel-added and slash plots combined. This is only about 1 percent of the total number of germinants in slash plots.

Table 3a-b. Mean French broom seedling densities (followed by Standard Error) in three young and old stands burned with and without fuel manipulations (Control= cut slash left where felled).¹

Old broom (n=3)			
	control (n=9)	fuel addition (n=12)	fuel removal (n=12)
Burn			
1996 Recruitment	1649.6 628.8	478.4 218.4	298.8 36.4
Burn			
1997 Recruitment	368.4 107.6	216.8 87.2	292.8 111.3
1998 Recruitment	1.2 0.6	4.5 3.6	128.2 56.0
1998 1.5-3 year old broom	12.0 5.6	6.0 4.0	4.8 2.4
Young broom (n=3)			
Burn			
1996 Recruitment	317.2 125.2	706.8 220.0	132.0 36.4
Burn			
1997 Recruitment	126.8 49.3	13.6 11.2	73.4 27.6
1998 Recruitment	11.5 4.5	0.8 0.4	6.2 2.4
1998 1.5-3 year old broom	3.0 1.4	1.5 1.0	1.2 0.6
¹ Densities are expressed on a 1 m ² basis			

After one fire, fuel-added plots still had considerable seed populations, indicating that there is a large reservoir of seed that is too deeply buried in the soil to be killed by heating. Parker and Kersnar (1989) found that seed populations decreased with increasing soil depth (fig. 1), and that

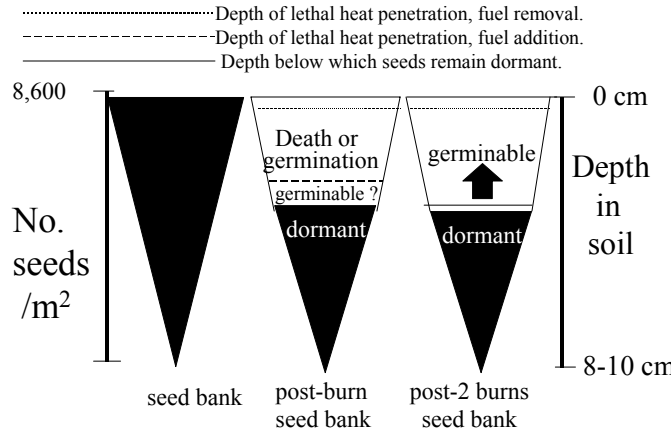


Figure 1. Seed bank depletion in old stands of French broom. Depth thresholds and decrease in seed bank sizes with depth are approximate.

about 10 percent of the seed bank was between 4 and 6 cm. Maximum temperatures in soils during fire decrease rapidly with depth (DeBano and others 1977). Seeds are affected much more by temperature maxima than by duration of heating, which may be prolonged at depth (Odion and Davis, In Press). Even in the most extreme chaparral wildfires, temperatures that would be lethal to broom seeds do not occur deeper than about 3 cm, and below about 5 to 6 cm they are not sufficient to break dormancy (DeBano and others 1977). In this respect, French broom is analogous to *Acacia suaveolens*, which maintains some deeply-buried seed that is unaffected by fire (Auld 1986).

Second-year germination data also demonstrate that considerable seed remained in the soil (table 3). Overturning soil after the first burn doubled the amount of seed that germinated the following year with no further treatment (table 4). The difference could be because seed low in the

Table 4. French Broom seedling densities in 2 by 2 m plots where soils were overturned, and adjacent paired control plots.

	Soil overturned		
	Unseeded	Seeded	Control
Mean	66.6	79.8	26.9
S.E.	22.8	40.0	16.1

soil remained dormant in control plots. However for Scottish broom, Bossard (1993) found that temperatures to provide minimal barriers to germination. Thus, the difference could also indicate that failed emergence may occur for deeply buried seed. Based on the average weight of broom

seeds (6.3 ± 1.1 mg for seeds retrieved from the soil) seedlings may only be able to emerge from depths of about 5-6 cm (see Bond and van Wilgen 1995, Fig. 5.12).

Characteristics of the seed bank in old broom stands are shown in [figure 1](#). Even though depth parameters are not known with precision, this model of the seed bank and its response to fire shows that there will continue to be persistent seed bank that, in the absence of seed natural seed predators, will primarily decrease by a rate determined by mortality and germination. The remaining seed bank will be below about 5 cm in the soil, which means that subsequent fire-induced germination or mortality depends on seeds moving upward. Although it may be possible to double germination by overturning the soil, this is a drastic, labor-intensive treatment. Thus, old broom stands may require burning many times to control seed input and eliminate re-emerging plants.

In young broom stands seeds begin to accumulate rapidly once plants start reproducing which often begin at 3 years. The difference in seed populations between 3 and 5 year-old stands will be substantial. For instance, samples from young stands had from 500 to 4,300/m². In direct contrast to old stands, the ~5 year-old stands produced more seedlings in fuel added compared to slash plots ([table 3](#)). The 1.5 m-tall cut broom, even when concentrated, did not provide sufficient soil heating to achieve significant mortality (12 percent). However, with considerable germination 700 seedlings/m² emerged, much of the seed bank can be exhausted by adding fuel, as evidenced by the low density observed after the second fire and low number of established plants after 3 years ([table 3](#)). Without fire, emergence in the fuel added area in year 3 was greatly reduced ([table 3](#)). In young stands, it might be possible to use fire to reduce the persistent seed bank to levels in which emergence without fire would be sparse and the prevention of recolonization would not be overly labor-intensive. Some follow up treatments would still be necessary. On the other hand, without added fuel, a majority of seeds persist and reduction of the seed bank to a level supporting limited recolonization would require many more treatments ([fig. 2](#)).

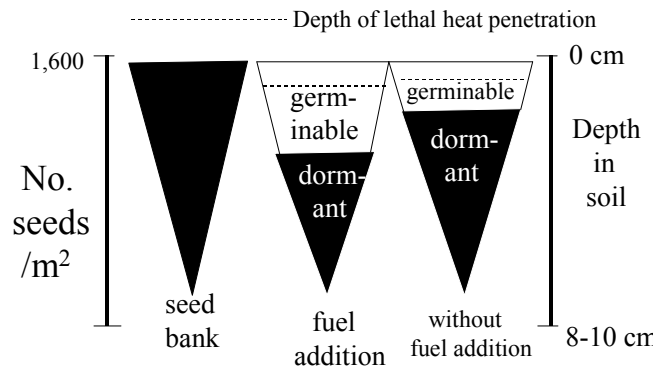


Figure 2. Seed bank depletion in young stands of French broom. Depth thresholds and decrease in seed bank sizes with depth are approximate.

As broom stands age (fig. 3), accumulation of seed at depth will cause a transition at some age after which they will be extremely difficult to eliminate using conventional methods because the size and depth distribution of the soil seed bank allows a large population of seeds to persist through fire. Fuel addition will no longer be effective. Parameters the models shown in figures 1-3 need to be refined in order to pinpoint when a broom stand undergoes this transition.

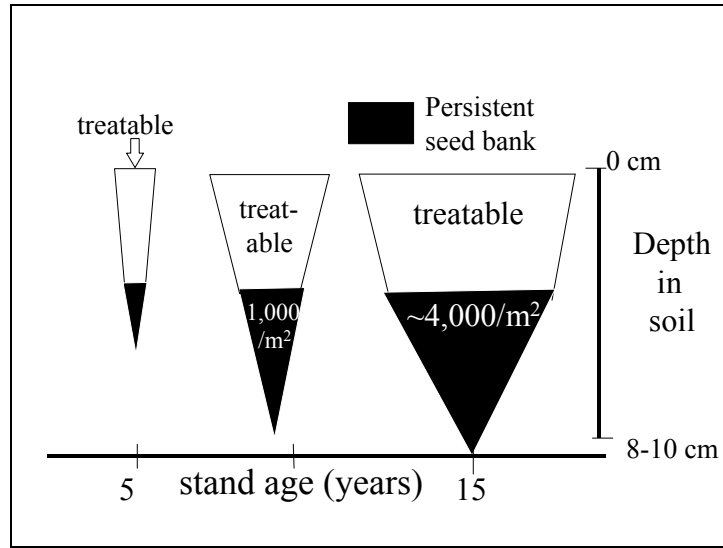


Figure 3. Changes in French Broom seed bank with time

Fire and Restoration of Habitat Conditions

Fire treatments had a positive effect on native species cover (fig. 4), especially in the old broom stands. This increase was considerably higher than in young broom stands, where there was no difference among treatments. Conversely, in old stands native species cover in fuel-added plots only increased to 7 percent (fig. 4), and to 10 percent with removal of slash. Native species contributing to the increase in cover were primarily the grasses *Nassella pulchra* and *Danthonia californica*.

Before burning, soils inhabited by broom had significantly more available nitrogen than soils without broom (fig. 5). It was demonstrated long ago that a fertilization effect increased dominance of nitrogen demanding species (Lawes and Gilbert 1880). Nitrogen availability may be a key element controlling community composition which has been documented in grasslands in Central California, where French broom invasion has reached its zenith (Huenneke and others 1990).

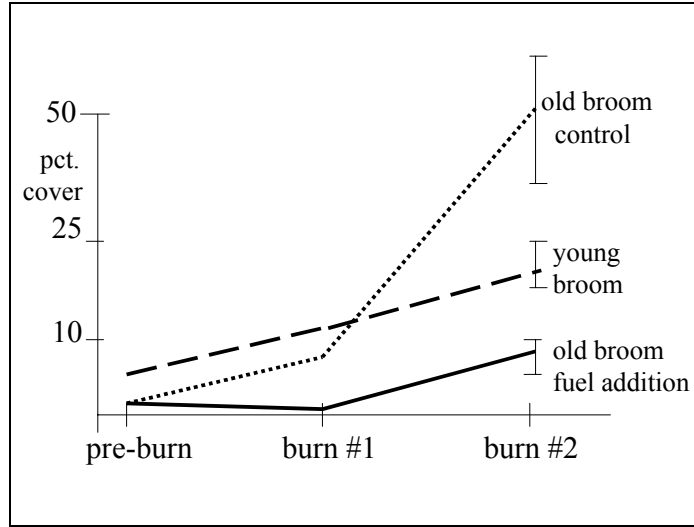


Figure 4. Changes in native plant cover with burning

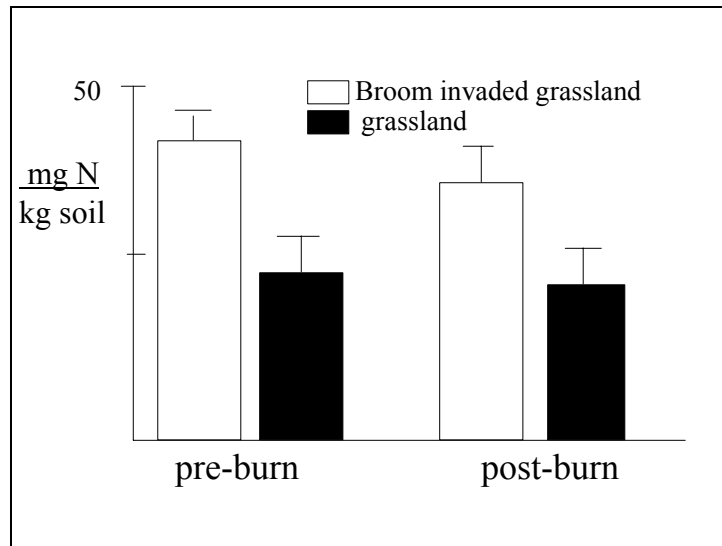


Figure 5. Anerobically mineralizable nitrogen in grassland soils invaded by French broom.

After burning, broom-invaded areas remain enriched. Nevertheless, there is clearly a trend toward lower available N in grassland plots that burned but did not have broom in them. In both February and April, burned grassland plots had lower amounts of available N, while all other treatments (burned and unburned broom, unburned grassland) had similar amounts of available N. Thus, broom may compensate for N losses caused by fire, and the N enrichment caused by broom invasion may persist in spite of fire.

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Biomass and Fuel Characteristics of Chaparral in Southern California

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Abstract

Knowledge of biomass components and fuel characteristics of southern California chaparral plant communities is important for planning prescribed fires, suppressing wildfires, managing the fire regime, and understanding the ecological interactions between fire and chaparral community development and succession. To improve our understanding of the relationship between fuels and fire behavior in chaparral, biomass and fuels were sampled on sites spanning a broad geographic range, as well as a range in age, species composition, and productivity. Total aboveground biomass of chaparral stands greater than 15 years old can range from 10 to 40 Mg/ha (1 Mg/ha = 1000 kg/ha) for *Adenostoma fasciculatum*, with canopy heights of 1.5 to 2.5 m, to as much as 120 Mg/ha for several *Ceanothus* species with canopy height as high as 5.5 to 6 m. Within a stand, coefficients of variation of biomass among plots are commonly 25 to 30 percent, and community structure can vary dramatically in relation to topographic and edaphic gradients over short distances of 5 to 10 m. Foliage accounts for 3 to 25 percent of total biomass in *A. fasciculatum* and *Ceanothus*-dominated stands. The fraction of stand biomass that is considered to be fuel available for fire propagation, which includes foliage, live twigs less than 6 mm in diameter, and dead woody material, ranges from approximately 30 percent to 75 percent in mature chaparral stands. This available fuel fraction is probably related to climatic factors such as prolonged drought periods, as well as species composition, species morphology, and site productivity. Our ongoing work is focused on improving efficiency of biomass and fuels sampling, and relating biomass development through time to site and climatic factors.

Introduction

Site-specific information on fuel characteristics is important for planning prescribed fires and suppressing wildfires in chaparral ecosystems in southern California. Knowledge of how chaparral biomass and fuels change over time, and how these changes are affected by climatic and site variability, will help us to effectively manage chaparral ecosystems to protect human life and property from wildfire and postfire flooding and sedimentation, while maintaining ecosystem productivity and biodiversity.

Although some research has been conducted on chaparral biomass and fuels, remains incomplete. For instance, several studies have reported on biomass components such as live wood and foliage, with no information on the distribution of this biomass among various fuel

1969, Stohlgren and others 1984). Fewer authors have presented detailed fuels information in addition to data on biomass components (Riggan and others 1988). Two limitations of these various studies are that the results represent only a limited number of sites and species, and little attempt has been made to relate differences in biomass or fuels among sites to geographic, topographic, or edaphic differences among sites. Rothermel and Philpot (1973) proposed a set of equations that describe age-dynamic fuel models and would allow estimation of biomass and fuels for different species compositions representative of a broad range of sites in the chaparral ecosystem. However, comparing these models to published data illustrates that the model for total biomass may not account for the wide variability of biomass among sites (fig. 1). This dynamic fuel modeling system also assumes a dramatic increase in dead fuel with increasing age, caused by widespread branch dieback (Rothermel and Philpot 1973). This assumption has been challenged by both Riggan and others (1988), and Paysen and Cohen (1990), who found no evidence that chamise chaparral dead fuel fraction was reliably predicted by age. Paysen and Cohen (1990) found wide variation in dead fraction, irrespective of age, and hypothesized that temporal climatic variability, especially rainfall, may be a primary factor influencing the accumulation of dead fuel in chamise. The opportunistic fungal pathogen *Botryosphaeria dothidea* has also been implicated as a primary cause of branch dieback of drought stressed shrubs, especially *Ceanothus* spp. (Riggan and others 1994).

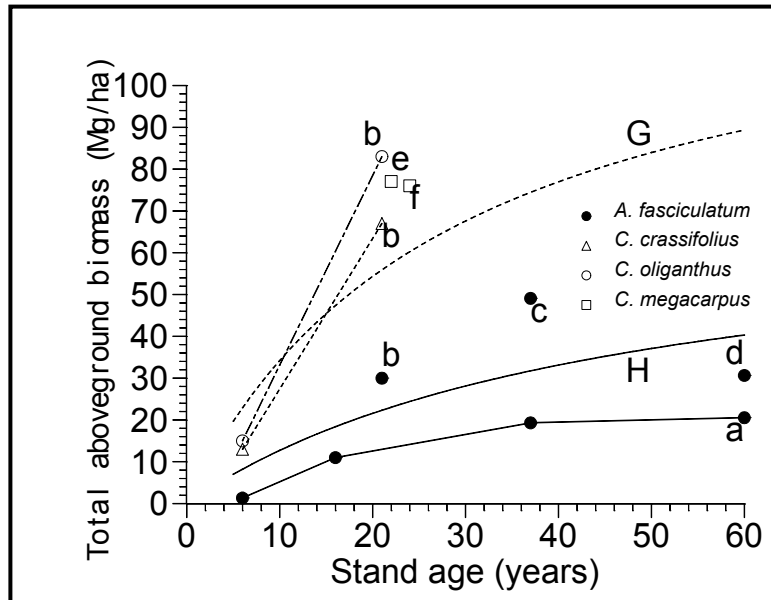


Figure 1. Biomass of various chaparral plant communities in relation to stand age. Different letters indicate different authors. **a** = Rundel and Parsons 1979; **b** = Riggan and others 1988; **c** = Specht 1969; **d** = Stohlgren and others 1984; **e** = Schlesinger and Gill 1980; **f** = Gray, 1982; **G, H** = Rothermel and Philpot 1973, fuel models for mixed chaparral and chamise chaparral, respectively.

Although much work has been focused on chaparral fuel and biomass, land managers and scientists currently lack the means to estimate reliably fuel loading, fuel structure, and biomass components of specific chaparral sites, or how these characteristics of sites will change as a stand regenerates and matures after fire. This paper presents an overview of our ongoing research into

the estimation of chaparral fuels and biomass components, including some preliminary results, and to discuss gaps in our knowledge that need to be addressed in future research.

Methods

Study Sites

We have acquired data on chaparral biomass components and fuels from 16 sites in southern California over the past several years, as parts of several different studies. These studies have been conducted to assess smoke emissions from prescribed burning of chaparral, describe chaparral water use in relation to soil and weathered rock water holding capacity, determine efficient sampling and estimation procedures for quantifying chaparral biomass and fuels, and to obtain ground-based data for calibration of remotely sensed data to chaparral stand characteristics, including species composition, canopy water content, and fuel and biomass loading and structure. These sites span a broad range of geographic distribution, species composition, and years since last fire. Eight sites were sampled in each of two of the most important general types of chaparral communities, chamise (*Adenostoma fasciculatum* Hook. & Arn.) chaparral and mixed chaparral, which is commonly dominated by members of the genus *Ceanothus*.

Sampling and Estimation Procedures

The specific data collection, processing, and analytical procedures differ somewhat among sites because these data were collected as part of several different studies (Regelbrugge and Conard, in press). Detailed description of methodology and rationale for each study is beyond the scope of this paper, but we will briefly describe in general terms the different approaches used. The methods used in all of the studies allow estimation of total aboveground biomass of the dominant shrub community, and the partitioning of this biomass into live wood, dead wood, and foliage components. Because herbaceous plants are not common in mature chaparral (Hanes 1971), we made no attempt to quantify them in our study. Accumulated surface litter, or forest floor, also tends to be very sparse under many mature chaparral stands, particularly stands dominated by *A. fasciculatum*. Although litter accumulations are greater in stands dominated by *Ceanothus spp.* and *Quercus spp.*, we were primarily interested in canopy fuels that dominate fire behavior; thus, we did no sampling of surface litter. Because one of the goals of our ongoing research into chaparral ecosystems was to quantify patterns of fuel loading with respect to species composition, site factors, and age, we further partitioned the live and dead woody material of a subsample of shrubs into size classes related to fuel particle surface to volume ratio (Burgan and Rothermel 1984). This partitioning allowed the development of site-specific, or more general, fuel models for chaparral sites that can be used to simulate fire behavior with the Rothermel fire spread model (Rothermel 1972) by using the BEHAVE system (Andrews 1986) or the spatially explicit implementation of the Rothermel model, FARSITE (Finney 1994). Detailed analyses comparing various fuel models is beyond the scope of this paper, although some general fuel parameters will be discussed, such as total fuel loading, fuel dead fraction, and foliage fraction. We used the definition of total fuel available for fire propagation described in Burgan and Rothermel (1984), i.e., dead woody material less than 76

mm (3 in) in diameter, live wood less than 6.3 mm (.25 in) in diameter, and foliage. We acknowledge that in some stands, such as those dominated by scrub oak (*Quercus berberidifolia*), accumulated leaf litter may be an important component of the available fuel, as would be grasses and other herbaceous plants in very young stands up to 5 to 10 years old. However, these issues are not a concern for many chaparral sites, including those we sampled.

Results and Discussion

Total Biomass

Total aboveground biomass of all sites ranged between 16 and 118 Mg/ha (Figure 2A), with an overall mean of 50 (± 7.5 , standard error of the mean (SE)) Mg/ha (1 Mg/ha = 1000 kg/ha). Aboveground biomass of *A. fasciculatum*-dominated stands ranged from 16 to 40 Mg/ha, with an average of 26 (± 2.6 , SE) Mg/ha, while *Ceanothus*-dominated chaparral had much higher biomass, ranging from 50 to 118 Mg/ha, with an average of 74 (± 8.6 , SE) Mg/ha (fig. 2A). Age of the stands sampled ranged from 10 to 55 years (fig. 2A), with stands of both species spanning a similar range. Any clear relationship between biomass and age is not apparent, which may not be surprising given the broad range of site conditions these stands represent. These stands represent a broad geographic range, with some stands being within a few kilometers of the Pacific Ocean, and others lying as much as 200 km inland. Average annual rainfall within the study area may vary between 300 and 800 mm/yr, depending on the site. Differences in site factors such as aspect may be reflected in species composition, but other studies have noted large differences in total stand biomass among sites of identical age and species composition (Riggan and others 1988, Schlesinger and Gill 1980). We suspect that water balance and nutrients may account for differences in site productivity that are reflected in the wide variability in stand biomass. These factors will be related to soil depth, soil chemical and physical properties, and topographic influences such as slope aspect, inclination, and position, as well as rainfall. The manner in which site factors influence productivity, and therefore biomass yield, is understood only in a general sense for chaparral. Although further analysis of our data and that found in the literature (e.g. Riggan and others 1988, Schlesinger and Gill 1980) will help to elucidate the relationship of site factors and productivity, we believe that additional data need to be collected to address this question specifically.

Available Fuel

Because available fuel contains only dead wood less than 76 mm in diameter, live wood less than 6.3 mm in diameter, and foliage, total available fuel is somewhat less than total aboveground biomass for most stands, but otherwise displays similar trends with respect to stand age. An important question is what fraction of total biomass comprises available fuel, and is this

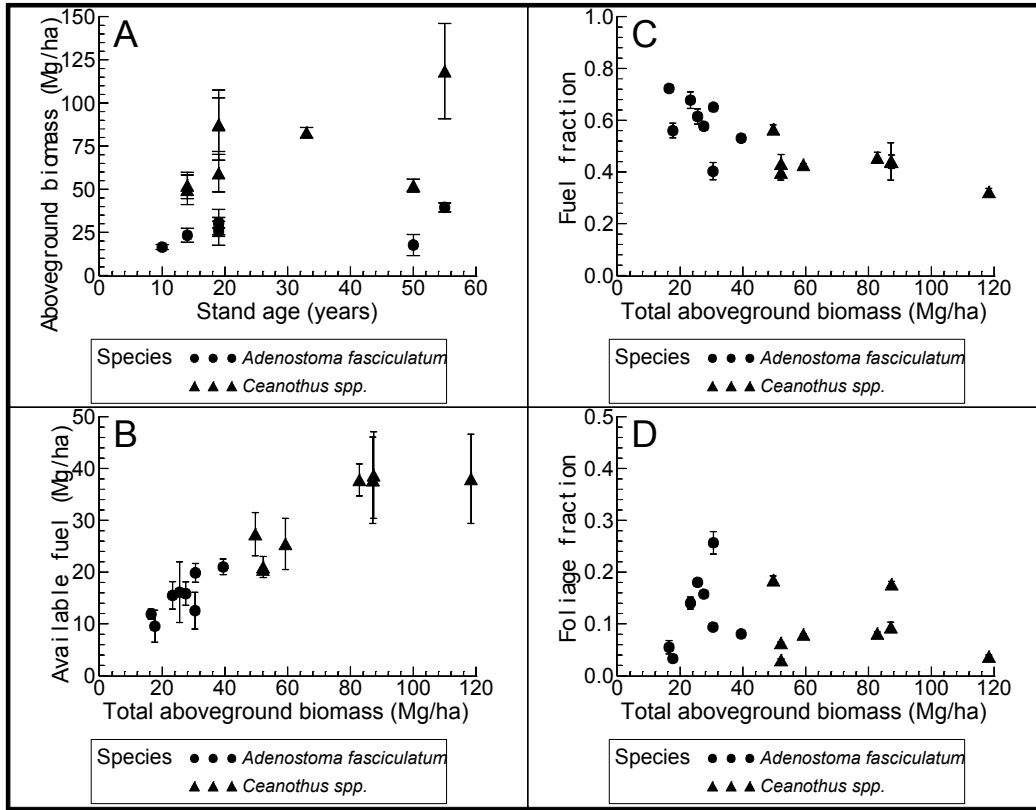


Figure 2A. Total aboveground biomass for 16 chaparral sites in southern California versus stand age.
Figure 2B. Total aboveground biomass for 16 chaparral sites in southern California versus available fuel.
Figure 2C. Total aboveground biomass for 16 chaparral sites in southern California versus fraction of stand biomass that constitutes available fuel.
Figure 2D. Total aboveground biomass for 16 chaparral sites in southern California versus foliage as a fraction of stand biomass.

fraction related to variables like species composition, stand age, or total stand biomass. These relationships could be used to estimate total fuel, or perhaps fuel components, without the need for costly, labor intensive partitioning of shrub samples into components. Total available fuel increases with total biomass (fig. 2B), but total available fuel does not appear to be a constant proportion of total biomass (fig. 2B, 2C). *Ceanothus* species tend to grow larger diameter stems and branches than does *A. fasciculatum*, and this is illustrated in the lower fuel fraction in *Ceanothus*-dominated stands (fig. 2C) where more of the total stand biomass is concentrated in large diameter woody material which is not considered to be available fuel. Average fuel fraction was $59 (\pm 4, \text{SE})$ percent for *A. fasciculatum* stands, and $43 (\pm 2, \text{SE})$ percent for *Ceanothus*-dominated stands (fig. 2C). We suspect that the relative dominance, i.e., proportion of total biomass, of species with different physical structure, in stands of mixed composition will be related to the fuel fraction. For example, the *Ceanothus*-dominated stand with the highest fuel fraction in our study, 56 percent, had a larger *A. fasciculatum* component than any other *Ceanothus* stands we observed (fig. 2C). Future analyses will incorporate any published data available to investigate variability in fuel fraction within species, and in relation to species proportion in mixed stands.

Foliage Biomass

Foliage of chaparral plants has very high surface-to-volume ratios (σ), which means it is rapidly dehydrated and ignited by a flame front, and is therefore a very important fuel for fire propagation in chaparral. Foliage as a fraction of total stand biomass ranged from 3 to 25 percent, with an average of 11 (± 2 , SE) percent (fig. 2D), and did not appear different between *A. fasciculatum* and *Ceanothus* stands. However, the two *Ceanothus* stands with the lowest foliage fractions, about 3 percent, were composed of *Ceanothus oliganthus* and *Ceanothus spinosus*, species with very thin, mesophytic leaves compared to the thick, sclerophyllous leaves of many *Ceanothus* species (fig. 2D). Foliage has high σ compared to woody fuels, which gives foliage strong influence on fire behavior in simulations; thus, it may be necessary to consider the influence of leaf morphology on foliage biomass if constructing site-specific fuel models. Observations of actual fires also indicates that propagation of fire through the chaparral canopy is strongly dependent on foliage.

Dead Fraction

Dead woody biomass in chaparral originates from two distinctly different sources. The first, and that most commonly described in the literature, is from mortality of branches and plants during stand development. This mortality likely results from shading and competition for soil water, and perhaps nutrients. The other source is from residual "skeletons" of shrubs that were not burned in the last fire. Dead biomass varied widely in our study, ranging from 12 to 46 percent of total stand biomass (fig. 3A), and showed no clear trends with respect to species composition or stand age. Although several authors have previously indicated that chaparral dead fraction increases strongly as stands age, (e.g. Green 1981, Rothermel and Philpot 1973), our data are consistent with the findings of Paysen and Cohen (1990), in which chaparral dead fraction is not reliably predicted by age. Distinguishing whether dead fuel is expressed as a fraction of total fuel, or of total stand biomass, is important for clarity, but this distinction is rare in the literature. In our study, virtually all dead wood was within the size range to be considered fuel, but if this dead fuel mass is expressed as a fraction of available fuel, we get a range of 27 to 72 percent, considerably higher than dead fuel as a fraction of stand biomass (fig. 3B). We do not know whether this ambiguity in terminology is responsible for part of the confusion over dead fuel fraction in the literature but hope that future authors will define and use terminology clearly. Although most dead fuel is assumed to result from branch and shrub mortality during stand development, we caution that this may not always be the case. The youngest stand in our study appears to have an extremely high proportion of dead fuel, 63 percent of total fuel (fig. 3B). We observed that this stand contained many dead shrub stems 25 to 76 mm in diameter, with no fine branchwood attached, that appeared to be residual from a fire 10 years earlier. Although this situation may be atypical, it will influence fuel bed geometry in potentially significant ways.

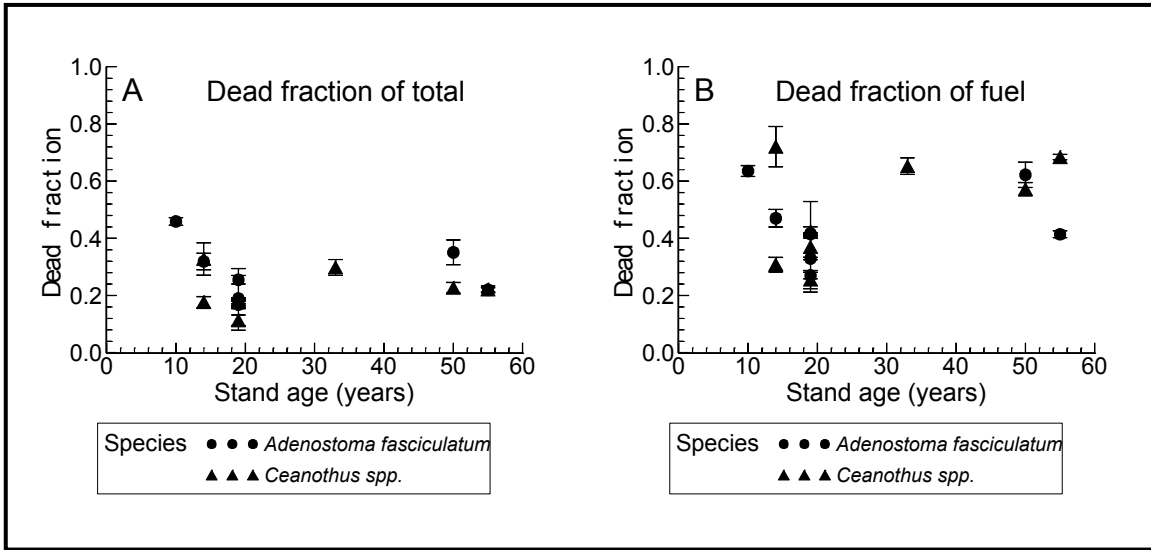


Figure 3A. Dead biomass in relation to stand age, expressed as a fraction of total aboveground biomass of 16 chaparral sites in southern California.

Figure 3B. Dead biomass in relation to stand age, expressed as a fraction of available fuel of 16 chaparral sites in southern California.

Spatial Variation of Biomass and Fuels

Although variation in biomass and fuels among chaparral sites has been well documented, much less information has been published on variability within a site. Several of our studies have involved sampling multiple plots within a given stand. Compared to surrounding areas, these stands were relatively homogeneous within an area between 0.5 and 5 ha. The coefficient of variation among plots in estimated stand biomass was often as high as 25 or 30 percent (fig. 4). For the stand of *A. fasciculatum* with *Arctostaphylos glandulosa* Eastw. (Eastwood manzanita) as an associated species at the North Mountain Experimental Area, biomass of 5 by 5 m subplots ranged between 20 and 60 Mg/ha (fig. 4), with a mean of 39 (± 2.6 , SE) Mg/ha. This variability in biomass is readily apparent from the variable structure of the plant community as one explores this site. The topography of this area is highly dissected, and variability in soil depth to bedrock and the degree of weathering of the bedrock are also quite variable (Sternberg and others 1996). These factors could very well influence microsite productivity, and consequently, biomass and fuel accumulation, through their influence on water availability for plant growth.

Variable fuel structure may well have an important effect on both model predicted and actual fire behavior (Fujioka 1985). The degree to which spatial variation in fuels will affect fire behavior is unclear for several reasons. Although it is possible to assess the sensitivity of the Rothermel model to changes in chaparral fuel, we still do not have a good sense of how well predictions from the Rothermel model correspond to actual fire behavior in chaparral fuels. This uncertainty is due at least in part to the difficulty of collecting data on fire spread where all of the required inputs for fire modeling are accurately known (Albini and Anderson 1982). Secondly, we do not know clearly at what spatial scale the variability in fuels becomes important. There may well be a spatial scale below which variability in fuels does not affect fire behavior in an

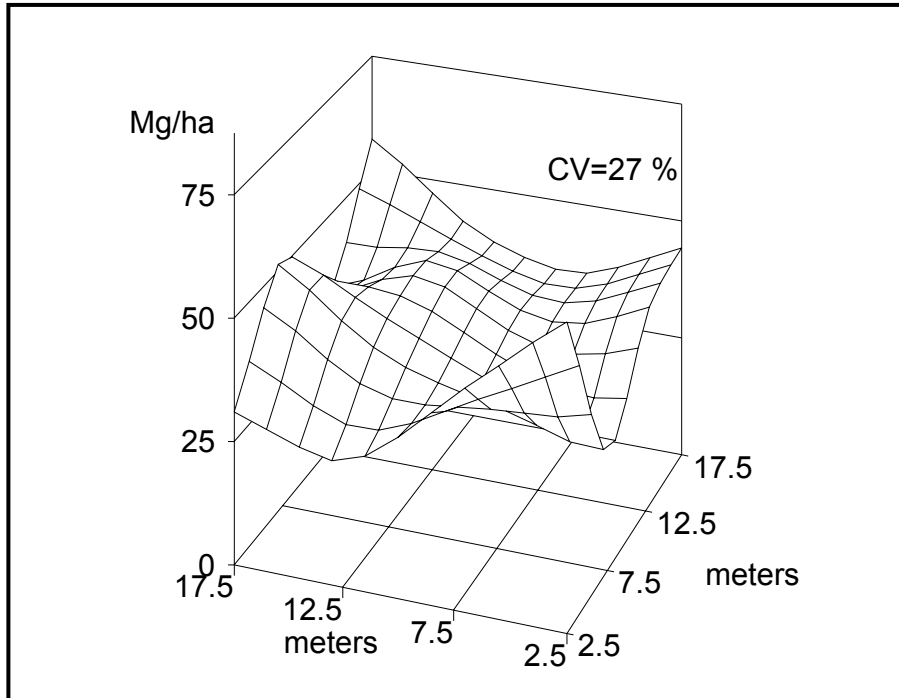


Figure 4. Spatial variation of aboveground biomass in an *Adenostoma fasciculatum* - *Arctostaphylos glandulosa* stand at the North Mountain Experimental Area in the San Jacinto Mountains of southern California. The surface shows a spline interpolation of biomass values estimated for 16 contiguous subplots (5 by 5 m in size), and the x and y axes show relative position of subplot centers at 2.5 m intervals. Coefficient of variation of total aboveground biomass among these subplots was 27 percent.

observable manner; therefore, the average condition of such a unit would be sufficient knowledge. Above this scale, however, variability could strongly influence fire behavior as the flame front moved through fuel zones with different physical structure. This topic requires much investigation to answer these questions.

Future Research Needs

A computerized fuels database with sufficient accuracy, accessibility, and geographic coverage is a necessary element for fire modeling for both strategic and tactical applications (Albini and Anderson 1982). To implement such a system, we need to elucidate further patterns of chaparral growth through time and in relation to site characteristics. We also need to correlate ground-based measures of chaparral fuels and biomass with remotely sensed data. This would allow mapping chaparral fuels at broad landscape levels, facilitate incorporation of fuels data with other pertinent landscape attributes via GIS, and allow relatively easy updating and modification of the database as needed to account for growth or disturbances such as fires or episodes of dieback related to drought and pathogens such as *Botryosphaeria dothidea*. Although remote sensing is vital to the development of an extensive fuels database, several important knowledge gaps can be filled only through ground-based sampling. These questions mostly relate to quantifying the effects of site productivity on chaparral growth, and relating the

accumulation of dead woody fuel to causal, or perhaps only associative, factors. Identifying the causal mechanism of deadwood accumulation would be ideal, but an associative relationship potentially could be exploited in a predictive manner as well.

Fuel bed geometry is probably also very important to the manner in which fire propagates in chaparral. Unlike forest floor fuels, chaparral fuel particles typically are oriented vertically, and chaparral fuel beds have very high porosity compared to many other wildland fuel types. Fine twigs and foliage tend to be stratified vertically, and the height of greatest concentration of these most flammable fuels above the ground surface varies both within and among species. These and other structural properties of chaparral fuel beds have only been described in a very cursory, simplistic fashion. Yet, practical experience indicates that these may have a profound influence on fire behavior. *A. fasciculatum* stands, with many fine branches in relatively compact crowns, which tend to be close to the ground, seem relatively easy to burn under prescribed burning conditions, while mature *Ceanothus* stands, with taller canopies composed of fuels with lower σ , often seem able to sustain combustion only under extreme conditions. Although many fire professionals have an intuitive sense of these types of phenomena, quantitative descriptions of thresholds such as these have not been developed, in spite of their potential utility. Not only do we lack understanding of where spread thresholds may occur, we can't describe the relative influence of σ versus fuel bed porosity or fuel particle arrangement on spread thresholds. Experimental fires, in which fire behavior can be closely monitored and related to measured fuels and weather information, would help to describe thresholds which separate conditions where fires either will or will not spread, and help to detect the scale in which variability in fuels affect fire spread and intensity in a detectable fashion.

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Impacts of Postfire Grass Seeding on Vegetation Recovery in Southern California Chaparral

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Abstract

Postfire grass seeding as an attempt at erosion control on chaparral slopes has been a common practice for decades. Annual ryegrass (*Lolium multiflorum*) has been most frequently used. Critics point out that ryegrass can suppress native species and may reduce shrub seedling survival. In 1986, we began investigating the impacts of seeded ryegrass on chaparral regeneration. We gathered prefire vegetation data on sites scheduled to be burned in wildfire-intensity prescribed fires. After four prescribed fires and a wildfire, half of the vegetation plots at each site were seeded with annual ryegrass, and vegetation cover, composition, and shrub seedling density were measured each spring for 5 years. At only one site was average total herbaceous plant cover significantly greater on seeded plots than on unseeded plots. At all sites, average herbaceous plant cover other than ryegrass was less on seeded plots in at least one postfire year. Mean shrub seedling density was never significantly different between seeded and unseeded plots. After 5 years, surviving shrub seedling density appeared to be sufficient to replace plants killed by fire. Our results suggest that seeded ryegrass has a greater impact on the chaparral postfire herbaceous flora than on shrub seedling regeneration in southern California.

Introduction

Chaparral is the fire-prone, shrub-dominated vegetation type that cloaks steep hillsides in the hills and mountains adjacent to many southern California cities. At the end of a typical warm, dry summer, fuel moisture (plant water content) is very low and high-intensity fires may occur, killing all aboveground biomass (Keeley and Keeley 1988). A flush of annual and perennial herbaceous plants appears during the first spring growing season after a fire, along with shrub seedlings and resprouts from underground structures of some species (Horton and Kraebel 1955, Keeley and Keeley 1981). By about 4 years after a fire, shrubs again dominate burned areas (Hanes 1971, Keeley and Keeley 1988).

During the first winter after a chaparral fire, while slopes are still bare, rainstorms of even moderate intensity can mobilize destabilized hillslope surface material and cause major downstream debris flows and flooding (Wells 1987). To try to reduce this erosion and the threat posed to human structures and utilities, agencies such as the California Department of Forestry

and Fire Protection and the USDA Forest Service often seed burned chaparral hillslopes with annual grasses such as annual ryegrass (*Lolium multiflorum* Lam.; Hickman 1993), a native of Europe. Ryegrass has been chosen because it germinates quickly, produces an extensive fibrous root system, is inexpensive and readily available, and it can easily be applied from the air (Barro and Conard 1987). Critics of the practice point to studies showing that postfire grass seeding interferes with growth of the native postfire flora, particularly annuals with fire-stimulated germination, and seedlings of shrub species that are killed by fire (Gautier 1983, Keeler-Wolf 1995, Keeley and others 1981, Taskey and others 1989).

Previous studies often used a limited number of usually small plots located in areas burned by wildfire, where the prefire vegetation composition could not be known for certain. To address some of these limitations, in 1986 we began a long-term study of the effects of postfire grass seeding on vegetation development and erosion in southern California chaparral (Beyers and others 1998, Wohlgemuth and others, this volume). This paper summarizes the vegetation results of our study on the impacts of seeded ryegrass on chaparral regeneration after fire.

Methods

Study sites were established in areas of mature, mixed chaparral scheduled to be burned in wildfire-intensity prescribed fires. At each site, forty 2 m by 10 m vegetation plots were installed before the fire. Prefire vegetation measurements included density and cover of shrub species. After the fire on each site, fire severity was evaluated on each plot and only those plots where severity was moderate or high (table 1) were retained in the study. In the fall after each fire, half of all completely burned plots were seeded with annual ryegrass. Seed was applied by hand with rotary fertilizer spreaders at a target density of 430 seeds m⁻² (approximately 9 kg ha⁻¹ [8 lb. ac⁻¹], a common target rate for aerial seeding). Vegetation development on seeded and unseeded plots was measured each spring when herbaceous species were at peak biomass, for up to 5 years after fire. Cover of all species present was determined by eye after dividing each plot into five 2-m by 2-m subplots. Shrub seedlings were counted within five 1-m by 1-m subplots in each plot. The canopy volume of each sprouting shrub within each plot was estimated by measuring the shrub's height and two perpendicular canopy diameters. Differences between seeded and unseeded plots were analyzed using a two-sample randomization test (Manly 1991); each P-value was estimated from 1,000 randomizations, and only P-values less than 0.05 were considered significant.

Table 1. Characteristics of five chaparral study sites in coastal southern California.

	Bedford	Belmar1	Belmar2	Buckhorn	Vierra
Mountain range	Santa Ana	Santa Monica	Santa Monica	Santa Ynez	Santa Lucia
Elevation (m)	670	450	450	1035	425
Mean aspect	NE	S	SSE	SSW	S
Mean slope (°) ¹	36 ± 0.8	27 ± 0.9	27 ± 0.8	33 ± 0.7	28 ± 0.7
Prefire live shrub cover (pct) ¹	33 ± 1.7	45 ± 4.3	48 ± 2.7	28 ± 3.3	31 ± 1.1
Dominant prefire shrub species	<u>Quercus berberidifolia</u> <u>Prunus ilicifolia</u> <u>Rhamnus ilicifolia</u> <u>Fraxinus dipetala</u>	<u>Ceanothus megacarpus</u> <u>Malosma laurina</u> <u>Cercocarpus betuloides</u> <u>Heteromeles arbutifolia</u>	<u>Ceanothus megacarpus</u> <u>Malosma laurina</u> <u>Cercocarpus betuloides</u> <u>Heteromeles arbutifolia</u>	<u>Ceanothus cuneatus</u> <u>Adenostoma fasciculatum</u> <u>Quercus berberidifolia</u> <u>Prunus ilicifolia</u>	<u>Adenostoma fasciculatum</u> <u>Ceanothus cuneatus</u> <u>Salvia mellifera</u> <u>Prunus ilicifolia</u>
Burn month/year	July 1990	June 1988	Nov. 1993 ²	Mar. 1994	Nov. 1990
Fire severity ³	High	Moderate	High	High	High/Mod.

¹ Slope and shrub cover values are means ± s.e.

² Burned in wildfire; other sites burned in prescribed fires.

³ Moderate severity: leaf litter mostly consumed; soil charred to 1 cm depth; >25% unburned foliage remaining.

High severity: leaf litter completely consumed; soil charred to 2.5 cm depth; foliage completely consumed.

Results

Study sites were located in four coastal mountain ranges and burned in different years (table 1). One site (Belmar2) burned in a wildfire in November 1993; it was adjacent to a site burned 5 years earlier in a prescribed fire (Belmar1). The Buckhorn fire was conducted in March 1994, and seeding was not done until the following fall. Although vegetation sampling was conducted at Buckhorn in the spring of 1994, the spring of 1995 is considered the first growing season after fire for the purpose of comparing seeded to unseeded treatments on that site.

At the end of the first growing season after fire, total vegetation cover was not significantly different between seeded and unseeded plots at any site except Vierra (burned November 1990). At Vierra, vegetation cover was extremely low even on the ryegrass-seeded plots and consisted mostly of sprouting shrubs (fig. 1). At Belmar1 and Buckhorn, cover of herbaceous species other than ryegrass was significantly less on seeded plots during the first

year; there was no difference at the other sites. Ryegrass achieved its maximum absolute cover during the first growing season at Belmar1 and Buckhorn and declined thereafter.

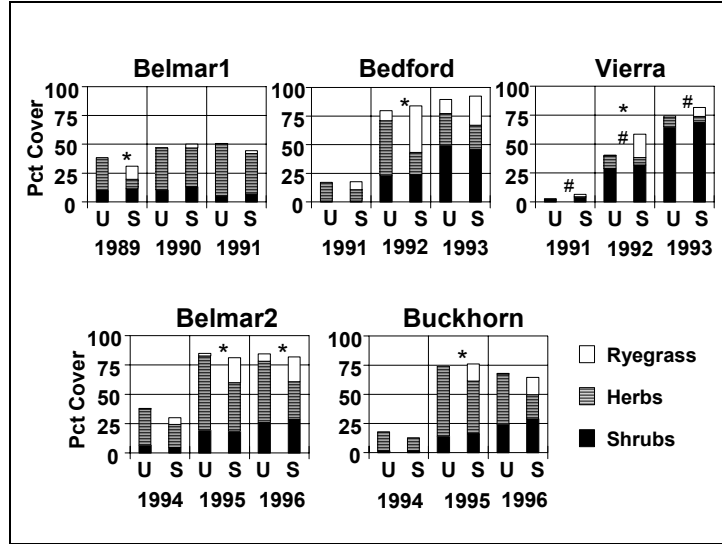


Figure 1. Mean total vegetation cover at five chaparral study sites, measured in late spring during the first three growing seasons after fire and seeding. Bars are divided into relative amounts of shrub, herbaceous, and ryegrass cover (actual cover of individual species added to more than 100 percent in some years). Within each year, U=unseeded plots and S=seeded plots. #=mean total cover significantly different between seeded and unseeded plots at $p < 0.05$. *=mean herbaceous cover other than ryegrass significantly different between seeded and unseeded plots at $p < 0.05$.

After the second and third postfire growing seasons, total vegetation cover again was significantly greater on seeded plots only at Vierra. Ryegrass cover was greatest during the second growing season after fire at Bedford, Vierra, and Belmar2. Cover of herbaceous species other than ryegrass was significantly less on seeded plots during the second growing season after fire on these sites as well (fig. 1). Ryegrass cover was low on all sites in the fourth and fifth year.

Sprouting shrub canopy volume and total shrub cover were not significantly different between seeded and unseeded plots at any site. At all sites except Bedford, species of Ceanothus were the most common chaparral shrubs regenerating from seed (the Bedford site produced few shrub seedlings of any kind). Ceanothus seedling densities in seeded and unseeded plots were not significantly different ($p > 0.05$) at any site during the first three growing seasons after fire (table 2). At all sites, density of surviving Ceanothus seedlings after 3 to 5 years was greater than prefire shrub density.

Table 2. Mean prefire density¹ of obligate-seeding *Ceanothus* species at four study sites, and mean postfire densities of seedlings of those species in seeded and unseeded plots.

	Belmar1		Belmar2		Buckhorn		Vierra	
	Unseeded	Seeded	Unseeded	Seeded	Unseeded	Seeded	Unseeded	Seeded
Prefire # m ⁻²	0.3 ± 0.15	0.2 ± 0.09	0.4 ± 0.09	0.4 ± 0.10	0.3 ± 0.03	0.5 ± 0.08	0.4 ± 0.06	0.3 ± 0.05
Postfire # m ⁻²								
Year 1	4.6 ± 1.4	1.7 ± 1.0	9.4 ± 3.4	6.6 ± 3.2	6.9 ± 1.7	4.2 ± 1.3	5.4 ± 0.9	5.6 ± 1.0
Year 2	0.4 ± 0.2	0.2 ± 0.2	2.9 ± 0.9	2.3 ± 0.7	0.7 ± 0.3	0.4 ± 0.2	3.9 ± 0.7	3.4 ± 0.8
Year 3	0.4 ± 0.2	0.4 ± 0.2	2.2 ± 0.7	1.7 ± 1.7	0.6 ± 0.3	0.4 ± 0.2	2.0 ± 0.4	2.0 ± 0.4

¹ number m⁻² ± s.e.

Discussion

Chaparral stands have a soil “seed bank” of shrub and herbaceous species, many of which are released from dormancy as a result of fire (Keeley 1991). Seedlings appear during the first spring after fire. Annual grasses are sown onto burn sites with the intention of increasing plant cover over what will be produced naturally.

Keeley and others (1981) observed a negative relationship between ryegrass cover and cover of native fire-annuals at several sites in San Diego County. Similar to other researchers (Gautier 1983, Taskey and others 1989), we found that annual ryegrass tended to replace, rather than add to, natural herbaceous plant cover on post-burn sites in southern California chaparral. At all sites, average herbaceous plant cover other than ryegrass was less on seeded than on unseeded plots in at least 1 postfire year. Herbaceous species richness was lower on seeded plots as well (Beyers and others 1994). Only on the site with the least herbaceous vegetation cover, Vierra, did ryegrass seeded plots have significantly greater total plant cover. The slightly greater plant cover did not produce a significant decrease in winter erosion (Wohlgemuth and others, this volume).

Conard and others (1995) presented a conceptual model of postfire vegetation development in chaparral based on results from our first three study sites (Belmar1, Bedford, and Vierra). The model suggested that under environmental conditions favorable for plant growth, natural postfire plant regeneration should produce as much cover as sites augmented with seeded grass. Our results from two new sites (Belmar2, Buckhorn), where rainfall during the first few postfire winters was relatively high (Wohlgemuth and others in press), appear to support the model.

An obligate seeding *Ceanothus* species was an important component of the prefire vegetation at all sites except Bedford (table 1). Obligate seeders are killed by fire and must regenerate from seed. Unlike the herbaceous flora, *Ceanothus* seedling density was not negatively affected by ryegrass seeding. Average ryegrass cover during the first winter after fire, when shrub seedlings germinate and become established, did not exceed 20 percent on our study sites. Where greater winter rainfall results in higher grass cover during the first growing season

after fire, as in northern California, shrub seedlings may be suppressed by seeding (Schulz and others 1955). Shrub seedling density after 3 to 5 years on our sites appeared sufficient to replace plants killed by fire, though more seedling mortality may be expected in later years (Riggan and others 1988).

The long-term impact of the reduction in postfire native herbaceous plant cover on ryegrass-seeded sites is unknown. Keeley and others (1981) identified a group of annual plants (“pyrophyte endemics”) that germinate and grow almost exclusively in the first growing season after a fire. Two of our study sites had enough ryegrass cover the first year to apparently cause a reduction in the abundance of native herbs (including pyrophyte endemics). These species may persist into the second year after fire, when ryegrass cover is usually greater. Reduction in growth of postfire specialists may reduce the seed bank available to germinate after the next fire. Resampling our seeded and unseeded plots after they burn again may help address this concern.

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What Unmanaged Fire Regimes in Baja California Tell Us about Presuppression Fire in California Mediterranean Ecosystems

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Abstract

Long-term change in California chaparral and conifer forest ecosystems as the result of fire suppression management is important because fire control has led to unintended alteration and degradation of these ecosystems. Baja California has not experienced the same utilization or protectionist management policies as has Alta California, and the potential divergence in the disturbance ecology of similar ecosystems in the two countries may provide insight into the nature of historical vegetation change in Alta California. In California chaparral, a discrete transformation exists in stand configuration across the international boundary—from a fine-grained patch structure in Baja California to a coarse patch structure in California related to self-limiting fire occurrence in the ecosystem. Fire control in California selects for nonrandom fire occurrence in extreme weather, resulting in higher average spread rates and flame line intensities than in Baja California. Historical writings suggest that fire was self-regulating and that patchiness similar to that in currently seen in Baja California was characteristic of chaparral during the late 19th century. Spatial fire history in the Sierra San Pedro Mártir show that the open structure of mixed conifer forest was maintained by intense understory fires with fire rotation periods of 35 to 70 years. Return intervals in the U.S. Southwest may be underestimated because fire scars recorded in dendrochronologies could represent both landscape burns and spot burns that have limited cumulative spatial extent and have limited demographic impact on forests.

Northern Baja California's mediterranean landscape of shrublands and conifer forests is a mirror of California's past. The remoteness of this region has preserved a rural land-use system of local cropping and open range cattle grazing. Fire control is practically nonexistent as the mountains are still accessible only by foot, or horseback, and a few unimproved roads. Local residents deliberately burned until recently for purposes of livestock access, browse improvement, and agricultural purposes. Yet, the vegetation has remained little altered from the late 18th century, when Europeans first described the region (Minnich and Franco 1998).

The Baja California Landscape

The chaparral appears as a diverse, fine-grained patch mosaic, much like that of a quilt. From any view, a dozen patches of different ages are visible—from fresh burns, to medium-statured thickets, to impenetrable old-growth tracts. The burns, which invariably have a myriad of unburned islands, often stretch from west to east, parallel to the daily rush of sea breezes and slope winds moving onshore from the Pacific. Almost any afternoon during summer are a few

smokes that can be seen in the distance, some capped by cumulus clouds, reflecting the humidity brought in from the ocean. Thunderstorms habitually form along the high Sierra Juárez and Sierra San Pedro Mártir, the lightning from them triggering small fires almost daily. A few larger storms drift toward the Pacific coast before fading away. Beneath the smoke columns are fires creeping along a slope, sometimes in long flame lines, more often in discontinuous flame fronts weaving through the brush.

In the highest mountains are extensive open stands of large pines - the subcanopy having only a few young trees and scattered shrubs. Many trees bear large burned-out cavities (catfaces) on their lower boles that were created by ground fires. Others bear coiled narrow strips of denuded bark that were peeled off by lightning strikes that pummel the mountains. Some trees bear both types of scars. The recent burns had left behind denuded shrubs and saplings as large as 10 to 20 m. The old surviving pines display an umbrella-like canopy because live branches seldom grow below 15 m, the lower boughs apparently removed by burns equally intense long ago. Stands untouched by fire have a proliferation of young conifers, some forming dense thickets. In the evening, the dissipating fires leave long thin stringers of smoke that wander aimlessly in the darkening skies. The flames seemed to have put themselves out, yet many of the larger burns will reestablish the next afternoon, and the next - with a few burning for weeks or the entire burning season until ultimately doused by the first winter storms.

This picture of northern Baja California may seem exotic to those experienced with similar landscapes in California. North of the international boundary, the mountains support unbroken carpets of dense, old-growth chaparral that are sliced by an occasional fuel break along a ridge, and interspersed with a few extensively denuded watersheds from a fire driven by a past Santa Ana wind. Forests are thick with young shade-tolerant firs and cedars, with duff layers burying partially decomposed logs. The older pines show high levels of mortality from disease and insect attacks. Ever-increasing patches of oak and timberland chaparral are displacing formerly mature forests denuded by extremely intense stand-replacement burns.

Changes in California Ecosystems

Long-term change in California chaparral and conifer forest ecosystems as the result of fire suppression management is important because fire control has led to unintended alteration and degradation of these ecosystems, as well as engendering unprecedented fire hazard in California. It may seem peculiar that questions are being asked only after fire control has been in place for nearly a century, but ecosystem change moves slowly so that even broad-scale impacts have not been seriously recognized until perhaps the last 30 years. With our memory of the past limited to scarce written records and ground photographs, it is difficult to address fundamental questions about the management of California ecosystems, including: What was the vegetation like? How did past fire operate in ecosystems? Without concrete answers to these challenging inquiries, we cannot even address the most pertinent question: How can fire be reintroduced to restore stable ecosystems and ultimately to protect property and resources?

It was suggested that Baja California has been too dissimilar for meaningful comparison with California. However, the two regions are not only contiguous with one another, but they also are rooted in a similar physiography and ecology. The Peninsular Ranges that extend from the San Jacinto Mountains of southern California to the Sierra San Pedro Mártir of northern Baja California have uniform topography, climate, and flora (Barbour [this volume]; Minnich and

Franco 1998). The mountains are a gentle westward dipping fault block with a precipitous eastern escarpment facing the Sonoran Desert, much like the Sierra Nevada. Extensive granite substrates in the range are flanked toward the coast by an extensive belt of marine sediments, prebatholithic volcanics and metavolcanics. Northern Baja California's vegetation consists of ecosystems familiar to California - exotic annual grasslands, coastal sage scrub, chaparral, closed-cone conifer forest, oak woodlands, pinyon-juniper woodlands, riparian forest, mixed evergreen forest, and mixed conifer forests (Barbour and Major 1988, Minnich 1987a, Minnich and Franco, 1998, Rzedowski 1978). Temperature and precipitation gradients run at right angles rather than parallel to the international boundary, and prevailing winds, depth of the marine layer, and relative humidity during the fire season are virtually identical in both countries (Alvarez and Maisterrena 1977; DeMarrias and others 1965; USDA 1982; Reyes-Coca and others 1990).

In the comparison of landscapes, no two places are identical. The physical and biological environment changes gradually between Baja California and southern California, just as there are small differences between southern California and the Sierra Nevada. The primary difference is that Baja California has not experienced the same utilization or protectionist management policies as has Alta California, and the potential divergence in the disturbance ecology of similar ecosystems in the two countries may provide insight into the nature of historical vegetation change in Alta California. Indeed, the largely independent economic development of the two countries has created a 100-years "natural experiment" across the international boundary, where factors influencing fire occurrence have been systematically altered by divergent management systems.

Chaparral

Perhaps the most conspicuous outcome of the transborder experiment is a discrete transformation of chaparral stand configuration - from a fine-grained patch structure in Baja California to a coarse patch structure in California (Minnich and Chou 1997). The small size of fires in Baja California has been accompanied by high burn densities (about $7 \text{ kha}^{-1} 50 \text{ yr}^{-1}$), with most burning accomplished by fires $< 2,000 \text{ ha}$. In California fire densities are only $1.0 \text{ kha} 50 \text{ yr}^{-1}$, with most burned area accomplished by a few events $> 10,000 \text{ ha}$. Despite these differences, the fire rotation periods in both countries are about the same, about 70 years, i.e., the past century of suppression has not altered the pace of fire disturbance in chaparral at the landscape scale.

These trends are explained by a model in which the spatial extent of fires over time is self-limiting (Minnich and Chou 1997). The model recognizes that fire probability is heterogeneous from stand to stand, depending upon the differential fuel build-up related to previous fire history. Fires burn mostly old stands, and their spatial extent is limited by surrounding younger stands with lower flammability. A steady rate of fuel build-up results in temporally uniform long-term fire intervals. As a consequence, there is an inverse relationship between fire frequency and fire size. Baja California fires were small because historically high burn densities fragmented patch structure that precluded large fires. Low burn densities in California encouraged homogenous patch structure and large fires (Minnich 1983).

The time-dependence in fire occurrence is related to fire behavior and successional processes. The denudation of chaparral by stand-replacement burns limits carryover fuels through burn cycles. Post-fire fuel build-up develops only gradually in relation to increasing

stand fuel continuity (cover), total biomass, and dead fuels, as well as the hastening of soil drying and shrub phenology due to expanding leaf canopy and transpiration (Barro and Conard 1991, Hanes 1981, 1988, Keeley and Keeley 1989, Minnich and Chou 1997, Riggan and others 1988, Rundel 1983).

Local patch structure, of course, is not fixed because the spread of fires reflects some unique combination of allogenic factors - wind speed, humidity, ignition rates, precipitation variability, and terrain - that modify fire occurrence independently of successional fuel build-up. The result is that patch dynamics are expressed in a shifting mosaic. The shape of a burn never duplicates existing patch configurations because the spread of any given flame front, while primarily constrained by patch heterogeneity, exhibits random and chaotic behavior due to short-term changes in weather, and long-term changes such as drought, flood, and pathogenic disturbances.

Two fundamental assumptions can be made about the role of allogenic factors before fire control was implemented:

1. Allogenic variables each have probability distributions of their own: Data compiled fire management agencies and the National Weather Service show that lightning from thunderstorms have predictable spatial and temporal distributions, and various components of fire weather (humidity, wind speeds) are expressed in probabilistic climatic distributions.
2. If fire is unmanaged, then fires will occur randomly relative to allogenic factors: Under random probabilities, fires would primarily “sample” the modal ranges of these factors, because “normal” conditions are more frequent than extreme conditions. Indeed, Baja California does exactly that: fires mostly occur during ordinary conditions, i.e., during summer, with slope winds, and with moderate humidity. Few events take place during extreme conditions such as Santa Ana winds and heat waves, because these physical states are temporally rare. Moreover, the expansion of fires establishing under extreme conditions is shaped by a patch mosaic created by fires occurring in modal conditions.

Evidence also suggests that allogenic factors are not as important as successional processes in fire occurrence.

Ignition Rates

The similarity of fire rotation periods in Baja California and southern California, despite large differences in burn density in each country, shows that burning is not accelerated by ignition rates. In addition, the fined-grained patch structure seen in Baja California is not a singular artifact of deliberate burning. Lightning detection data shows that a 1,000 ha patch - the modal fire size in Baja California - experiences a discharge every 1 to 3 years and is struck about 5 to 20 times before ultimately generating a burn. Most discharges fail to establish fires because they are too frequent, i.e., discharges mostly strike immature stands with insufficient fuel loadings to carry fire. The addition of anthropogenic ignitions will have the same effect, mostly failures, but punctuated by rare successful ignitions and spread.

Precipitation Variability

The rate of burning is poorly related to annual precipitation - with or without fire control - because interannual changes in chaparral flammability due to annual growth and litterfall are small, compared with flammability associated with total biomass. The effect of precipitation variability is further diminished by long fire return periods. Although above-normal rainfall and drought may modestly alter the minimum age of stands that burn easily, anomalous precipitation episodes seldom persist more than a decade, or about 15 percent of a fire cycle. Hence, changes in chaparral flammability effect only a small proportion of total stands.

Terrain

The Peninsular Ranges are uniformly dissected and local variability in fire size are minor compared to transborder differences (Minnich and Bahre 1995). However, terrain is a fixed variable and will have predictable local effects on passing fires. A steep, uniform slope, for example, will consistently support more vigorous fire runs than a flat or basin. Dissected terrain tends to host widespread fire resistant habitats, especially along canyon bottoms and on bedrock outcrops.

Weather

Most burning in southern California coincides with offshore Santa Ana winds, while fires in Baja California primarily coincide with westerly sea breezes and slope winds. Landsat data also establish a disparate seasonality of burning - summer in Baja California, fall in southern California (Minnich 1983). The weather of fires is different across the international boundary because fire occurrence is nonrandomized by fire control, rather than being shaped by differences in meteorology. In California, the efficient elimination of countless small fires in modal weather selects for large fires in severe weather. Differences in transnational fire intensities are expressed by styles of denudation. In Baja California fires frequently have braided, reticulate configurations of denuded land and countless islands of unburned cover. California fires are invariably conflagrations that virtually denude entire watersheds.

The disparity in the weather of fires across the international boundary can be graphed hypothetically (fig. 1), showing how the probability distributions of fire climate and active fire spread combine to produce an expected fire spread rate probability distribution at the landscape scale. With respect to the fire climate distribution, the probability of fire spread (= fire spread rates) without fire management in a mature chaparral stand would be expected to gradually increase as the weather becomes drier. However, the suppression of small fires selectively reduces the probability of fire spread during modal weather conditions. The expected spread rate frequency distribution without fire control in Mexico peaks at moderate fire climate because modest spread rates are phased with modal fire climate (high frequency of days). With fire control in California, the expected fire spread rate is skewed to extreme weather, resulting in higher average spread rates and flame line intensities.

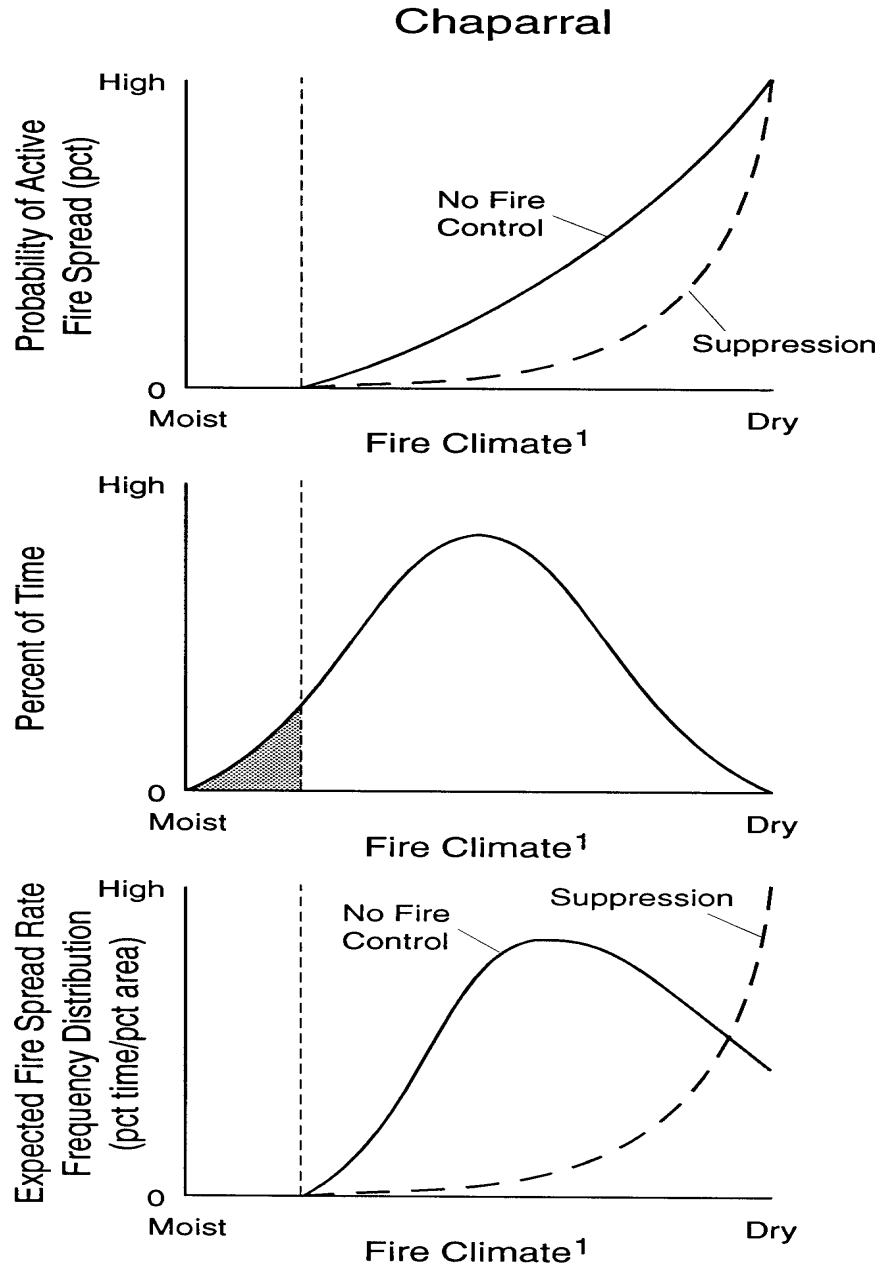


Figure 1. Hypothetical probability distributions: active fire spread (top) with the climatic distribution (middle), and the resulting expected fire spread rate frequency distribution (bottom), under suppression and no fire control.

It was suggested that differences in transnational fire weather reflects climatic gradients. For example, it was postulated that Santa Ana winds are less significant in Baja California compared to southern California. However, Santa Ana winds are distinctive mesoscale conditions that arise from hemispheric circulations operating at scales of thousands of kilometers or an order of magnitude larger than the 200 kilometer span of the study area. The entire Peninsular Range from the San Jacinto Mountains to the Sierra Juárez is too small for large

gradients in the strength of these winds. Without distinctive suppression histories, changes in fire weather and patch dynamics should be expressed in a continuum of fire weather and patch structure, not the discontinuity presently seen along the international boundary.

Historical change in patch structure

Historical evidence suggests that a Baja California fire regime has evolved into the modern conflagration regime during the early 20th century (Minnich 1987b). These writings suggest that fire was self-regulating and that patchiness was characteristic of chaparral during the late 19th century. According to Mendenhall, an early forest ranger in the San Gabriel Mountains north of Los Angeles, “fires occurred every year...and were not extensive due to the fact they ran into older burns and checked themselves.” In the San Bernardino Mountains, the 1903-04 L.C. Miller Silviculture Survey party saw evidence of fire at 10 localities between Waterman Canyon and Barton Flats, an area of about 20,000 ha. During the U.S.-Mexican boundary survey of the 1890’s, which encompassed the coast ranges between Mexico and the San Jacinto Reserve, boundary workers stated that “the signs of fire having gone through the brush are constantly evident.” John Leiberg, who conducted the forest reserve surveys under the U.S. Geological Survey at the turn of the century, noted that in the San Gabriel Reserve, recent fires burned over 12,000 acres in Lytle Creek, San Gabriel River, Tujunga Creek and Mt. Gleason (Leiberg 1899, 1900). These fires must have been small because a modest total burn area is spread out over four drainages. Leiberg made the most explicit account of patch mosaics in the San Jacinto Mountains, 50 km SE of the San Bernardino Mountains, describing the chaparral as “a growth which varies from extremely dense to thin or open, but rarely forms large uninterrupted patches. The dense portions are commonly separated by narrow lanes [burns], which are wholly free of brush....” He also stated that “recent fires...[were] scattered throughout the reserve in small tracts.”

William Mulholland, better known for his efforts in importing Owens Valley water to Los Angeles, deduced a change in the pattern of fire at the turn of the century, and explained it in terms of pre-existing patch mosaics (Minnich 1987b). In an interview with the *Los Angeles Times* after a fire in 1908, he stated “If the portion of watershed burns off each year, then there is always a large majority of watershed covered with a new green growth that will defy any fire. Experience has taught us that we cannot prevent fire. It is better to have a fire every year, which burns off a small area... than to have a big one denuding the whole watershed at once.” Eleven years later, two simultaneous conflagrations denuded 110,000 acres in the San Gabriel Mountains, after which Mulholland stated to the *Los Angeles Times*: “Hardly any natural occurrence can be regarded with greater grief than the fires now prevailing in the mountains... as it is almost impossible to combat mountain brushfires when once they have well started. The deplorable thing about the present fires is the vast extent of the territory burned over in a single season. Fires we have every year, but only small areas have been generally burned over at a time and very rarely does it occur that the growth on a watershed is of such maturity as to burn out with a single occurrence.”

The enlargement of fires by 1919 is likely related to the initiation of initial attack suppression of small fires that began in 1900. Short-term decreases in burning was possible because these efforts coincided with a fine-grained patch mosaic resistant to broad-scale fires. Indeed, newspaper reports reveal that forest rangers combed the mountains and put out fires by the hundreds (Minnich 1987b). Because present fire return intervals are roughly similar to those

in the past, the stand age composition of the presuppression mosaic may have been similar to that now in southern California: 30 percent of stands were old but highly fragmented, while the remainder comprised continuous young to medium aged stands. A small percentage of the landscape consisted of barren watersheds of fresh burns. During the ensuing 20-year “honeymoon,” medium-aged patches blended with old patches to form a more continuous flammable patch structure, leading to extensive fire outbreaks of 1919.

An alternative hypothesis proposed during the panel is that fires in California have always been large and intense. The only direct prehistoric evidence cited is the varved charcoal in the Santa Barbara Channel (Byrne 1978) which reveals that fire return intervals in the surrounding mountains were similar to those currently in Baja California and southern California. Thus, burning rates in California chaparral may not have changed significantly with the establishment of fire control, as would be expected in a time-dependent fire regime. However, the assertion that charcoal layers reflects large burns is compromised by uncertainties in the mechanisms of charcoal transport to the core site, some 50 km distance from the nearest mountains.

The large fire hypothesis is also examined using 20th century fire history records. It was proposed that because the size of fire perimeters have remained unchanged since records began in 1910, and because suppression became effective with improvements in technology only by the 1940's, fires have always been large. This argument is self-contradictory, and fails to address pre-1910 historical evidence, and the current discontinuous shift in patch structure along the U.S.-Mexican border. If suppression were effective, then why do fires *not* decrease in size or spatial coverage with increasing improvements with suppression funding and technologies after 1940? Why are post-world war II California fires larger than those in Baja California where suppression is minimal or nonexistent? Why was there a profound discontinuity in patchiness along the international boundary by the 1920's? Clearly, the most expensive part of suppression - encircling a perimeter with men and equipment, plus aerial support - has never been effective in altering the behavior of large fires. The use of extremal statistics - weighting historical analysis exclusively on the largest annual events - makes the presuppression large fire hypothesis a self-fulfilling prophecy because the role of small fires has been systematically disregarded.

Moreover, fire scar dendrochronology studies reveal that Europeans were able to modify fire regimes in mixed conifer forest at an early date, as evidenced by a decline in fire scarring beginning in mixed conifer forest by 1900 (Swetnam 1993).

Early fire perimeter data is also suspect. Early aerial photographs show that some perimeters for the Cleveland National Forest and San Bernardino Mountains during the 1920's were poorly mapped. Problems in record keeping may have been even more generic during the early days of the USDA Forest Service. In 1974 Donald McLain, then almost 90 years of age, and who worked for the San Bernardino National Forest in the 1910's, stated in an interview with me that many burn perimeters were deliberately modified, in order to impress the public that the forestry was doing its job. He further stated that many burns were not mapped. An interesting case was a fire that involved much of upper Bear Canyon around 1910-15. Evidence of this burn is seen in young, even-aged, post-fire Coulter pine (*Pinus coulteri*) forests that are recorded throughout the canyon on 1938 aerial photographs. McLain was told that Forest Service maps showed three small perimeters near the base of the canyon that dated to the 1910's (he could not see the maps because he was blind). He replied that “fire took the entire canyon” [ca. 1,500 ha]. It appears that a youthful bureaucracy, coupled with casual record keeping and

mapping, had compromised the fire history data until 1925-1930, and this is far too late to capture the presuppression fire regime in chaparral.

Mixed Conifer Forest

Mixed conifer forests in California have experienced widespread directional changes over the past century, including stand-thickening, build-up of understory fuels, and an age-specific trend away from dominance by mature pines toward dominance by juvenile firs and cedars (Barbour and Minnich [in press], Kilgore 1973, Parsons & DeBenedetti 1979, SNEP Science Team 1996, Vankat 1977, Vankat and Major 1978, Weatherspoon *et al.*, 1992). Historical writings and 19th century ground photographs reveal that forests comprised open stands of mature trees. In the San Bernardino Mountains of southern California, field plots of the 1929-1934 Vegetation Type Map (VTM) Survey show that most trees had diameters > 60 cm and averaged 100 to 200 stems ha⁻¹ (dbh > 10 cm). Replication of VTM plots in 1992 give densities of 200 to 400 stems ha⁻¹, with some second growth forests logged in the 19th century having densities as high as 900 ha⁻¹ (Minnich and others 1995). Densities in the Sierra Nevada typically exceed 500 ha⁻¹ (Vankat 1977, Vankat and Major 1978).

There is broad consensus that the open structure of forests before fire control was maintained by recurrent understory fires that selectively eliminated shrubs and young trees. Fire-scar dendrochronology (FSD) studies estimate that presuppression fire intervals in Californian mixed conifer forest ranged from 3 to 20 years depending on vegetation type and slope aspect (Finney and Martin 1989, Kilgore and Taylor 1979, McBride and Laven 1976, Show and Kotok 1924, Swetnam 1993, Wagener 1961, Weaver 1974). FSD methods employ site specific sampling in which fire frequencies can be computed directly from fire scars, either from sets of fire intervals from single point samples, or from composite synchronized fire intervals integrated from a large sample of trees at multiple adjacent sites, using a master chronology as a baseline (Arno and Sneek 1977, Dieterich 1980). However, site specific estimates have not been independently confirmed by spatial fire history data.

A spatial fire history of mixed conifer forests in the Sierra San Pedro Mártir of Baja California (*Pinus jeffreyi*, *P. lambertiana*, *P. contorta*, *Abies concolor*, *Calocedrus decurrens*, and *Cupressus montana*) was reconstructed for the whole range, using ten repeat aerial photograph coverages for the period 1925-93 (Minnich and others [in press]). The isolation of the region has kept the region insulated from conventional fire-management practices, as understory burns still spread through the forests.

Fire perimeters and forest damage for burns > 5 ha were mapped by delimiting burn scars using rollfilm and pocket stereoscopes. Repeat aerial photographs were then matched site-specifically on a Zoom Transfer Scope (ZTS) to follow fire distributions, patch turnover, and forest damage. On the ZTS two scenes are superimposed exactly to scale, as recognized from the unique nearest-neighbor configurations of trees and shrubs within a stand, as well as from surrounding fixed features such as rock outcrops and watercourses. Burns were recognized by the contrast between reflective denuded land (light soils) and surrounding unburned vegetation. Inside burn perimeters are scorched or burned shrubs and trees, with resprouting species exhibiting new basal canopy from root axes. Repeat aerial photographs show that the nearest-neighbor configuration of nonsprouting species were "rearranged" over time, i.e., stems died and recruits established *en masse*. Outside perimeters, the nearest-neighbor configuration of stems was fixed. Oversight of burns was minimized by the short intervals between photo coverages.

Burn scars resulting from shrub and conifer damage persist > 30 yr, whereas the interval between photo coverages never exceeded 18 years.

The primary finding was that forests were burned by intense understory fires recurring at intervals of 35 to 70 years, much longer than estimated for California mixed conifer forest from FSD methods. The long fire intervals notwithstanding, forests throughout Sierra San Pedro Mártir still comprise open, park-like stands of mature trees (50 to 156 trees ha⁻¹), similar to presuppression forests of California. There were 865 burns > 5 ha, or 11.8 burns per year for the entire range. Evidence that long fire intervals were characteristic of the region is seen in a self-organizing patch structure, similar to chaparral. Although a few burns reached 5,000 to 9,000 ha, the abundance of smaller fires create a fine-grained patch mosaic of heterogeneous flammability in association with gradual cumulative fuel build up generated by subcontinuous shrub cover, conifer recruitment, and litter accumulation. Nearly all reburns involved stands last burned > 40 years before. The potential for short interval fires is minimized by scarce cover of flashy herbaceous fuels due to summer drought, and the high lignin content and packing of needle litter. Most fires spread with slope winds during summer, with a few reported to last 1 to 2 months. Most fires caused severe damage to forest understory. Shrub cover was denuded and scorch heights of 10 to 20 m typically resulted in fatal injury to saplings and pole-size conifers.

Temperature and precipitation data for Sierra San Pedro Mártir strongly overlap the range of climate for many stations in mixed conifer forests of California (Minnich and others [in press]). Hence, differences in fire return intervals compared to California ranges cannot be explained solely by differences in climate, productivity, and fuel accumulation rates.

Alternatively, the disparity in fire interval estimates may arise from the contrasting methods employed. A valid question was raised concerning spatial analysis of fire using repeat aerial photographs: Are only intense fires being mapped? For purposes of this discussion, I define “light fires” as burns which fail to damage evergreen shrubs and trees, i.e., fires that could not be mapped from repeat aerial photographs because so little biomass was altered. However, we did map “light fires” in the form of ash-blackened areas on color photography flown in July 1991. These were current year (1991) burns because ash is readily washed away by winter rains (Minnich 1983). From this preliminary data, we had four major conclusions: light fires consumed primarily needle litter. Prostrate shrubs and conifer saplings were unburned or marginally scorched; light fires occurred at high frequencies, and in 40,000 ha of mixed conifer forests, there were 189 burns within a few weeks of the 1991 flight, which were apparently lightning ignitions (two thunderstorm episodes) because they were far removed from roads and trails; nearly all light fires were “spot” burns (< 1 ha), and only two exceeded 5 ha; and no extensive “light fires” that burned needle litter exclusively were observed. These fires are distinct from other mapped burns in that woody cover was not removed. However, only a few burns, mostly > 5 ha, had sufficient damage to be captured on repeat aerial photographs.

These findings led us to consider another central question during the panel: What is the cumulative spatial extent of “light” burns at the landscape-scale, and what is their cumulative effect on forest dynamics?

Size Frequency Distributions and Fire Intensity

The high density of spot burns in the Sierra San Pedro Mártir is consistent with a general finding in many ecosystems that fire occurrence is expressed in long-tailed size frequency distributions of numerous small events, and relatively few large events that account for most

burn area, i.e., most fires fail and ever fewer fires reach larger size classes (Chou and others 1993, Minnich 1983, Minnich and Chou 1997). At the same time, a high density of small events still have limited spatial impact on the landscape, i.e., as fire frequency (events/area) becomes infinitely high, the cumulative fire area approaches zero (fig. 2).

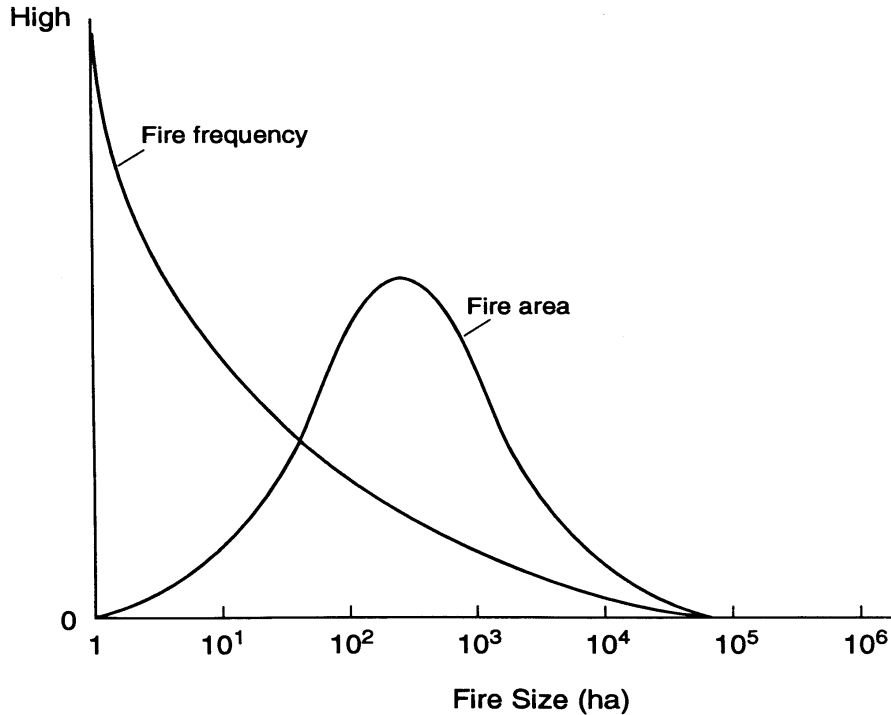


Figure 2. Hypothetical distributions of cumulative burn area along a fire size frequency distribution.

Lightning detection data provide support for long-term high levels of “spot” fire frequencies from summer thunderstorms. For the period June to September 1985-1990, the Sierra San Pedro Mártir averaged 3.0 discharges $\text{kha}^{-1} \text{yr}^{-1}$ (Minnich and others 1993). The fact that only two of 189 burns in 1991 were greater than the 5 ha minimum fire size for other mapped burns during 1925-1993 strongly indicates that fire frequencies increase rapidly with decreasing fire size for very small events. Hence, it is possible that for every mapped burn in 1925-1993, there is a “hidden map” of spot events that are more frequent by one two orders of magnitude. At this rate, the number of fire starts in the Sierra San Pedro Mártir for 1920-1993 could potentially number in the thousands, i.e., at the order of magnitude of one spot ha^{-1} for each fire cycle of 35 to 70 years.

A rigorous assessment of very small burns in forests without fire management is essential to work out the cumulative spatial extent of small fires, as they effect fire interval estimates from FSD methods. Whereas large fires produce simultaneous fire scars in trees over wide areas, long-tailed fire size frequency distributions predict frequent scarring from small burns. Clearly, fire scar dendrochronologies could represent both spot and landscape burns, but relative importance of each is very sensitive to spot fire densities over time and sampling resolution. If spot fire densities are lower than sampling resolution, then fire scar records would mostly represent landscape burns. Conversely, under high spot densities, such as those recorded in the

Sierra San Pedro Mártir in 1991, any randomly selected sampling site may have a greater probability of recording local events than large ones, especially at a time-scale of 35 to 70 years. Unfortunately, the rapid disappearance of spot burns precludes the development of a long-term database of spot burn densities from repeat aerial photography.

FSD methods address the issue of small burns by evaluating the synchronicity of fire scars over some sample area. Synchronous fire scar years at separate localities are conventionally interpreted to reflect single burns. However, this explanation is equivocal as some evidences indicates that spot fires could be vicariant and synchronous: individual thunderstorms produce multiple lightning strikes over small areas; lightning flux rates in a year are sufficiently high that relatively small areas receive multiple strikes each year; and over time scales of decades are massive thunderstorm outbreaks that produce thousands of strikes and fires in single day, such as the 1987 Stanislaus fire complex. While events of this magnitude are rare meteorologically (ca. every 10 yr.), they are ubiquitous in ecological time-scales of forest dynamics.

It is unlikely that spot fires have significant effect on forest dynamics. Although large fires may have highly variable spread rates and intensities due to changes in weather, it can be argued on physical grounds that small fires *are* small because they have insufficient intensity (energy release) to form flame lines. Evidences in the Sierra San Pedro Mártir suggest that "light fires" have little effect on forest dynamics. Current year spot burns of 1991 had insufficient intensity to burn or kill prostrate shrubs such as *Arctostaphylos patula* and *Ceanothus cordulatus*, as well as small conifers. Repeat aerial photographs outside mapped fire perimeters consistently reveal fixed nearest-neighbor configurations of overstory and understory vegetation.

A final question that arose during the panel was why fire scars are so rare in the 20th century in the face of high lightning fluxes in the region? Several factors appear to be reducing the rate of scarring: efficient initial attack suppression has reduced the number of small fires, as well as nearly eliminating mass fires; catfaced trees are disappearing due to removal from harvesting; in unlogged forests, there is heavy mortality of old trees (and fire scar records), especially during droughts, as a consequence of competition with thickening forest understory, i.e., the density of stems > 60 cm dbh has decreased over the past 60 years because there is greater mortality of old-growth stems than younger stems graduating into old-growth classes (Minnich and others 1995); and in the absence of broadscale understory fires, catface wounds have been permitted to heal, reducing chances for incorporation and detection of scarring events.

Management Implications

Restoring altered ecosystems requires knowledge of the past. Land managers in California should critically examine the "well-managed" status of ecosystems in Baja California, including the fragmentation of brushlands by small fires and the openness of conifer forests. Indeed, the northern peninsula could be a "showcase" of ecosystems functioning under natural-disturbance that can be compared with similar ecosystems in Alta California. A central concept for effective chaparral fire management is the long-term spatial and temporal predictability of fire in these ecosystems. The self-regulating property of chaparral makes it an ideal candidate for the establishment of broad-scale, proactive prescribed fire management systems. In mixed conifer forest, we need to clarify the role of small, low intensity fires in landscape-level dynamics. Our long-interval, high intensity surface fire model suggests that fewer fire cycles were missed and that stand-thickening was less severe relative to pre-suppression levels. A trend

for high intensity understory fires in Baja California suggests that hotter prescribed burns may fall within the bounds of ecological stability in California mixed conifer forest.

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Fire Protection Assessment... A Dynamic Planning Process

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Introduction

Ecosystem based resource management and evolving Fire Policy demand a shift in fire planning perspectives. Variations in spatial and temporal scales demand alternatives in cooperation and integration of databases to assess effects and determine priorities. Resource managers, planners, local government and the public are trying to determine the impact of fire. A renewed effort to determine the appropriate role of fire in ecosystems, increasing concerns for fire fighter and public safety and scrutiny of program costs, shape the need to examine fire planning. The expanding impact of human habitation and an increasing range of social values dictate the need to develop tiered and dynamic processes in fire management.

Fire Protection Assessment is an integrated planning process designed to determine how fire fits in the landscape and conversely how landscapes influence fire behavior. As with other land planning techniques, it attempts to identify priorities, conflicting demands and the allocation of energy and resources. It serves as a means to integrate all components of fire management while serving as a basis for linkage in planning. It optimizes the use of existing technology and may be streamlined with emerging technology.

Fire Protection Assessment is a process of defining, ranking and mapping of hazards, risks and values. Hazards are defined as the physical and biological features which result in similar fire behavior. They are ranked by their potential for extreme fire behavior. Risk is the potential for ignition, natural or human caused. Based on historical fire occurrence they are grouped by location, source and fire size. Values, both natural and social are affected by the occurrence of fire. The most sensitive component, mapping remains a challenge and techniques continue to evolve. Map layers are aggregated to arrive at a spatial identification of potential fire effects.

The Colorado Experience

In Colorado, an interagency group developed a pilot project to conduct a Fire Protection Assessment on a Statewide basis. The project was designed in response to the Federal Wildland Fire Program and Policy Review which direct land management agencies to "jointly establish an accurate, compatible and accessible database for fire and ecosystem related data" as the basis for fire management and fire reintroduction decisions. The effort establishes a platform for agencies and states to work together to develop Fire Management Plans that address the needs of the community and the health of the landscape, promotes fire fighter safety and acts as a public education tool. The project partners included: US Fish and Wildlife Service, National Park Service, Bureau of Land Management, Bureau of Indian Affairs, Colorado State Forest Service

and the USDA Forest Service. The purpose of the project was to answer the following key land management questions:

- Where can we tolerate fire and what can we do to promote the natural role of fire?
- What are the probabilities for catastrophic fire and how can we improve preparedness?
- To what degree is rural interface an issue and can areas of concern be identified?
- With budgetary constraints, are there opportunities for increasing efficiency and avoid redundancy?

The Project objective was to develop a process for tiered and coordinated planning both at the strategic (statewide) and tactical (local) levels. The project was shaped by the need to:

- Recognize and accommodate the changing needs of the public and land management agencies with relations to fire.
- Promote interagency strategies, coordinate priorities and identify opportunities for collaborative management.
- Serve as a platform for linking fire programs with other land management functions.
- Develop formats and techniques that facilitate further planning at regional or provincial scales.

Process

The Hazard Layer was developed from existing vegetative mapping, refined from High Resolution satellite imagery. Vegetation types were grouped into fuel models and ranked based on their expected fire intensity. Data focused on forested vegetation and confidence in its accuracy is moderate. Climate data was found to be too variable and seasonal for purposes of a strategic map and best left to tactical planning. Topography, slope and aspect are important variables but at a strategic level the detail would not have substantially altered vegetative typing. Fuel loading and stand densities were not consistently available and while recognized as significant was best left to tactical scale planning.

The Risk Layer was developed from occurrence data regarding human and lightning caused fires. Differences regarding how fire statistics were obtained led to gaps in data and future efforts need to refine this process. Refinements were made to insure data compatibility since differences were found in how agencies record locations. Some agencies collect occurrence data as points, others had spatial data, especially for large fires. The state has a voluntary system for fire reporting leaving a wide variety of responses from county records, resulting in many fires with no recorded location. The map was built with approximately 60% of reported fires and future efforts will be needed to define data. The initial map identified point data of lightning and human caused fires for the most recent ten year period. It was refined to fires per section and further grouped into fires per township then ranked as high, medium or low

The Values layer proved to be the most challenging. There was much discussion on the level of detail, their relevance of data and the ability to select measurable items that could be readily mapped. Efforts and discussions are currently underway to refine and improve this critical element of the assessment. For the purposes of the pilot, the team which includes a sociologist and economist chose to develop a map based on the broadest objective social concerns defined as a function of population density. It remains an assumption that the higher

the density of population, the wider the range of social values. It should be noted that property values were not an element of the assessment and it is not intended to diminish the importance of values in areas of lower populations. Tactical and local planning efforts need to account for concerns which shape responses to the effects of fire. Census and dwelling density data was selected as the primary data set in part due to the consistency in data collection across political boundaries. The primary assumption of the values layer is the higher the population, the higher the concern with respect to fire and is ranked as a function of dwelling per acre. Land Use data, appraisal, insurance data, tax rolls were all considered but variations and the level of detail precluded the use on a strategic basis but remain key for local planning efforts.

Conclusions

The Colorado Statewide Assessment was the first one attempted on a large scale. It was a successful learning experience with several positive outcomes:

- It demonstrated that agencies can cooperate and integrate databases.
- It quickly identified some key issues at a reasonable cost in time and resources. For example, based on initial assessment one agency is further evaluating relocating resources to increase efficiency.
- As coincidence a large scale prescribed fire project, managed by two national Forests and a BLM District validated the decision support capabilities of a large scale assessment.

Issues surrounding wildland/urban interface and forest health (Front Range Forest Health Assessment) were assessed with the same techniques resulting in mapping areas with high probability of disturbance. In turn these results are being used to develop tactical plans, alternative strategies and serve as a communication tool with local agencies and communities.

The initial product has been well received and shared with a wide audience with the focus on continuing to enhance the process. Several other states have expressed strong interest in developing their own assessments. The application of techniques is being explored to look at disaster preparedness as well as other aspects of all risk incident management. Several BLM Districts and national Forests within Colorado area are adapting techniques for Land Planning Revisions. The pilot effort has already identified that the technique is relevant and effective in compiling a common database for interagency planning and coordination. It provides managers with quick identification of priorities and areas that require additional tactical planning. Fire managers and administrators can better define sustainability, plan appropriate responses, develop prescriptions and improve execution on landscape scales. Because it employs emerging technology in information systems (GIS and GPS) the process lends itself well to refined analysis of complex landscape and fire situation. It allows managers to coordinate tactical plans to improve emergency responses in increasingly complex situations, determine the priority for intervention and identify areas that can tolerate large scale fire. It also allows for the refinement of plans to the use of complex fire prescriptions in key interface zones. Participants can begin the process with existing data and refine it as new, better or different data becomes available. The technique is an ongoing process accommodating data refinement. It is designed for local and tactical planning to generate data that continues to shape the scope of landscape assessment.

Most importantly, it has already served as a strong communication tool among a variety of fire and resource specialist, managers and affected publics.

Applications

The Assessment Process is not designed nor should it stand alone but rather serve as a vehicle to knit other planning efforts. It serves as an opportunity to link plans based on landscape characteristics, infuse resource and social values and tolerate changes as data and issues become refined or better defined. The simplicity of its application encourages involvement of partners and is effective in reaching a wide cross section.

Traditional planning is viewed as a process with an end product, usually, collection of land prescription and decisions with appropriate level of approval. Fire Protection Assessment is by its very nature a fluid approach to planning, a process subject to continuous refinement. It brings together elements important in fire management decisions, influenced by other elements of land planning. Efforts are being explored to blend fixed data bases (GIS) and variable data (weather) to determine the feasibility for real time modeling of fire on the landscape. Possibilities of multiple downlink, may refine decision making by providing multiple parties to influence fire decisions or share in the monitoring of fire effects. In conclusion we believe fire protection assessment is a technique who's time has come. We believe that landscape based decisions across political boundaries, informed affected public, and the ability for continued refinement, of data remains the key to sustainable systems with respect to fire and disturbance. This technique offer us to ability to blend ecosystem process and functions into various elements of fire management.

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Ways to Minimize Environmental Impacts of Fuel Reductions at the Urban Wildland Interface

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The 1991 Tunnel fire in the Oakland-Berkeley hills served as a major wake up call to the region. Fire was not new to this area -- there had been five major interface fires in the previous 20 years. However, the magnitude of the fire in 1991 served as an alarm that the region could not ignore. With this acceptance land managers must develop environmentally sustainable ways to address the issues over the long term. The following is an overview of techniques used in the San Francisco Bay area to minimize the environmental impact of fuel reduction treatments. This paper incorporates experiences from the Oakland and Berkeley hills (East Bay), Marin County and the South Bay community of Portola Valley near Stanford University.

The underlying fire issues are not unique to our region, but rather common to many at the urban wildland interface. Like much of California, areas that once were sparsely populated in terms of both people and vegetative biomass are now dense with homes and synthetic forests. Areas such as Strawberry Canyon on the University of California Berkeley campus that were once oak studded native grasslands adapted to periodic low intensity fires have seen the addition of exotic plant species that dramatically increase the fuel loads.

Since the 1991 fire, new ways of dealing with these issues have included increased communication and coordination in regional pre-fire planning. The region has learned the importance the hard way of local agencies working together. In 1992 a consortium of six major land agencies and municipalities directly impacted by the Tunnel Fire signed a letter of intent forming the Hills Emergency Forum. This forum is supported by two consortium -- the East Bay Fire Chiefs Consortium including 14 regional fire chiefs and the Vegetation Management Consortium. Each of these consortium members agreed to work within a framework that accommodates each institution's diverse mission while undertaking meaningful regional collaboration.

In 1993 the Vegetation Management Consortium began a regional fuel management plan; funded from local agencies, State Office of Emergency Services, and the Federal Emergency Management Agency. One plan component was the development of a Geographic Information System (GIS) by researchers at the University of California Berkeley. The GIS provided the ability to evaluate fire hazards based on potential fire behavior on a region-wide basis. The GIS assisted in the identification of treatment priority areas by identifying those high hazard areas within 500 feet of values of risk. These were locations where potential fire behavior included eight foot long or greater flame lengths or having a high potential for crown fires, as modeled by BEHAVE. The wildland zone within 500 feet of homes, evacuation routes, communication facilities and other values at risk became known as the "buffer." Because these high priority areas are located right in citizens' back yards it is critical that land managers develop mitigation treatments that address a wide range of issues in addition to meeting fire goals.

The regional fuel management plan which was developed in response to the identified hazard is unique because it is based on a descriptive tool box of treatments including hand removal of fuels, selective tree cutting, grazing, use of prescribed fire, mechanical and chemical treatments. The Vegetation Management Consortium identified general prescriptions for each vegetation type. These include measurable attributes in the treated vegetation which would result in the desired fire behavior. The prescriptions also highlighted regional sensitivities. These acknowledge the need for integrating ecology, prevention and management. The plan also provides a system for agency managers to match the appropriate treatment on a site by site basis, continually refining these prescriptions.

The refinements summarized here are based mostly on anecdotal evidence, because we cannot wait to conduct treatments until all the studies that are needed are complete. Treatments offer opportunities to monitor and further refine future treatments. The timing of treatment is one of the key methods managers can use to integrate ecological concerns into fire prevention treatments. It is so much of a concern that consortium member agencies are collaborating with the local native plant society to develop a calendar that lists the sensitive times for various local plant and wildlife species so that managers can understand the tradeoffs of conducting fuel treatments during those seasons. It is also often helpful to formally evaluate the alternative of "no treatment" with the accompanying potential encroachment of grasslands by woody species or the impact of an intense fire or effects of fire suppression equipment such as dozer lines.

Costs

As treatments are matched to sites, area managers go well beyond considerations of economic costs and productivity to weigh the environmental benefits and impacts. Hand labor is desirable for aesthetic results and selectivity, but it is usually economical only for strip treatment like roadside clearing, not for area treatments that are regularly needed. In grasslands, grazing with goats and prescribed burning are costly treatments for their one year effect, unless the treatment is part of a broom control program where it takes longer for the broom to re-establish. Oak woodlands generally represent a "low cost" vegetation type because it usually is a low hazard and requires minimum treatment. It is both cost and environmentally effective to avoid opening an existing stand's tree canopy. In fact, speeding succession of mixed scrub stands to a closed canopy oak woodland by protecting emerging oaks and removing competing understory is an investment that will increase treatment cycle longevity and reduce long term program and environmental costs.

When discussing potential environmental issues it is helpful to divide them into two categories: 1) short term impacts associated with the treatment itself, and 2) long term impacts that also include the by-products of the treatments.

Short Term Environmental Issues

The region has found that the intensity of concern surrounding environmental issues is often directly related to the public perception of the targeted treatment area. This umbrella term "public perception" covers such factors as the ease of public access, visibility of the site, general acceptance of the technique, perceived selectivity of fuel management treatment and a multitude of emotional "hot buttons" unique to each neighborhood. Other short term issues that commonly arise include: air quality, odors, noise, as well as the short term loss of visual quality.

The East Bay managers have recently been challenged by such issues when dealing with our aging stands of Monterey pines. The acres of pines throughout our hills provide an example of how the regional fuel treatment prescriptions have had to change. The Monterey pines are dearly loved by residents -- they screen buildings, harbor a wide variety of wildlife, and frame the back yard views of many homes. However, only 15% of the trees are expected to survive the recent onslaught of pitch canker and insects. So while the regional fuel management plan accommodated management of the stands, we are likely to change prescriptions recognizing many trees will be gone. Convincing neighborhoods of the wisdom of this choice is an ongoing educational process.

The public's lack of familiarity with certain treatment tools has led regional managers to anticipate the understandable fear of herbicide over spray or escaped prescribed fires and accept that an extra effort will be required to use these techniques. These efforts may include ensuring the vendor uses visible safety methods with proper safety gear, following all warning labels and directions during applications, and putting up signs to inform the public regarding the treatment and safety periods. Burning around homes in scrub and chaparral often requires a pre-treatment to assist control and to avoid scorch. Grazing with goats is an effective pre-treatment in many vegetation types. Additional refinements include protecting specimens with a Class A water-based foam, or using such foam to enhance control lines rather than creating wider strips of bare dirt. A way to minimize public concern when prescribed burning is to burn after a foggy day because smoke is not as apparent or disconcerting when the fog lifts.

Regional fog patterns also enables us to burn safely in mid-summer in light fuels. In spite of the public perception, prescribed burning in eucalyptus as a maintenance tool is fairly easy -- if the stand has been pre-treated and thinned -- because there is hardly any weather that is too moist to burn—so the window of opportunity to burn is wide. Our managers have found it best to burn with high relative humidity (such as fog) to minimize ember production. Another refinement is to burn coniferous stands, such as Monterey pine, in late January to February. There's almost always a dry spell when litter can carry fire. This time is also before even bulbs pop, birds nest and bark beetles fly, so it avoids many environmental conflicts. At this time of year adjacent grassy and shrub sites are moist and green, and the cool weather tends to reduce the number and anxiety of onlookers. The goal of most prescribed burns in the high priority treatment areas is fire behavior that produces a creeping, low intensity fire with high consumption. It is necessary to budget plenty of time for ignition to accommodate backing fires.

Successful projects have in many cases required a change in status quo with frank acknowledgment that fuel treatments are messy work. Even when treatments are well accepted, new short term issues may arise -- using goats for fuel treatment are normally well-accepted in our area, but recently the local labor union raised concerns. Their union offer was to either
1) have no future goat grazing contracts without discussion with the union; 2) compensate union members for lost opportunity to work; or 3) make the goats union members -- with full benefits.

Selection of a vendor that is sensitive to the variety of public concerns is crucial. Many of the vendor crews are not used to working in areas surrounded by urban populations. In many cases the local agencies have had to accept increased costs and prepare tighter specifications for work methods so that even sites in progress do not exceed the surrounding neighborhood's threshold of acceptable disorder.

Re-vegetation or other follow up treatments are sometimes not enough. Techniques such as seeding or biotechnical treatments may not be recognized by the neighbors without an extra step of explanation and public information about the project. An education campaign such as site visits or volunteer replanting programs may become as important as the physical mitigations.

Long Term Environmental Issues

The long term environmental issues are usually more contentious and crop up repeatedly with no easy solutions. Most of these issues are tied to worst case scenarios and reflect a lack of trust by the public for public agency land managers. It is critical to address these issues on a case-by-case basis, as generalized discussion do not usually move the discussion forward toward resolution. It is important to search for the common goals and avoid adversarial postures. Regional agencies have recognized they must allocate both staff time and funds to allow the needed discussions.

Erosion Control

Erosion control is a common issue tied to all mitigation methods throughout our region. The challenge is to separate the real potential for erosion from the fear of the technique's worst-case scenario for abuse of the land. We are fortunate in the Bay Area that we generally do not have soil types that create major erosion and mud flow problems found in Southern California. Many of our erosion issues can be addressed with a good match of methods to the place. It is critical for land managers to recognize special sites, such as where slopes are greater than 30 percent or where there is a history of slope failure, so that the necessary geotechnical expertise can help refine the treatment prescription and potential follow up methods.

To reduce fire hazards with finesse, managers avoid creating bare dirt. If traditional disking or dozing which leave exposed soils must be utilized, erosion can be reduced by blending the berms into smooth edges and re-establishing continuous water flow at the end of the fire season. It is important that treatments which disturb the soil follow the contour of the slope - to reduce erosion avoid creating strips of bare earth that run parallel to the slope.

Cattle grazing is very controversial because, in part, of poor past practices which increased erosion. Cattle grazing has been traditionally used because it produces income and can treat large areas. Ways to reduce the environmental insult is to manage the time of cattle grazing (start late and shorten duration), watch the stocking level and manage the cattle distribution through placing salt licks and supplemental feed away from sensitive areas. Requiring supplemental feed helps ensure the regional standards for residual dry matter of 1000 pounds/acre are met which reduces erosion and appearances of being "cow burnt."

There are a variety of types and sizes of machinery, and in the urban wildland intermix the use of smaller machinery produces less soil disturbance while increasing the ability to create

shrub islands or remove entire trees. Equipment with long articulated arms can minimize ground disturbance because its long reach allows it to travel over less terrain. Mastication attachments can produce a mulch layer as an after product that can also reduce soil erosion. Even a standard dozer with a raised blade can be effective to crush shrubs without disturbing root structures. But regional managers still find that machinery is best matched with a site with gentle slopes.

When burning, a method to minimize erosion is to specify a maximum of 50% bare dirt as the end product. However, when burning in eucalyptus, expect complete consumption even in mild weather. Area managers must plan on mitigating bare dirt with a follow-up seeding of a native grass/flower mix.

Biodiversity and Habitat Destruction

Biodiversity issues and habitat destruction are straight forward when there are identified populations of rare, threatened or endangered species within a targeted treatment area. Treatments can be customized and may actually enhance the habitat for the species of concern. For instance, creating islands in dense north coastal scrub stands not only reduces the fuel load, but can also increase the grassland edge favored by the western fence lizard, the endangered Alameda whipsnake's primary food source. Use of dry season prescribed fire appears to favor the local native needle grass populations over the exotic annual grasses. This allows area managers to meet fire management goals, since the native perennial grasses cure later with less biomass, but also meet biodiversity goals of favoring native seed banks. Burning around homes in scrub or chaparral often needs a pre-treatment to assist control. Conversion of narrow buffer strips in the aged scrublands to grass may allow a burn that will accomplish the regeneration of the scrub population thereby increasing biodiversity.

Hand labor is a traditional treatment and can be the most selective as workers have the opportunity to protect desirable native species. Use of hand labor is warranted along roadsides where flora is of high value. Species diversity and frequency of rare plants is highest along roadsides (and most visible when these special plants are cut in error). Area managers have enlisted members of the local native plant society chapter to tag specimens prior to treatment. Worker training and skill is crucial. They need to be trained to identify the plants to retain and to cut or mow to the increased height of four inches, which is often crucial, but hard to control with weed whippers or mowers.

Timing of treatment is also important when balancing fuel management with biodiversity concerns. Area managers avoid pruning during time of bark beetle or long-horned beetle flight, and during nesting season. Removing young material, such as two-thirds of understory bay trees to sustain oak overstory, not only reduces the potential fire impact but is easier to accomplish because it is easier to cut young trees or shrubs with loppers rather than waiting until they are so large that chain saws are required. The sensitivities of the timing of prescribed burns are well documented -- area managers try to burn outside nesting season, in dry soils, after seeds have matured, and when air quality permits. Timing needs to consider not just the season or life stage of targeted fuels, but also the duration of a treatment. For instance, by limiting their grazing duration goats can be used to manage for native grass. In one local stand 450 goats only spent the night and when they left, the native needle grass remained with seed heads intact, yet, the exotic annuals were eaten.

The use of goats needs to address the potential for a shift in the species distribution. Where desired species, such as young oaks, need to be protected, pre-treatment may be required. Techniques such as fencing off areas or wrapping individual trunks prevent these desired specimens from being girdled by the browsing goats. If a prescribed burn is planned as a follow-up treatment the non-selective nature of goats is usually acceptable.

One of our region's greatest challenges is dealing with large stands of north coastal scrub or chaparral and how to achieve desired hazard mitigation (potential flame lengths under 8 feet) without converting it to another vegetation type. If cut, grazed or burned, scrub tends to revert to grassland, which may be acceptable in many locations. However, at other sites the scrub communities offer important wildlife habitat and has great floral diversity. The resulting prescription includes a non-traditional approach of creating shrub islands, where spacing between islands is a function of shrub height to slow the movement of a fire. The prescription highlights necessary precautions regarding treatment of obligate seeding species, for when we are successful in preventing wildfire through continued cutting or grazing, we are dooming those obligate seeding plants to their last generation by removing these parent seed sources. Seeds in the soil may be another source for regeneration, however, the length of time in which the seeds are viable is usually unknown. Area managers have had success with the Brontosaurus (a specialized piece of equipment with an articulated arm) which has the ability to "dance" around patches with obligate seeders and emerging oaks to create shrub islands with a mulch layer as an after product. Managers have found that this concept of shrub islands works best where the population includes smaller sized individual bushes, and where young oaks facilitate speeding succession to a woodland community.

Regional managers have found dealing with the slippery concept of biotic communities a greater challenge. The community level interconnections are not as well understood, with little or no documentation of the overall response to fuel treatments. The more holistic approach also often uncovers conflicted values where environmental advocates do not agree on the best course of action. This often results in difficult, no win, value judgments that managers have to make with limited scientific information.

Invasion of Weed or Pest Species

Invasion of weed or pest species is an issue with room for common ground between environmentalists and fuel managers. Common weed species often represent a higher fuel load as well as a threat to native plant populations. Follow up treatment must be planned, and may include heavy mulching or prescribed fire. Reducing the size of the area disturbed and the amount of time the treatment stays on the site also reduces the potential for weed species.

Managers have found that mowing grasslands for fuel management can also reduce exotics like yellow star thistle. Here the timing of treatment is important in order to match yellow star thistle's growth and production of seed. Timing is equally important for mowing those grass stands free of yellow star thistle, because if treated when perennials are setting seed, the treatment gives the undesired exotic grass species a competitive edge. Understanding these environmental consequences may mean mowing early with a second mowing later, rather than mowing by June 1 regardless of the phenological stage of desired species.

Refining vendor specifications is critical to reducing the spread of invasive pests. When using goat herds that have previously grazed areas of broom or invasive weeds, managers need

to specify that the herder feed them clean feed for three days prior to them coming onto the treatment site. In eucalyptus stands, area managers generally allow vendors to prune only between October to April to avoid entry sites for eucalyptus long-horned borer. They also generally require the vendor to remove the eucalyptus slash off the site, because fresh cut wood is a siren that attract the bugs. Similarly, as a precaution to reduce the spread of pine pitch canker, Monterey pine stands should be pruned only when bark beetles are not flying, usually from October to April..

A serious regional challenge has been controlling resprout of cut eucalyptus. If area managers choose not to use herbicide in order to reduce the environmental impact, they need to budget hand labor to pull or cut eucalyptus sprouts. If chemicals are used to prevent regrowth, the best regional success has been with Garlon 4, which achieved 90% kill, with no translocation between remaining trees. The use of Garlon also allows a delay in treatment and selective tree cutting and chemicals. This separation is important because it is difficult to cut trees and apply an herbicide to the stumps in the same operation.

Conclusion

Unfortunately, there is no shortcut to resolve all the issues associated with fuel management in the urban wildland interface. It does get somewhat easier as many of the environmental issues are discussed each time a new site is proposed for treatment. The process involves continually verbalizing the desire to balance goals of fuel treatment with environmental concerns. This involves getting people out on the site to look at the issues together and bridge the communication gap. It becomes an iterative process that focuses on specific sites and proposed treatments, and looks to balance both the fire management goals and the environmental issues. East Bay managers have been successful in using the latest in fire modeling in the form of FARSITE (Fire Area Simulator) fire growth model to help residents understand what the treatment can “buy” in terms of fire behavior. Another successful technique has been involving volunteers in follow-up treatments such replanting programs. Providing services directly to residents, such as curbside chipping programs, familiarizes residents and makes them more tolerant of fuel treatments on adjacent wildlands.

As we work it is important not to underestimate the long term commitment required to address fuel reduction at the urban wildland interface. The work is never done -- hazard reduction and fuel treatment are not a one time event or even done on as long a cycle as ten years. It is important to establish dialogues, foster working relationships and sustain long range visions. The costs and benefits must be reviewed in terms of recurring cycles when making management decisions. Developing environmentally sustainable solutions with flexibility to make mistakes and improve the collective understanding of a technique, potential refinements, impacts and benefits are the keys to on-going success.

Increasing Biodiversity Through the Restoration of a Natural Process by Prescribed Burning in California State Parks "A Sonoma County Experience"

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At Annadel State Park, prescribed fires were utilized to promote native grass and forb understory in oak forests and to control invasions of Douglas-fir (*Pseudotsuga menziesii* (Mirbel) Franco var. *menziesii*) due to long fire return intervals. The natural fire cycle is between 2 and 8 years as determined by analyzing fire scars. Young Douglas-fir seedlings were killed by fire but older seed trees were not.

At Sugarloaf Ridge State Park, prescribed fires were utilized to control yellow star thistle (*Centaurea solstitialis* L.) which has dominated many grasslands in the park. After three consecutive summer burns yellow star thistle was practically eliminated from the burn plot. Purple needlegrass and creeping wildrye (*Leymus triticoides* (Buckley) Pilger) stands increased with every burn. Native taxa also increased in numbers.

Annadel State Park

Annadel State Park is located in the Coast Range, just south east of Santa Rosa, California; it is within the California Mixed Evergreen Forest Ecological Region. Oregon oak (*Quercus garryana* Hook) forest communities occur on north facing slopes while south facing slopes support open savannas of oak hybrids *Quercus x explingii*, as well as stands of Blue oak *Q. douglasii* Hook. & Arn.), California black oak (*Q. kelloggii* Newb.) and coast live oak (*Q. agrifolia* Nee). Stand age analysis by Barnhart, et al. (1996) showed that *Quercus* spp. were much older than Douglas-fir. Douglas-fir and California bay (*Umbellularia californica* (Hook. & Arn.) Nutt.) have been invading the oak understory due to increased fire intervals in the park. This Douglas-fir invasion apparently began around 1910 and has decreased natural diversity in oak communities.

Fire intervals were derived from analysis of fire scars on samples taken from 14 coast redwood (*Sequoia sempervirens* D. Don (Endl.) stumps located throughout the park. Before the mid 1800's, mean fire intervals between 6.2 and 23.0 years were found on individual stumps, with single intervals as low as 2 years. The park is in an area of sparse lightning activity, thus Native American burning seems to be the plausible explanation of the high fire frequencies recorded (Finney and Martin, 1992). Redwood groves in the park occur as riparian communities where fire is less frequent than in more xeric grass and oak communities where fire likely occurred every 2 to 8 years.

Douglas-fir seed trees often overtop the surrounding oaks. Many of these trees have been girdled or cut in order to discourage new seedling production. Younger trees have been removed by

a cadre of volunteers. Prescribed fire has been successful in killing seedlings and saplings and stimulating native grass and forb growth. In 1995, prescribed burns were conducted on 95 acres of Douglas-fir invaded oak communities. The acreage figures for 1996 and 1997 have not yet been compiled.

Sugarloaf Ridge State Park

Three consecutive summer prescribed burns within the park have demonstrated over 99 percent reduction of yellow starthistle seedlings while promoting the growth and spread of native bunchgrasses and sod forming grasses. Burns were timed to coincide with the thistle's flowering stage. This has proven to be an effective, economical way to control yellow star thistle and at the same time increase the natural diversity of herbaceous plants. Percent cover of native perennial grasses increased from 6 in unburned to more than 21 percent in burned plots. Native forbs increased from 5 in unburned to 26 percent in burned plots. The original burn plot was about 150 acres, this area was increased to 380 acres for the July 1996 burn.

Acknowledgments

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Comparison of Montane Ecosystems under Natural Fire Regimes in the Sierra San Pedro Martir and a Century of Fire Suppression in the Sierra Nevada

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In 1989 a binational, multi-agency research team was formed to investigate the ancient forests of Baja California's highest mountain range, the Sierra San Pedro Martir. The science team quantified ancient quaking aspen (Populus tremuloides Michaux var arurea Daniels), white fir (Abies concolor (Gordon & Glend.) Lindley var concolor), California incense cedar (Calocedrus decurrens (Torrey) Florin), sugar pine (Pinus lambertiana Douglas), lodgepole pine (P. contorta Loudon) ssp. murrayana (Grev. & Balf.) Critchf.), Parry pinyon pine (P. quadrifolia Parl.) and Jeffrey pine (P. jeffreyi Frev. & Balf.) forests in Mount San Jacinto State Park (SJM) and Parque Nacional San Pedro Martir (SPM) in Baja California. Fire regimes were also reconstructed for the two parks; SJM has been under fire suppression policy since the early part of the century while SPM has a near natural fire regime. Fire return intervals are 15 to 20 years in the SPM while only one fire has been recorded in fire scars from SJM since the turn of the century. The forests of SJM has around 200-500 trees/ha while the SPM has about 100 trees/ha (Barbour, et al., 1992). Similar Sierra Nevada mixed conifer forests also have 200 or more trees/ha and often contain thick shrub understories.

We have quantified ancient forest stands at Sailor Flat (Placer County), Sugar Pine Point, and D. L. Bliss State Parks using point quarter sampling techniques modified to show both trees older than 150 years and trees younger than 150 (less than 18 to 20 inches diameter breast height (dbh) in white fir). This gives us stand structures for both ancient forests and post fire suppression invaders. Sugar Pine Point State Park had average fire return intervals of 8 years while Emerald Bay State Park had average return intervals of 11 years prior to 1850 (Rice, 1991). This difference in only a few miles is accountable to the rocky terrain of Emerald Bay State Park. Primeval (500+ years old) and ancient (100 to 500 years old) forest stands at Calaveras Big Trees State Park have also been quantified and fire history have been worked out by others. Phytolith studies are currently underway, by DPR staff. These studies will help determine pre-grazing composition of forest understories. Fire histories for Calaveras Big Trees State Park has been studied in detail by Swetnam and his students.

The forests of the Sierra San Pedro Martir give us a picture of what the Sierra Nevada was like prior to fire suppression and logging. Unfortunately, in the SPM, systematic cattle grazing began in 1928 and large herds of sheep began grazing in 1915 and continued until 1963 when sheep access to the Mexican National Park was denied, however cattle grazing is still allowed (Minnich, et al., 1994). In contrast the Sierra Nevada underwent heavy grazing starting with the drought year of 1864 (Kinney, 1996). In both ranges heavy grazing has changed understory composition, favoring unpalatable taxa, especially shrubs.

In the SPM small, isolated meadows and forest stands, far from water sources, still contain fairly unaltered understory associations. The native bunchgrass needle-and-thread (Achnatherum coronatum (Thurber) Barkworth) forms a solid understory under Jeffrey pine woodlands in the

center of the range. The Sierran analog is lemon needlegrass (*Achnatherum lemmonii* (Vasey) Barkworth). Which occurs as understory dominates in Jeffery Pine and Pacific ponderosa pine (*Pinus ponderosa* Laws.) woodlands in the Tahoe Basin and the west slope of the Sierra Nevada to around 2500 ft elevation. Jeffery Pine Forests at Grover Hot Springs State Park on the east slope of the Sierra Nevada have the same understory dominants as those found in the northern end of SPM, ashy wildrye (*Leymus cinereus* (Scribner & Merr.) A. Love). Prior to grazing understory grasses likely carried cool, but more frequent fires, but for the last 150 years intense grazing has removed these grasses from the understory, thus fires do not carry well, and though lightning fires are frequent, they often cover very small areas and go out because of lack of understory fuels.

The results from our binational research efforts have far reaching applications; as we have shown that ancient forests, under natural fire regimes, are quite resistant to crown fires, drought and insect predation. The fire storms that have been so frequent in the last decade do not occur in similar ecosystems in Baja California where fires are not generally or effectively suppressed. Future policies on fire management in California need to address the need to restore natural like fire regimens in California's wildlands. Prescribed fire can reduce understory fuels and help restore less flammable herbaceous understories. Thinning of understory trees and shrubs are often necessary to reduce latter fuels prior to reintroduction of fire. Native bunchgrass should be re-introduced into forest understories. Native bunchgrasses usually remain green at the base all year, thus fire burns cool and slow through bunchgrass stands in contrast to hot and fast in understories containing dry alien annual grasses or closed shrub canopies.

Recommendations for Restoration of Sierran Primeval and Ancient Forest Ecosystems

Understory Thinning (Spring, Summer)

1. Remove trees less than 18-20" dbh (150 year or less age classes. Leave 20 - 40 stems/ac. of various heights down to 8 ft tall. Trees under 6 feet can also be left as they will not survive prescribed burning (tested in Tahoe Basin State Park System units).
2. Trees of less than 18-20" dbh that have commercial value can be harvested, but not trees larger than 20" dbh. White fir has high value for Christmas trees and could help pay for the cost of restoration.
3. Select non-fire adapted trees for removal (white fir and incense cedar) and leave mostly pine species for regeneration. Leave non commercial portions in place on the forest floor; if stack and burn is necessary due to dangerous fuel accumulations, burn spots should be reseeded with native grasses and forbs (tested at Calaveras Big Trees State Park).
4. Cut shrub understory when above 3 feet; leave in place on forest floor along with the non-commercial tree slash (tested at Empire Mine State Historic Park and South Yuba River State Park).

Prescribed Fire

1. When shrub and tree understory slash is dry (fall or early winter), cool prescription prescribed burning should be initiated to decrease downed fuels. Fuel reduction burns may be necessary for several years in succession. Spring burns retard the growth of native grasses and forbs and should not be utilized under most circumstances.

2. Re-establishment of natural fire regimes will enhance herbaceous understory that will carry frequent, low intensity fires. Mosaic burning then can be maintained to enhance natural diversity in the understory of ancient forest ecosystems.
3. Monitoring program should include pre-management base line information such as permanent point-quarter transects and understory plots. Plots and transects should be monitored periodically and should be placed in each plant association within the treatment area. Management manipulations and adjustments are made dependent on monitoring results.

Scientific names used here are those of the Jepson Manuel (Hickman, 1993).

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Landscape Fire-hazard Reduction and Plant Community Restoration Within the Carberry Creek Watershed of the Applegate Valley in Southern Oregon

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The Carberry Creek Planning Project resulted in the long-term landscape visualization defined in this paper, and an environmental assessment covering the first round of projects aimed at the restoration of the Carberry Creek sub-watershed. This paper describes the planning process developed while the project was underway, the ecological issues confronted by the planning team, and the results of the landscape planning procedure. This planning procedure and results reflect a determined effort at soliciting the participation of local Carberry Creek residents, and the population of the larger Applegate Valley.

The major ecologically disruptive forces of the past decades have been fire suppression and timber harvest, so it is not surprising that projects of high priority address the problems arising from these processes. Several projects are focused on restoring ailing pine plant communities suffering from Douglas-fir or brush invasion. These projects serve the dual function of restoring endangered plant communities (and associated wildlife habitat) and creating areas of low fuel load. These patches of reduced fuel form the basis of a system of fire-defensible areas across the landscape, reducing landscape-level fire hazard.

The landscape design process followed by the planning team and Carberry Creek residents helped prioritize issues of concern, prioritize which issues should be addressed, and define the management actions for achieving landscape objectives. It is envisaged that economically viable restoration projects (for example, the thinning of dense, even-aged stands of mature Douglas-fir) be paired with uneconomical projects such as pre-commercial thinning of sites recovering from past clear-cuts. This process would create a trust fund on the land, and ensure that funds derived from timber harvest remain within the Carberry Creek sub-watershed.

Project Mission, Primary Goals, and Issues

Residents, local experts, and USDA Forest Service employees at the Star Ranger District of the Applegate River watershed in southern Oregon have been involved in an exciting effort to develop effective long-term strategies for reducing fire hazards and improving watershed health in the 15,000 acre Carberry Creek sub-watershed. The Carberry Creek Planning Project formed the basis for the creation of a long-term visualization and accompanying implementation schedule for projects. Shorter-term management projects were designed to alleviate current ecological problems and place the landscape on a trajectory of change towards long-term visualization. In addition to ecological issues, the planning group and participating public thought it essential to address key social, management, and economic issues (table 1).

Table 1. Ecological, management, social, and economic issues.

Issues	Reference
Ecological Issues	
Fragmentation and decreased connectivity	Many publications, public meetings
Increased landscape fire-hazard	FEMAT report, ecosystem health assessment, watershed analysis, public meetings
Reduced old-growth	FEMAT report, ecosystem health assessment, watershed analysis, public meetings
Douglas-fir population explosion	Many papers
Loss of fire dependent plant communities	Various publications
Noxious weed invasion	Ecosystem health assessment, watershed analysis, public meetings
Stream embeddedness	FEMAT report, watershed analysis
Lack of riparian vegetation	Aerial photos, field observation
Threatened and endangered plants and wildlife	FEMAT report, ecosystem health assessment, watershed analysis, public meetings
Management Issues	
Livestock grazing	Watershed analysis, public meetings
Alternative density management techniques	FEMAT, watershed analysis, public meetings
Road construction and maintenance	FEMAT, watershed analysis, public meetings
Ecosystem maintenance and monitoring	FEMAT report, ecosystem health assessment, watershed analysis, public meetings
Social Issues	
Neighborhood health and safety	Public meetings
Public participation	Public meetings
Private land management	FEMAT, public meetings
Economic Issues	
Economic viability of management	FEMAT report, public meetings
Diversity of economic opportunities	Public meetings
Ongoing cost of ecosystem management	Public meetings

The Planning Process

Until recently, land planning has been primarily based on single resource management. This has led to the classification of the landscape into zones designated for single uses. The landscape analysis and design process developed by Diaz and Apostol (1992) unites forest planning with the principles of landscape ecology. This approach assumes that different landscape structures present in the watershed (clear-cut, riparian areas, plant communities, etc.) can be maintained on the landscape and meet social objectives in addition to maintaining ecological integrity.

Integral to the concept of landscape design is the maintenance of “flows” across the landscape. Flows included the connectivity of late-seral mixed-conifer plant communities, as well as the movement of fire, people, and wildlife across the landscape. Stand-level objectives were reassessed by considering their effect on these flows. Although some flows needed to be facilitated by stand-level management, others needed to be disrupted. For example, stand-level management might effectively break the flow of fire between ignition point and upslope areas by creating zones of low fuel.

Such management actions are central to one of the most important project objectives: reducing fire-risk to the residential areas. Therefore, the first task of the planning process was to create a long-term design of the idealized watershed in 200 years by considering the fire hazard and other objectives. The fire hazard objective was particularly concerned with the maintenance of low fuel zones within strategically located fire-dependent plant communities.

Areas affected by past timber harvest show altered plant community composition, often dominated by trees of a single age-class and species. These are not sustainable plant communities. Furthermore, their structure does not facilitate the continued presence of many threatened plants and wildlife species. In such areas, management actions are aimed at protecting threatened components of the plant and wildlife community, while allowing the establishment of a new multiple-species, multi-cohort (age/structure class) of trees. This strategy contributes to a more diverse and sustainable plant community in the future (dying trees can be replaced by the younger generation) and responds to many of the health issues (insect and pathogen outbreaks) found in such stands.

Analysis of the ecological issues and affected areas resulted in a prioritization of management actions: the re-introduction of fire as a maintenance tool for fire-dependent species; thinning and favoring pine within suitable secondary growth areas falling within the range of pine species; and the creation of multi-cohort, Douglas-fir stands from single-aged, second-growth and fire-initiated stands.

Several projects were also defined outside of the context of economically viable timber harvest operations. These include riparian restoration, weed control, and monitoring of water quality in conjunction with stream embeddedness. Many of these issues implicate private as well as public land. The success and implementation of these projects will depend on public participation and the formation of cooperative agreements between landowners and public agencies. The strategic location of these management activities resulted in the realization of fire-hazard reduction objectives while addressing many ecological, social, and economic issues (table 1).

Conclusions

The 200-year landscape vision represents a palette of plant communities and stand structures organized over the landscape to answer to ecological, management, and social needs/issues identified during the public scoping process of this project. Most importantly, this project has contributed to the development of a landscape planning process incorporating local public opinion. Since the initiation of this project, several other landscape designs have been implemented. All of these planning ventures will contribute to the development of a more sophisticated planning process suited to local conditions.

Acknowledgments

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Fire Hazard Reduction and Oak Woodland/Shrubland Restoration in the Humbug Creek Watershed of the Applegate Valley, Southern Oregon

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The Bureau of Land Management (BLM) recently initiated the Humbug Creek project, a fire-hazard reduction and watershed-level restoration project within the Applegate Valley of southern Oregon. Although the project will be supported by fire hazard reduction funds, the long-term strategies incorporate the ecology of individual plant and wildlife species and communities, and landscape criteria. The project encourages public participation through public tours, educational outreach, and the funding of work on adjacent private land to achieve landscape objectives. Because the project is occurring within the Applegate Adaptive Management Area under the Northwest Forest Plan, an experimental approach is being used to test different short and long-term management strategies for attaining a range of preferred plant community conditions.

The availability of funding for fire-hazard reduction offers a unique opportunity for restoring excessively brushy grasslands, brushlands, and oak woodlands. Our ecosystem based approach prioritizes the reintroduction of fire as part of restoring ecosystem function. The restoration effort also includes reseeding with native grasses to restore the balance of native plant life-forms in the face of weed plant invasion. Where the reintroduction of fire is not possible, alternative shrub reduction techniques and long-term strategies are being examined to maximize the retention of native plants and wildlife habitat. This strategy is designed to reduce the severity and extent of wildfires that occur within the high-hazard brush-dominated slopes common on south-facing slopes of southwestern Oregon. Inventory and monitoring techniques are being developed to assess plant community change within management areas, in the context of adaptive management.

This paper presents management and research objectives in an educational context on fire hazard reduction and restoration of the Humbug Creek watershed in southern Oregon, and is part of our public outreach effort to increase trust in agency work and provide a forum for public participation and discussion.

Project Definition, Goals, and Objectives

The Humbug Creek watershed encompasses 7,166 acres, including 4,848 acres of BLM administered land, and 2,317 acres of non-BLM administered land. Southern exposures are commonly composed of grasslands, shrublands, and oak woodlands. With fire suppression, the shorter-lived woody shrubs have come to dominate a large portion of non-conifer plant communities. Increased shrub abundance creates a high fire hazard by creating continuous high fuel loads. In addition to increased risk to human life and property, such high fuel loads create wildfire characteristics detrimental to soils, plants, and wildlife. High canopy cover by shrubs may already have resulted in the loss of much of the herbaceous component of shrublands and oak woodlands.

The desire for watershed-level fire hazard reduction coupled with interspersed private land ownership and multiple ecological problems defines the need for a unique planning and management process. The BLM has been implementing projects aimed at fire hazard reduction in shrublands and oak woodlands of the Applegate Valley for several years. However, in densely populated watersheds, it is not possible to achieve landscape fire hazard reduction without involving private landowners.

The BLM is collaborating with a private group, the Applegate Watershed Council, for public outreach purposes. This includes education concerning fire-hazard conditions and planning the location of fire safety zones in the event of a fire. The Watershed Council will also coordinate the inventory of fire hazard conditions on private lands to facilitate watershed-wide planning.

In the Humbug Creek project, the BLM will be reducing landscape fire hazard by implementing different strategies. Reducing fuel loads in strategically located fire dependent plant communities can combine plant community restoration with fire hazard reduction. An alternative strategy is the placement of shaded fuel breaks on key ridges.

Restoration of shrublands and oak woodlands will be conducted in the context of adaptive management. Different prescriptions will be tested across the landscape and monitored to determine the effect of management on the maintenance of native plants and the exclusion of undesired weeds. Of particular concern is the potential dominance by annual grasses, such as cheatgrass and medusahead, and the invasion of yellow starthistle, a noxious weed. Native grass seed has been collected and will be cultivated to provide a suitable seed source for reseeding where the native herbaceous component has been lost. Plant inventory and monitoring techniques have been specially designed for use across a range of plant communities and structures unique to the Applegate Valley.

Vegetation Inventory, Monitoring, and Project Planning

Inventory and monitoring protocols were designed to aide project planning and yield a better understanding of the plant communities within the Applegate Valley ecosystem. Management activities, monitoring, and planning were based on our present perception of plant community dynamics within local shrublands and oak woodlands.

Conceptual Framework of Plant Community Change

A conceptual framework was determined for plant community dynamics within the shrublands and oak woodlands of the Applegate Valley (fig. 1). Models defining different conditions (including desired and undesired states) are essential for formulating management programs across the landscape. Such models help define management objectives, ecological issues that need to be understood and addressed by management, and help with the placement of monitoring to assess restorative management practices.

Publications dealing with oak woodlands and shrublands indicate that a wide range of plant communities (associations) are possible. Some associations may show a predilection for particular undesired changes (for example, more mesic oak woodlands are susceptible to Douglas-fir invasion). Other associations may show a combination of problems (fig. 1). For example, some oak woodlands show excessive cover by oaks and show understory domination by weeds. Ultimately, we would like

General plant community state changes

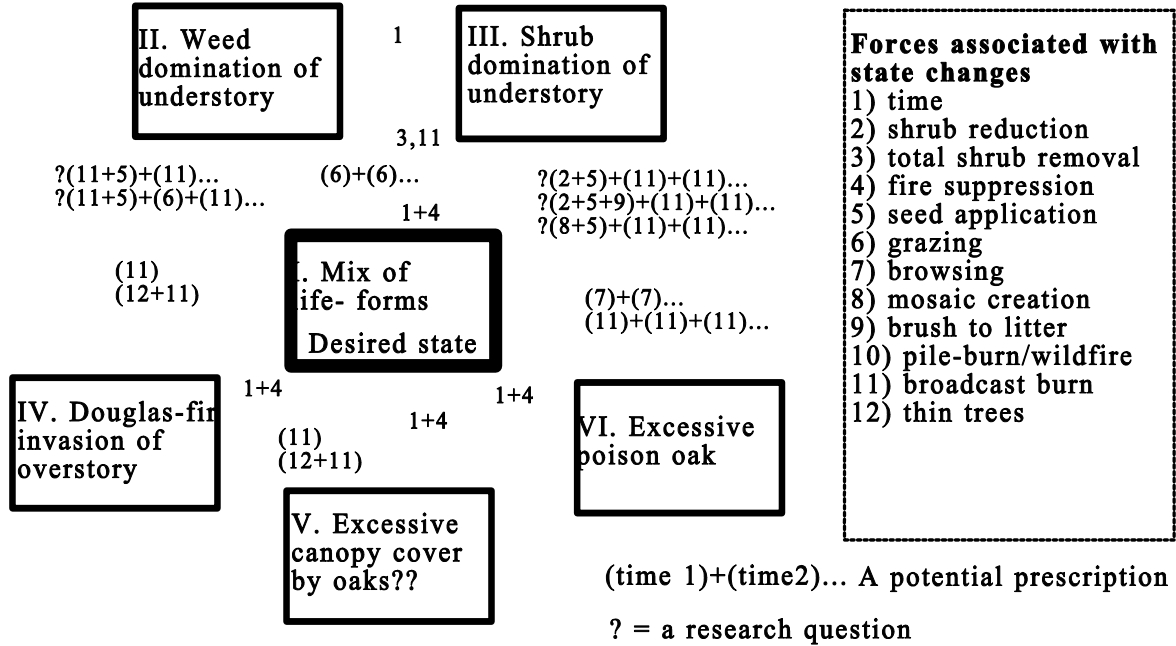


Figure 1. A “state-and-transition” diagram for plant community changes in oak woodlands and shrublands of the Applegate Valley.

to have a plant community structure (composition and spacing of different life forms) suited to site characteristics that includes as few introduced weed species as possible. Although the desired plant community includes a balance of different life-forms, it is envisaged that the complete range of vegetation structures be represented across the landscape. To achieve this, watershed-level inventory of variables identified by the conceptual framework is necessary.

Landscape Inventory for Project Planning

BLM administered lands have been divided into polygons (forest operations inventory -- FOIs) representing broad plant communities and conditions. The arrangement of grasslands, shrublands, oak woodlands, and conifer communities can therefore be mapped within a geographic information system (GIS). Standard silvicultural inventory occurs within conifer-dominated plant communities. In grasslands, shrublands, and oak woodlands, woody plant species and herbaceous cover are visually ranked in abundance. Although estimated cover is an important variable for the planning of fire hazard reduction, such data remains very subjective. To include a more objective variable in our data collection at the landscape level, the ratio between woody and herbaceous cover is estimated from aerial photos using grids on transparent overlays. These variables allow us to see the distribution and condition of shrublands and oak woodlands across the landscape. The resultant maps of plant community composition and condition provide the spatial context for project planning.

Ecosystem Plots for Plant Community Monitoring

Ecosystem monitoring plots have been designed to monitor plant community dynamics (interactions between trees, shrubs, perennial grasses and forbs, and annual grasses and forbs) and associated environmental variables of interest. The sampling macroplot is comprised of a 100 meter transect. Point cover quadrats and canopy cover measurements are collected along a central tape measure. Additional silvicultural data is collected within the area extending 5 meters to either side of the tape measure. The macroplots are permanently marked to enable the same data collection before and after treatment. With many management actions, repeat data collection may be necessary 2, 5, and 10 years after treatment.

To facilitate public participation and sharing of information, the sampling protocol was designed to be easily applied with a minimum of training. Thus, participating agencies, private landowners, and private groups can all contribute to the research and monitoring effort. The data pool will also yield important information concerning the range of plant composition and conditions across the landscape and provide a plant community classification upon which to base our improved understanding of the ecosystem.

Conclusions

The integration of management objectives, inventory, and monitoring within an ecological-conceptual framework (fig. 1) is key to developing adaptive management projects. Inventory is necessary to identify the extent and condition of plant communities in the context of local ecological issues. In the case of the Applegate Valley, we are trying to integrate plant community restoration with landscape fire hazard reduction. Landscape-wide inventory is necessary to strategically locate management action to achieve these multiple objectives. More detailed monitoring is used to examine plant community changes within the range of prescriptions applied to the landscape. In this manner, we are able to develop prescriptions to treat local management problems. Monitoring will also test assumptions in the conceptual model of plant community change, thereby increasing our understanding of the local ecosystem

Fire Effects Monitoring Results in Yosemite National Park's White Fir-Mixed Conifer Forest: Fuel Load and Tree Density Changes

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Abstract

Fire effects monitoring data collected over a period of five years in Yosemite National Park, California are analyzed to evaluate changes in fuel load and tree density following management ignited prescribed fire. Total fuel load in the white fir-mixed conifer forest was reduced by 57 percent immediately after the prescribed fire. Total woody fuel load was reduced by 40 percent, with the smaller woody size classes showing the greatest reduction (≥ 76 percent). Duff load was reduced by 92 percent. Total fuel load increased to 72 percent of prefire levels within 5-years postfire. Woody fuels increased to 91 percent of prefire loading, while duff accumulated to only 15 percent of prefire levels. Mean fuel accumulation rates were 2.1 tons/acre/yr (0.8 tons/ha/yr) for woody fuels, and 0.4 tons/acre/yr (0.1 tons/ha/yr) for duff. Overstory and pole tree densities were reduced by 38 percent and 80 percent respectively within 5 years after prescribed fire. The pole tree mortality resulted in a shift in stand structure with pole tree proportion of total tree density declining from 50 percent prefire to 24 percent five years postfire. Little change occurred in species composition. These results are used to assess achievement of Yosemite fire management objectives and to provide recommendations for objective refinement.

Introduction

Yosemite National Park in California began implementing a management ignited prescribed fire program in 1970. Goals of the program included the utilization of prescribed fire as a tool both to simulate natural fire regimes and to reduce hazardous fuel loadings. Although these goals can be complementary, a century of effective fire exclusion has resulted in unnaturally high fuel loads, thereby precluding burning under natural conditions in many areas. Management ignited prescribed fires in heavily fueled areas have fuel reduction as their primary objective. These fires are intended to restore fuel loadings and forest structure to levels within the range of natural variability. Once this has been achieved, subsequent burns more closely resembling fires occurring under natural conditions can be implemented.

The white fir (*Abies concolor*)-mixed conifer forest occupies 31 percent of the area in which Yosemite conducts management ignited prescribed fire. The estimated natural fire return interval in this community is 8 to 18 years (USDI National Park Service 1990). Between 1931 and 1995, 947 lightning fires were suppressed in Yosemite white fir-mixed conifer forests, leaving 77 percent (88,000 acres) of this community with unnaturally high fuel loadings. Fire exclusion has favored the invasion of white fir and incense-cedar (*Calocedrus decurrens*) understory trees (van Wagtenonk 1985). Dense thickets of these trees, coupled with higher downed woody fuel loadings, have created conditions conducive to unnaturally severe wildland fires. The Ackerson Wildfire of 1996 burned an additional 19,000 acres in Yosemite white fir-mixed conifer forest, serving as a poignant example of increased flammability due to fire exclusion.

The primary objective for the initial prescribed fire in the white fir-mixed conifer forest is ≥ 50 percent reduction in total fuel load that is to be achieved through a universal ≥ 50 percent reduction across all size classes of woody fuels, litter, and duff. A secondary objective for the initial prescribed

fire is to achieve mortality on ≥ 40 percent of pole size (1.0- 5.9 inches (2.5-15cm) dbh) white fir and incense-cedar, thereby reducing the aerial fuels that contribute to development of crown fire.

Recognizing the need for a method of evaluating achievement of objectives and over-all program success, fire managers began implementing a long-term fire effects monitoring program in 1989. The monitoring program follows the methodologies outlined in the National Park Service Western Region Fire Monitoring Handbook (USDI National Park Service 1992). This paper discusses the analysis of fire effects monitoring plots used to assess fuel reduction and accumulation, and it examines short-term changes in pole and overstory tree density after prescribed fire.

Methods

Site Description

The white fir-mixed conifer forest forms an almost continuous zone of dense forest between 5,000 and 7,500 ft (1,500-2,300 m). Overstory species consist primarily of mature white fir, sugar pine (*Pinus lambertiana*), incense-cedar, and ponderosa pine (*P. ponderosa*), with lesser amounts of red fir (*A. magnifica*), Jeffrey pine (*P. jeffreyi*), and giant sequoia (*Sequoiadendron giganteum*). Understory tree species are primarily white fir and incense-cedar, with some sugar pine and ponderosa pine. The ground layer is sparse with < 20 percent shrub cover. Fuels are best described by the short-needled conifer fuel model (Fuel Model 8) with inclusions of heavy dead and downed fuels resembling Fuel Model 10 (Albini 1976). All burns in this analysis were conducted between 1989 and 1995 within the Yosemite prescription parameters specified for Fuel Model 8 (van Wagtenonk 1974). None of the burn units had experienced fire within the past 30 years.

Burning Conditions

Burns were ignited by using a strip head-fire ignition pattern. Backing rates of spread ranged from 0-1 chain/hr (0-20 m/hour) with flame lengths of 0-1 ft (0-0.3 m). Head fire rates of spread ranged from 1-2 chains/hr (20-40 m/hour) with flame lengths of 0-2 ft (0-0.6 m). Ambient conditions were as follows: temperature 40-80°F (4-27°C), relative humidity 20-65 percent, and mid-flame windspeed 0-6 mph (0-10 km/h). Fuel moistures were: 1-hour time lag fuel moisture (TLFM), 6-13 percent; 10-hour TLFM, 8-10 percent; 100-hour TLFM, 10-16 percent; and 1000-hour TLFM, 15-30 percent.

Data Collection and Analysis

Plot locations were selected by using a stratified random sampling design within white fir-mixed conifer forest areas designated for management ignited prescribed fire. Data were collected within the 20 m x 50 m plots prefire, immediately postfire, and 1-, 2-, and 5-years postfire. Overstory trees ≥ 5.9 inches (15 cm) dbh were recorded within the entire plot area while pole trees between 1.0 - 5.9 inches (2.5-15 cm) dbh were sampled within one 10 m x 25 m quarter of the plot. All sampled trees were tagged, mapped, identified to species, and recorded as live or dead in accordance with Western Region Fire Monitoring Handbook protocols (USDI National Park Service 1992). Fuel load was measured along four 50 ft (15.2 m) transects per plot by using the planar intercept method (Brown and others 1982). Woody fuel load included: 1-hour (0-0.24 inches or 0-0.63 cm in diameter), 10-hour (0.25-0.99 inches or 0.64-2.53 cm), 100-hour (1.0-2.99 inches or 2.54-7.61 cm), and 1000-hr (≥ 3

inches or ≥ 7.62 cm) TLFM fuels. Total fuel load also included duff that consisted of the layer of partially decomposed, consolidated organic matter below the litter layer. Litter, which is defined as the freshly cast organic matter still retaining its morphological characteristics, was measured but is not included in the total fuel load calculation.

Data were analyzed by using the Fire Monitoring Software version 3.0 (USDI National Park Service 1997). This software provides a platform for data entry and storage in addition to performing functions including minimum plot calculations and analyses of change over time. Using fuel load as the primary variable, calculations indicated a need for a minimum of 6 plots to achieve an 80 percent confidence level with a precision value of 20. In this analysis, immediate postfire results are based on 11 plots that burned in 4 prescribed fires. Postfire fuel accumulation and tree density results are based on 6 plots that reached the 5-year postfire stage. Minimum plot recommendations for the secondary variable of tree density were not met. Therefore, while trends can be observed, additional data collection will be necessary before generalizations can be made regarding tree density.

Results and Discussion

Immediate Fuel Reduction

Total fuel load (n=11 plots) decreased 57 percent from 52.1 tons/acre (18.8 tons/ha) prefire to 22.3 tons/acre (8.0 tons/ha) immediately postfire. Duff was reduced the greatest, decreasing 92 percent from 17.5 tons/acre (6.3 tons/ha) to 1.4 tons/acre (0.5 tons/ha). Woody fuels decreased from 35.0 tons/acre (12.6 tons/ha) prefire to 21.0 tons/acre (7.6 tons/ha) immediately postfire, representing a 40 percent reduction (fig 1).

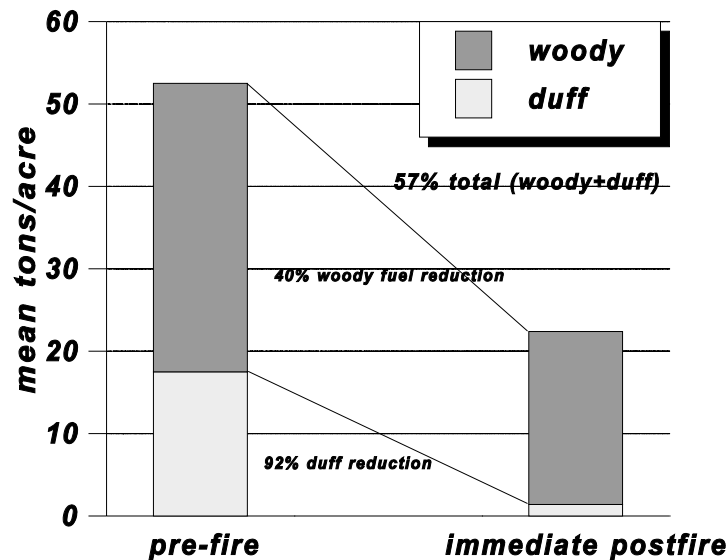
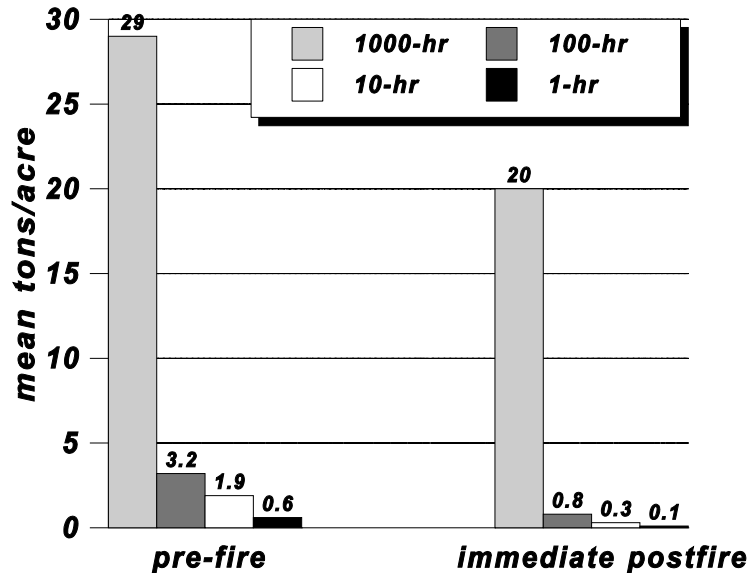


Figure 1--Fuel load (mean tons/acre) in white fir-mixed conifer forest before and immediately after prescribed fire (n=11 plots).

Within the woody fuel classification, the 1,000-hr size class fuels comprised the majority of the total loading (84 percent) prefire, yet they showed the least immediate postfire percent reduction (28.9 tons/acre prefire, 19.8 tons/acre postfire), leaving 68 percent of their original loading. This comparatively low reduction is the result of higher fuel moistures (>20 percent) in this size class. Smaller fuels generally have lower moisture contents and require less heat to reach ignition temperature. These smaller woody size classes (1-hour, 10-hour, 100-hour) all showed much greater immediate postfire percent reductions (≥ 76 percent), decreasing as a group from 5.7 tons/acre (2.0 tons/ha) prefire to 1.2 tons/acre (0.4 tons/ha) postfire (fig 2). Smaller fuels occupy a small proportion of total woody fuel loading (16 percent) yet are important targets in hazard fuel reduction burns due to their significant contribution to accelerated rates of spread. Although fuel reduction rates were not universal across all fuel size classes, prescribed fires under these conditions were successful in accomplishing the overall objective of ≥ 50 percent total fuel reduction.

Figure 2--Woody size class mean prefire and immediate postfire fuel loads (tons/acre) (n=11 plots).



These immediate postfire results correspond well with comparable data collected at Sequoia and Kings Canyon National Parks (Keifer 1995). Duff loading and consumption results were similar, while Yosemite woody and total fuel consumption values were slightly lower than those found in Sequoia and Kings Canyon. The differences in consumption can largely be explained by higher 1,000-hr fuel moisture during the Yosemite burns.

Postfire Fuel Accumulation

Total fuel load (n=6 plots) increased to 42.9 tons/acre (15.4 tons/ha) 5-years postfire, reaching 72 percent of prefire levels. Woody fuels achieved 91 percent of prefire loadings, increasing from 30.0 tons/acre (10.8 tons/ha) immediately postfire to 40.6 tons/acre (14.6 tons/ha) 5 years postfire. This equates to a mean woody fuel accumulation rate of 2.1 tons/acre/year (0.8 tons/ha/year). Duff accumulated at a much slower rate, reaching only 15 percent of prefire loading. Duff increased from 0.6 tons/acre (0.2 tons/ha) immediately postfire to 2.4 tons/acre (0.9 tons/ha) 5-years postfire, resulting in a mean duff accumulation rate of 0.4 tons/acre/year (0.1 tons/ha/year) (fig 3).

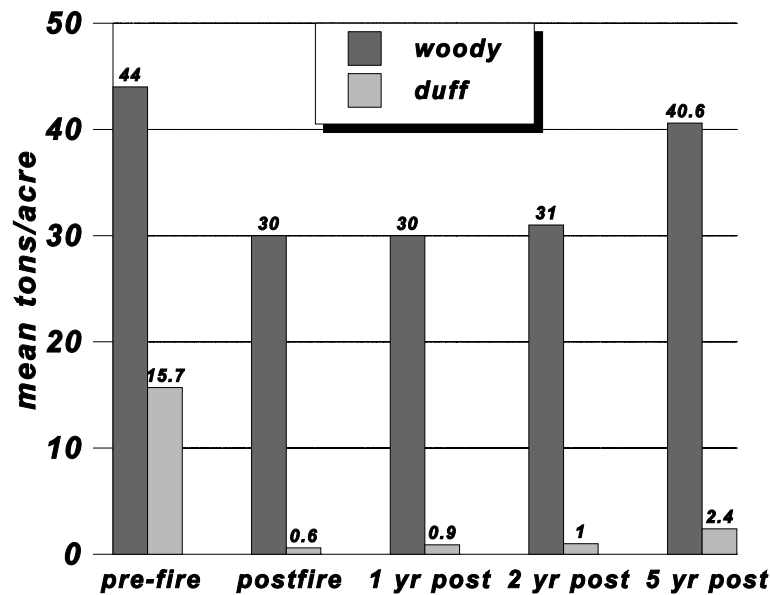


Figure 3--Fuel accumulation over time following prescribed fire in white fir-mixed conifer forest (n=6 plots). Mean values (tons/acre) for woody fuels and duff are included.

The mean woody fuel accumulation rate of 2.1 tons/acre/yr corresponds favorably with results of a similar study in Yosemite by van Wagtenonk and Sydoriak (1987) who found rates of 2.0 tons/acre/yr in white fir. However, their values for duff loadings and duff accumulation rates were significantly higher than those in this analysis.

Woody fuel accumulation after fire is generally attributed to fire-killed branches and small trees dropping to the forest floor. Although the initial prescribed fire resulted in significantly reduced total fuel loading, postfire fuel accumulation, in addition to the residual fuel loading, results in a fuel condition still exceeded levels considered to be within the range of natural variability. Although these ranges of natural fuel loadings are not exactly known, estimates can be made based on fire return interval and natural fuel accumulation rates data (van Wagtenonk 1986). A second prescribed burn within 10 years, targeting greater reduction in the larger size class woody fuels, would move toward bringing fuel loadings to more natural levels. Reduced stand density as a result of the first burn should result in slower fuel accumulation rates after the second burn. Once a natural

fuel load has been achieved, successive fires could be implemented under conditions and at frequencies more closely resembling natural fires.

Tree Density

Density of overstory trees (n=6) was reduced from 189 trees/acre (468 trees/ha) to 116 trees/acre (288 trees/ha) 5 years after prescribed fire, for a 38 percent reduction. Further analysis of overstory mortality by diameter class revealed that mortality was evenly distributed throughout the larger diameter trees both by size class and by species. Density of pole trees was reduced from 186 trees/acre (460 trees/hectare) to 40 trees/acre (93 trees/hectare), for an 80 percent reduction. White fir and incense-cedar poles, which together comprise 91 percent of the pole tree diameter class population, decreased 81 percent from pre-burn to 5 years postfire and showed little change in relative density between species. The remaining pole tree population consists of sugar pine that experienced similar mortality rates.

Current park objectives for burning in the white fir-mixed conifer forest do not specify desired or acceptable levels of mortality for the overstory diameter class. Therefore, while a 38 percent reduction in overstory tree density seems high, objective refinement and a limited sample size preclude such a conclusion. For the pole diameter class, the objective of ≥ 40 percent mortality on white fir and incense-cedar was achieved with a rate of 81 percent. This high mortality in the pole trees can be attributed to lethal cambial temperatures and crown scorch and has resulted in a change in stand structure. The percentage of trees in the pole category of 1.0-5.9 inches (2.5-15cm) dbh shifted from 50 percent prefire to 24 percent 5 years postfire (fig 4). Repeated burns may continue this structural shift toward a diameter class distribution more closely resembling stand structure believed to occur under natural conditions.

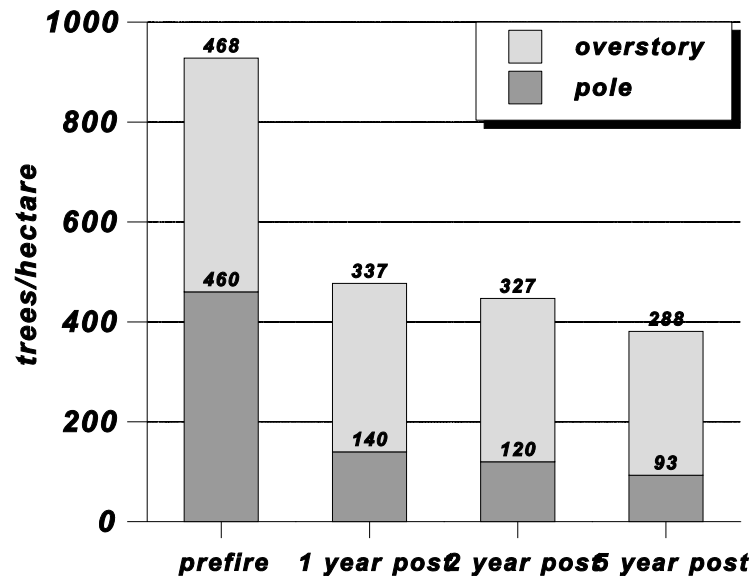


Figure 4--Density of trees by diameter class over time after prescribed fire (n=6 plots).

Conclusions

Five years of fire effects data collected in Yosemite's white fir-mixed conifer forest provide sufficient information to enable park managers to evaluate success of short-term fire program objectives. The primary objective of ≥ 50 percent fuel load reduction was achieved in total fuel load, duff, and in all woody size class fuels except the 1,000-hr fuels, which were reduced by only 32 percent. The secondary objective of ≥ 40 percent mortality on pole size white fir and incense-cedar was also achieved with a mortality rate of 81 percent within the plots sampled.

Although short-term burn objectives of reduced fuel loading and pole tree mortality were generally met, fuel reduction and accumulation rates as well as shifts in stand structure already indicate a need for prescription and objective refinement. The fuel reduction data suggest that universal ≥ 50 percent reduction across all woody fuel size classes may not be achievable without an unacceptably high level of overstory mortality. Using the current prescription, 1,000-hr fuels were reduced by only 32 percent yet the heat generated resulted in an overstory mortality rate of 38 percent. Objectives targeting greater fuel load reduction in the smaller woody size classes and less in the 1,000-hr would still result in significantly reduced hazardous fuels while potentially limiting overstory mortality. Similarly, objectives defining acceptable levels of overstory mortality need to be developed.

The fuel accumulation data demonstrate that a second burn will be necessary in white-fir mixed conifer forests within approximately 10 years of the first burn. Fuel reduction objectives for this second burn should target ranges of absolute values for fuel loadings rather than targeting percent reduction values. Such ranges would enable fire managers to evaluate when an area could be considered sufficiently devoid of hazardous fuels and would also provide direction as to timing of subsequent burns.

The overstory and pole tree density reduction data indicate a positive trend toward a more natural size class distribution. As with fuel loading, target ranges of absolute values for density by species and diameter class should be specified in the objectives of the second burn. These target values should be based on estimates of what the stand structure and composition would be under natural conditions, while also considering desired density for sufficient hazard fuel reduction.

These recommended changes for improving current objectives to better address over-all programmatic goals are based on 5 years of fire effects monitoring plot data. Although this is a small data set over a relatively short time frame, the recommended changes seek more to clarify program direction than to change it. Continued data collection and analysis must occur in order to provide information for further refinement of prescriptions and objectives to incorporate desired long-term results.

Acknowledgements

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Oak Woodland/Grassland Encroachment -- Implications for Fuels Management

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Within the forests, at all elevations from sea level to the top of the ridges, there were small open patches, known locally as "prairies" (Loud 1918). -- ethnographic excerpts

Introduction

As part of the Northwest Forest Plan of the USDA Forest Service, National Forests within a planning area are required to draft watershed analyses before implementation of prescribed burning projects. These analyses provide information on the state of the watershed in terms of riparian systems, distribution of vegetation seral stages, distribution and composition of plant communities, distribution and abundance of species and populations, upland conditions, land use history, and effects of natural and land-use related disturbance. The analysis primarily characterizes the watershed and ecological processes to meet specific management and social objectives (USDA Forest Service and USDI Bureau of Land Management 1994).

The Six Rivers National Forest is currently engaged in a watershed analysis for the Lower Middle Klamath River area. Two specific management objectives for the analysis are the restoration and enhancement of habitats that support traditional Native American gathering of subsistence and ceremonial materials and the restoration of distinctive habitats. This paper focuses on the work of the watershed analysis team members representing fuels/fire, ecology, and botany identifying potential areas for implementation of prescribed burning to meet the objectives and displays changes in tree cover over the last 55 years in two grassland areas within the Lower Middle Klamath River watershed.

Analysis Area

Two areas within the Lower Middle Klamath River watershed were chosen to display the changes in tree cover and conifer encroachment from 1940 to the present. The Cooper Ranch is a 160-acre Native American allotment that dates to the turn of the century. It is situated near 14 former Karuk and Yurok village sites. The elevation is 400 to 2,000 feet and the aspect is generally southern. Prehistoric uses included gathering acorns and hazel with a main trail passing through the area. As a ranch it is used for grazing and agriculture, with the grassland system maintained by application of fire.

Red Cap Glade is a very steep (80 percent) south-facing grassland dominated by California fescue at 1,000 to 2,000 feet elevation. Within the grassland are scattered islands of 50- to 100-year-old Douglas-fir trees. Above the grassland is a belt of manzanita and above this is a belt of well-developed clumps of madrone and tanoak. Below the grassland are stands of

300-year-old or greater Douglas-fir. The Slate Fire of 1928, which was incendiary, was the last recorded fire in this area.

Cultural Significance of Species and the Effects of Fire

Traditional gathering by Native American populations is one of the key human uses of the analysis area. Gathering by the Karuk, Hupa, and Yurok tribes predates Euro-American land use. Oak species, including tanoak, black and white oak, and live oak, are sources of various subsistence and ceremonial materials. Acorns, particularly from tanoak, were used as a primary food source.

In addition to the acorns provided by the oaks, oak woodland communities contain various other native species used by Native American populations. Bulb, rhizome, and tuber-forming species are generically called “Indian potato” and include members of the *Allium* sp., *Brodiaea* sp., *Calochortus* sp., *Dichlostemma* sp. and *Perideridia* sp. genera (Anderson 1993). Iris species and yarrow (*Achillea* sp.), present in this community, are respectively used for ceremonial and medicinal purposes (Heffner-McClellan 1984). Cooper’s Ranch, one of the gathering areas highlighted in this paper, contains bracken fern (*Pteridium aquilinum*) and hazel (*Corylus cornuta*); both are used in basketry.

Native Americans intensively managed the landscape to sustain their way of life. Fire was one of the most effective management tools available, and its application to the landscape in terms of season, extent, and intensity, was important in managing the oak/acorn resource as well as resources associated with other oak woodland species. Fire sustained oak woodland resources and gathering practices by:

1. Reducing fuel to temper the effects of large, intense wildfire
2. Clearing woodland ground cover to facilitate acorn gathering
3. Eliminating competitors such as shrubs and conifers, favoring the establishment and growth of oak seedlings and the dominance of oaks
4. Limiting insect predation of acorns
5. Promoting the growth and abundance of species associated with a post-fire environment (i.e., an open, post fire setting favors bulb-forming plants (Keeley et al., 1981).

In addition to the value of oak woodlands for social/cultural purposes, these habitats contribute to the landscape diversity in terms of flora and fauna. Perennial bunchgrasses such as California fescue (*Festuca californica*), blue wild rye (*Elymus glaucus*), and California brome (*Bromus carinatus*) are the primary ground cover in local oak stands. As the primary disturbance agent in these habitats, fire burns the thatch that develops from the bunchgrasses, resulting in space for colonization of forb species including those associated with the lily, iris, sunflower, and carrot families (Timbrook and others, 1993). California quail use bunchgrass-dominated habitats, feeding on seeds and broad-leaved forbs that occupy the space in between the individual plants (Lowry 1991). “Fawning” has been observed in Red Cap Glade partially due to the bedding material provided by the grasses and the protection from predators provided by the oak “clumps” and tall bunchgrasses (Terrill, pers. comm.).

Analysis of ecology plot data for the Lower Middle Klamath River watershed indicates that the tanoak series is well-represented, comprising 34,585 acres. The black oak and white oak

series occupy 340 and 70 acres, respectively. Subseries associated with oak woodland habitats are black oak-Douglas-fir, black oak-white oak, white oak-black oak, white oak-canyon live oak, and Douglas-fir-black oak (1,989 acres total for these subseries). Those subseries that include both Douglas-fir and oak species may indicate a successional transition from black oak or white oak stands to a Douglas-fir forest.

The abundance and distribution of oak woodlands is in part a function of environmental variables (soils being a primary defining variable) and climatic shifts. According to Popenoe and others (1991), evidence suggests oak woodlands displaced areas of conifer forest during a time of warmer, drier climates in the mid-Holocene; a shift to conifer dominance began around 2,500 years ago associated with a transition to a present-day cooler, moister climate. It was also found that soil variables played a key role in conifer establishment in grasslands and oak woodlands.

Distribution and abundance is also a function of pre-historic and historic disturbance agents. Studies in Redwood National Park (Sugihara and Reed 1987), west of the analysis area, and Annadel State Park (Barnhart 1996), south of the analysis area in Sonoma County, indicate that fire suppression practices have played a role in reducing the abundance of oak woodlands throughout the north coast. Germane to the National Forests, aggressive fire suppression and prevention beginning in the 1940's has promoted a shift in dominance of certain stands from oak species to Douglas-fir. The subseries that includes Douglas-fir and oaks within the analysis area may be replaced by conifers within these stands as a result of fire suppression practices.

Findings and Management Considerations

Aerial photographs from the 1940's, 1960's, and 1990's show the differences in structure and cover over the two areas. Cover estimates, comparing the 1940 and 1995 photo series, were averaged across the entire watershed. Estimates showed that most of the former grasslands displayed an increase in cover of 70 percent. The vegetative cover was composed of hardwoods that expanded across certain grasslands or a conifer/hardwood mix.

Given the historic land-use of the watershed, it is plausible that many of the grasslands were maintained by humans, specifically Native American populations residing in the area; however, this "cause and effect" should not be broadly applied until further site-specific analysis has been conducted. It has been found that successional pathways of certain oak dominated areas to conifer are guided more profoundly by environmental and climatic variables than human intervention (Popenoe and others 1991, Reed and Sugihara 1987).

From a management perspective, the decision to implement burn projects in oak woodlands or grasslands where stands are succeeding to Douglas-fir because of underlying soils or climatic shifts, is based on social values not ecological values. This exemplifies the need for stronger and broader interdisciplinary cooperation relative to the reintroduction of fire. The merging of ethnographic, climatic, fire and ecological data could provide a model (Lewis 1993) to assist land managers in determining the most appropriate settings for implementing prescribed burns to meet ecosystem management objectives.

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Fire/GIS Inputs to a Large Area Vegetation Analysis

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Wildfires have had the greatest influence on vegetational landscapes throughout the western United States, with strong evidence of these events throughout the Six Rivers National Forest. Fire ignitions, both from lightning and human sources, have been moderately frequent and widespread throughout the Forest, with aggressive suppression and prevention resulting in a sharp decline in fire sizes since the 1940's. Patterns of weather and climate have also been a major influence on fire regimes, especially as related to droughts and lightning "busts." Several social (Native American cultural areas), topographic (steep slopes, west-facing slopes), and locational (coastal fog) factors also contribute to variations within the fire regimes across the Forest.

The Six Rivers National Forest has initiated a large area vegetation assessment that is designed to determine how to best manage the Forest for ecological sustainability at a landscape scale. A major component of this process is to determine the role of fire/fuels management in this ecological sustainability. GIS analysis allowed us to spatially define modeled fire behavior (rates-of-spread and flamelengths), fire history (occurrences and perimeters), future risk ratings, modeled conifer mortality, recommended management ranges for seral stages of the primary vegetation series, soil parameters (susceptibility to burn damage, maximum erosion hazard), and position on slope.

The spatial focus of this poster was the North Zone, which includes the National Forest area north of the Klamath River to the Oregon border. Ecological (threatened and endangered wildlife, fish, and plant species) and social (recreation, Native Americans) issues abound throughout this zone, which complicates the need for re-introducing fire into the ecosystem. This "need" is reflected in past history and projected fire behavior. Records for the years 1909-1996 for the North Zone show 1,210 wildfires, accounting for 208,094 acres (approximately 40 percent of the entire zone) with 96 percent of the acres burned before 1950. Native American groups have inhabited selected areas within the North Zone for extensive periods of time. Early fire report forms (1911-1915) include several references to Native American burning, in the form of burning for "hazel sticks," "beargrass," "basket material." In addition, reported causes included "unknown Indian hunters," "probably Indian campfires," and "probably Indians burning trash and leaves under oak trees, to facilitate gathering acorns." The resultant sizes for these fires varied from 1 acre to 1,200 acres. Modeling "typical" August fire behavior resulted in 46 percent of the area falling into the high to extreme rate-of-spread and flamelength potential.

This poster displayed relevant GIS data (modeled fire behavior, fire history, fire effects, vegetational and topographic features) and showed how the different layers can be used to help determine fuel treatment priority areas by watershed within the North Zone. These results will set the stage for discussions on managing late successional reserves, riparian reserves, roadless areas, Native American cultural areas, and other special interest areas within a landscape perspective.

NEXUS: A Spreadsheet-based Crown Fire Hazard Assessment System

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Introduction

Fire researchers have produced numerous models of wildland fire behavior. Many of these models are implemented in fire behavior prediction systems such as BEHAVE (Andrews 1986), FARSITE (Finney 1998), the commercial version of BEHAVE by Remsoft³, and the Canadian Forest Fire Behavior Prediction (FBP) System (Forestry Canada Fire Danger Group 1992). A revision of BEHAVE is now under development by the USDA Forest Service's Intermountain Fire Sciences Laboratory and by Systems for Environmental Management. Fire managers are increasingly interested in making assessments of crown fire hazard and designing treatments to reduce that hazard. Of the currently available systems, only FARSITE and the Canadian FBP System have crown fire behavior prediction capabilities. Although some have used FARSITE to assess crown fire potential, it is cumbersome if the user requires only a simple, non-spatial analysis. None of the systems are designed specifically to assess surface and crown fire hazards.

This paper describes a new system called NEXUS, an Excel-based spreadsheet that integrates surface and crown fire behavior predictions and computes two indices of crown fire hazard. In addition, NEXUS also predicts surface fire behavior as in the FIRE1 module of BEHAVE. It allows the user to compare up to six surface/crown fuel complexes and permits the construction and adjustment of custom surface fuel models. NEXUS was first developed as a research tool to calculate indices of crown fire hazard to compare proposed hazard reduction, but was later expanded and refined.

Models Included in NEXUS

NEXUS includes models of surface, crown, and transitional fire behavior, and crown fire hazard. Like the other prediction systems, surface fire behavior is predicted using Rothermel's (1972) mathematical model. Potential behavior of an active crown fire is estimated by Rothermel's (1991) correlation with fuel model 10 predictions. The link between the surface and crown fire predictions is based on the work of Van Wagner (1977), which fixes the transition points between surface fire, passive crown fire (torching, intermittent crowning), and active crown fire (running or continuous crown fire). Final (overall) fire behavior is estimated by scaling between surface and crown fire

³Mention of trade names of products is for information only and does not imply endorsement by the U.S. Department of Agriculture.

behavior predictions using Van Wagner’s (1993) crown fraction burned transition function. NEXUS also includes a model of fire shape and size (as in BEHAVE) and computes two indices of crown fire hazard (Scott and Reinhardt in preparation).

Features of NEXUS

The current version of NEXUS has the following features:

1. Direct fire behavior/hazard comparisons of up to six different surface/crown fuel complexes. The user enters input data in a table (fig. 1), specifying fuel model, surface fuel moisture, crown fuel characteristics (bulk density, crown base height, total stand height, and foliage moisture content), wind reduction factor for estimating mid-flame wind from 20-ft wind, and, if desired, a multiplier for rate of spread or fuel load/depth. Constants such as mineral fractions, particle density, *etc.* are entered in a separate table.

Analyst: Joe Scott		Comments: example						
Project name: Big Fire								
Date: 10/21/98								
	projection point	A	B	C	D	E	F	
	fuel model	4	5	6	7	8	10	number
dead moisture	needles	0	0	0	0	0	0	percent
	1-hr	6	6	6	6	4	4	percent
	10-hr	8	8	8	8	5	5	percent
	100-hr	10	10	10	10	7	7	percent
live moisture	live1	100	100	100	100	100	100	percent
	live2	120	120	120	120	120	120	percent
	live3	120	120	120	120	120	120	percent
crown fuels	bulk density	0.00	0.00	0.00	0.00	0.15	0.15	kg/m ³
	canopy closure	0	0	0	0	75	75	percent
	foliar moisture content	100	100	100	100	100	100	percent
	crown base height	0.0	0.0	0.0	0.0	5	5	ft
	crown height	0.0	0.0	0.0	0.0	80	80	ft
site	slope	20	20	20	20	20	20	percent
	20-ft windspeed	18	18	18	18	18	18	mi/hr
	wind direction, from uphill	0	0	0	0	0	0	degrees
	wind reduction factor	0.4	0.4	0.4	0.4	0.15	0.15	fraction
multipliers	surface ROS	1	1	1	1	1	1	
	crown ROS	1	1	1	1	1	1	
	load/depth	1	1	1	1	1	1	

Figure 1. The NEXUS input table allows direct entry of fuel model number, fuel moistures, crown fuel characteristics, wind reduction factor, and load/depth multiplier. As many as six fuel complex scenarios, which may vary in any or all of the above inputs, can be specified.

2. Standard tabular output for the six fuel complexes. Standard outputs (fig. 2) include: surface fire behavior (rate of spread, heat per unit area, fireline intensity, reaction intensity, flame length, effective mid-flame and 20-ft windspeeds, direction of maximum spread, length/breadth ratio, perimeter length and growth rate, fire area, power of the fire and wind),

overall fire behavior (fire type, crown fraction burned, rate of spread, fireline intensity, and power of the fire and wind), critical parameters for starting and sustaining a crown fire, and crown fire hazard indices.

OUTPUTS	fuel scenario						
	A	B	C	D	E	F	
crown fire type	surface	surface	surface	surface	surface	passive	
crown fraction burned	0%	0%	0%	0%	0%	19%	percent
rate of spread	128.3	37.5	55.7	46.8	1.3	14.3	chains/hr
heat per unit area	2611	589	467	523	211	2461	BTU/ft ²
fireline intensity	6142	405	477	448	5	643	BTU/ft/sec
flame length	24.9	7.1	7.7	7.5	0.9	20.3	feet
reaction intensity, surface	11825	2582	1903	2127	1035	6353	BTU/ft ² /sec
wind reduction factor	0.40	0.40	0.40	0.40	0.15	0.15	fraction
effective mid-flame wind	7.4	7.4	7.4	7.4	3.0	3.9	mi/hr
direction of max spread	0	0	0	0	0	0	degrees
scorch height	342	42	48	45	1	76	feet
length-to-breadth ratio	2.8	2.8	2.9	2.8	1.8	2.0	ratio
perimeter growth rate	297.3	86.6	128.8	107.9	4.0	36.8	chains/hr
fire area	483	41	91	64	0	9	acres
map spread distance	4.23	1.24	1.84	1.54	0.04	0.47	inches
Critical values for crown fire							
Torching Index	N/A	N/A	N/A	N/A	166.5	12.6	mi/hr
Crowning Index	N/A	N/A	N/A	N/A	19.7	19.7	mi/hr
Surface Intensity	N/A	N/A	N/A	N/A	92	92	BTU/ft/sec
Surface ROS	N/A	N/A	N/A	N/A	24	4	ch/hr
Crown base ht	N/A	N/A	N/A	N/A	1	6	feet
Crown fire ROS	N/A	N/A	N/A	N/A	60	60	chains/hr

Figure 2. The standard NEXUS output table contains predictions of surface fire behavior (as in BEHAVE), overall fire type and behavior (surface fire, passive crown fire, or active crown fire), critical parameters for crown fire initiation and active spread, and indices of crown fire hazard.

- Automatic tabular and graphical output over a range of windspeeds. Fire behavior characteristics (surface fire intensity, rate of spread and flame length; overall fireline intensity, rate of spread and crown fraction burned) are automatically computed for a range of 20-ft windspeeds (0 - 60 mph in 5 mph increments) for all fuel complexes. This output is displayed in both tables and graphs.
- Rate of spread and fuel model adjustment factors. The user can perform sensitivity analyses by using adjustment factors. The rate of spread adjustment factor affects both rate of spread and intensity (e.g., heat per unit area is constant). The load/depth adjustment factor affects the fuel model itself, and therefore affects all fire behavior predictions.
- Worksheet for designing and testing custom fuel models. The user can easily create or adjust a fuel model using slider bars and direct entry of load and surface-area-to-volume ratios. Results are instantly compared graphically with any other custom or standard fuel model.
- Integration of surface and crown fire behavior predictions. The transition between surface and crown fire is predicted from fuel complex characteristics. The transition is based on Van

Wagner's(1993) crown fraction burned transition function.

7. Crown fire hazard assessment. NEXUS computes the critical windspeeds required to initiate and sustain a crown fire. A crown fire hazard assessment chart is displayed for any one of the six fuel complexes described in the input table. This chart shows predicted and critical rates of spread, overall rate of spread, and crown fraction burned.
8. Graphical display of fire size and shape with respect to wind/slope. A graph showing the shape and orientation (relative to upslope) of the fire for any one of the six fuel complexes is displayed automatically. This can be used to examine the relationships among wind speed, wind direction and slope for different fuel models. The use of slider bars for some inputs allows "animation" of this analysis.

Pros and Cons of the Spreadsheet Platform

The spreadsheet is a simple, flexible programming environment. Models are easy to build, update, and de-bug. New or task-specific models can be added by any knowledgeable user. The "exposed" code and auditing features allow the user to clearly see which variables affect which outputs. Spreadsheets have built-in analysis tools (sensitivity tables, input scenarios, backwards solving, etc.) that can be used in fire behavior analysis and prescription development. Entry of inputs is logical and easy. Links with graphing and word-processing programs are simple in the Windows operating system.

However, the user must already have the spreadsheet program running on his computer. In addition, in a spreadsheet there is less control of user input, and less opportunity for error-trapping than in a conventional computer program. Thus, the user must accept more responsibility for ensuring the inputs are correct when using a spreadsheet platform.

Future Development

A user's manual must be developed before NEXUS can be made available to fire managers. In addition, a paper describing the integration of surface and crown fire behavior predictions and the crown fire hazard indices is also needed. When these tasks are completed, NEXUS may be distributed via the Internet. Technical support may be in the form of a user-supported online discussion group similar to that for FARSITE. Many of NEXUS' unique features may eventually be incorporated in to the updated vesion of BEHAVE.

Acknowledgements

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Using Photographic Image Processing as a Planning Tool to Predict Future Landscape Appearance After Large Urban Fires

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Introduction

The Tunnel Fire of October 20, 1991 killed 25 people, burned 1,800 acres and destroyed more than 2,500 houses in Oakland and Berkeley, California. As part of a comprehensive effort to minimize future fire hazard in the rebuilt neighborhoods, the city of Oakland developed landscaping guidelines to be applied within the fire zone. These guidelines were based on fire safety considerations, and proscribed those plants that were characterized as “pyrophytes.” All pines, and some eucalyptus species, are prohibited. Plants characterized as less hazardous but still highly flammable, such as *Cupressus* spp. and *Acacia* spp., were allowed but only if planted at least 15 feet from the house. The guidelines did not specifically address other issues.

However, fire safety is only one of several concerns faced by homeowners as they rebuild. Views, privacy, solar access, and skyline value are also valued. These values can conflict with each other and can lead to conflict with neighbors. In hilly neighborhoods, privacy and skyline value are hard to reconcile with fire safety and views. Oakland’s view ordinance, which is not suited to address the unique situation caused by the fire, complicates the issue further.

The pre-fire Oakland landscape was dominated by Monterey pine (*Pinus radiata* Don), blue gum (*Eucalyptus globulus* Labill.), and redwood (*Sequoia sempervirens* [Lamb.] Endl.). Almost all the pines were killed, while most of the eucalyptus and redwoods survived, though the tops and lateral branches died. The species composition tables indicate that very few of the replacement plantings are of trees that will be large when mature. This will have a significant long-term effect on the visual character of the neighborhood.

The purpose of this paper is to demonstrate a use of Photoshop to predict future landscape appearance after large urban fires; to promote discussion about post-fire residential landscapes; and to incorporate other factors into the planning and design process in order to produce neighborhoods that are pleasant as well as safe.

Photo Manipulation

Much has been written about the appearance of the rebuilding neighborhoods, most commonly with a focus on the architecture. Many writers acknowledge that the area looks stark and that the houses in some areas are packed together tightly, but they claim that as the trees mature, they will soften in appearance. The photo manipulations are an attempt to test this hypothesis.

A photograph was taken of a west-facing Oakland hillside, in which 25 houses built after the fire are at least partly visible. Eighty-two trees (including street trees) were inventoried (Table 1), most in front and side yards. Vacant lots were not inventoried, because it is expected that the trees will be removed as the properties are developed. It was not possible to visit the backyards to do a complete inventory. However, the backyards of the houses in the photo are to the west of the middle row of houses, and the owners have planted small trees to avoid blocking their own views.

Table 1. Most common trees in the Margarido/Manchester/Alpine Terrace neighborhood

Tree ¹	No. of Trees	Height at Maturity ²	Evergreen/Deciduous	No. of Properties
Italian Cypress <i>Cupressus sempervirens</i> (L.)	9	30'	Evergreen	2
Olive <i>Olea europaea</i> (L.)	5	20'	Evergreen	4
American sweet gum <i>Liquidambar styracifolia</i> (L.)	5	35'	Deciduous	2
Evergreen pear <i>Pyrus kawakami</i> (Rehd.)	5	20'	Evergreen	1
Saucer magnolia <i>Magnolia soulangiana</i> (Soul.)	5	15'	Deciduous	3
Chinese flame tree <i>Keolreuteria bipinnata</i> (Laxm.)	4	25'	Deciduous	1
<i>Pittosporum tenuifolium</i> (Gaertn.)	4	20'	Evergreen	1
Strawberry tree <i>Arbutus unedo</i> (L.)	4	15'	Evergreen	3
Coast live oak <i>Quercus agrifolia</i> (Nee.)	3	35'	Evergreen	2
Flowering plum <i>Prunus</i> spp. ³	3	20'	Deciduous	2
Chinese tallow tree <i>Sapium sebiferum</i> (Roxb.)	3	20'	Deciduous	1
Weeping cherry <i>Prunus subhirtella</i> (Miq.)	3	10'	Deciduous	1

¹ Common names from *Sunset New Western Garden Book*.

² Heights are based on author's experience as an arborist in the area and reflect typical heights at maturity. Individual trees may exceed this typical height.

³ Includes *P. americana*, *P. blireiana*, *P. cerasifera*, *P. cistena*, and hybrids.

The photograph was digitized and then “aged” using PhotoShop 3.0™, by adding foliage to visible trees and inserting foliage in those locations where a now-hidden tree is expected to be visible in the future as it grows. The growth rates of the various trees were based on my experience as a local arborist. Notes taken in the field regarding location, slope, and building height helped to determine how much foliage to add and where in the photo to locate it.

Foreground trees, which were not part of the study area, were not aged. The digitized photo was manipulated to show three scenarios:

1. The expected appearance of the landscape after 10 years.
2. The expected appearance of the landscape after 25 years. The mature heights of the trees were used for this scenario.
3. The expected appearance of the landscape after 25 years if enough relatively tall trees are planted so that at least one-third of the houses have a tree growing as high as roofline (Oakland allows a maximum roofline height in R-1 zones of 46 ft without a variance), while still allowing at least a partial view from each house. The purpose of this scenario is to allow an evaluation of a landscape that is intermediate between the pre-fire landscape and that which has replaced it.

Manipulation of the photo shows virtually no change after 10 years and very little after 25 years. The only scenario that shows appreciable change is that which adds additional large trees. The apparent harshness of the two “real world” scenarios is partly a function of distance and camera angle. Someone walking along one of the streets in the future would notice a number of trees, though the vast majority would be less than 20 feet tall. An additional factor that is not addressed by the manipulation process is construction of more houses upon now-vacant lots. Although it is not apparent in the photograph, there are five vacant lots in the area of the photograph.

Tree Species Composition

The post-fire landscape bears little resemblance to the pre-fire landscape. The most obvious difference is the lack of large trees, especially Monterey pines (*Pinus radiata* Don.) and blue gum (*Eucalyptus globulus* Labill.). However, many other trees, such as redwood (*Sequoia sempervirens* [Lamb.] Endl.), Deodar cedar (*Cedrus deodora* Loud.), *Chamaecyparis* spp., and *Acacia* spp., are also less common in the postfire landscape. Other trees, such as Japanese maple (*Acer japonicum* Thunb.), eastern redbud (*Cercis canadensis* L.), and crape myrtle (*Lagerstroemia indica* L.), are more common. The post-fire landscape also has many fewer conifers. The effects of these changes have not been studied, but it is reasonable to expect that it will affect wildlife habitat, wind (especially in winter), solar access, glare, albedo and temperature.

To get an idea of how the post-fire treescape compares to that which existed before the fire, three matching pairs of streets were identified. These pairs are either streets that are divided by the fire boundary or nearby streets with similar views, aspects, and slopes:

- Leo Way is a north/south street east of highway 13. There are no bay views from this street. This sample includes 15 unburned lots south of Broadway Terrace, and 15 rebuilt lots north of Broadway Terrace.
- Broadway Terrace and Capricorn Ave. are farther up the hill, with moderate to steep slopes, and have bay views. The area has substantial numbers of both pines and eucalyptus, though the forest is not nearly as thick as in some other neighborhoods (unfortunately, I was unable to locate matching streets in the areas with the thickest stands of trees). This sample includes 19 unburned lots on Capricorn Ave., and 19

burned lots on Broadway Terrace and Swainland Rd., which intersects with Broadway Terrace and continues on the same general contour.

- Proctor Ave. and Harbord Dr. are west of highway 13, and south of Broadway Terrace, with moderate slopes and partial to panoramic bay views. Proctor Ave. is on the western boundary of the fire, while Harbord, one block over, was not burned. Twenty-five lots were included in each sample.

The mature height characteristics and diversity of the neighborhoods were determined (Table 2). The unburned neighborhoods have more large trees, with decreasing diversity as the trees get smaller. In the burned neighborhood, there is increasing diversity as the trees get smaller.

Table 2. Distribution of trees by height classes in burned and unburned neighborhoods.

Street	Tree Height at Maturity ¹								Totals	
	>35 ft		26 – 35 ft		16 – 25 ft		0 – 15 ft			
	No. of trees	No. of species	No. of trees	No. of species	No. of trees	No. of species	No. of trees	No. of species	No. of trees	No. of species
	Burned									
Leo Way	5	3	11	3	4	2	16	10	36	18
Broadway Terrace	20	5	15	3	14	7	18	10	67	25
Proctor Ave.	1	1	3	2	16	6	39	10	59	19
Subtotals, burned²	26	7	29	6	34	11	73	17	162	41 ³
	Unburned									
Leo Way	9	4	8	4	3	1	2	1	22	10
Capricorn Ave.	80 ⁴	11	8	2	15	4	24	6	127	23
Harbord Dr.	20	9	14	5	18	7	10	7	62	28
Subtotals, unburned²	109	17	30	9	36	9	36	9	211	44 ³
Totals²	135		59		70		109		373	

¹ Based on my experience as a local arborist. Heights at maturity are based on typical trees, not on extreme ranges. Coast live oak, for example, is rated as having a typical mature height of 35 feet, though individual trees may exceed that height. Each range is not the height range of any given tree, but of the class. “Species” includes some lumped species. “Flowering Plum (*Prunus*),” for example, includes several species which could not be distinguished in the field.

² Subtotals and totals for “no. of species” within a height range is less than the sum of the subcategories, due to duplication.

³ Total number of species in burned and unburned areas, respectively.

⁴ Includes one lot with 40 trees.

The fire zone is also distinguished by a relative lack of conifers. In part, this is because the city of Oakland has prohibited the planting of *Pinus* in the fire zone and places restrictions on the siting of others such as *Cupressus* and *Cedrus*. These prohibitions and restrictions, which are

based on fire safety considerations, have been reinforced by concerns about planting trees that will block homeowner’s views or solar access when mature. Because many conifers are large when mature, a landscape in which small trees are favored will inevitably have fewer conifers. Table 3 summarizes the distribution of conifers within the sample sites.

Table 3. *Distribution of conifers in burned and unburned neighborhoods.*

Street	No. of Trees	No. of Species
Leo Way, burned	2	2
Broadway Terrace, burned	18	4
Proctor Ave., burned	1	1
Total, Burned	21	5
Leo Way, unburned	8	3
Capricorn Ave., unburned	29	9
Harbord Dr., unburned	20	10
Total, Unburned	72	15

Conclusion

In the future, many cities in California will face the challenge of rebuilding neighborhoods after urban wildfire. Photo manipulation can be a useful tool for planners as they design building and landscaping guidelines. Planners using photo manipulation can use landscaping plans filed as part of the rebuilding permit process, which will provide additional information on backyard trees. This technique can also be used in presentations to help residents make decisions about their neighborhoods.

The rebuilt Oakland fire zone is much more fire resistant than before the fire. One factor that contributes to this is the treescape, which has a lower present and future fuel load, and is composed of less flammable plants than before. No one would seriously propose that the rebuilt neighborhoods should contain dense stands of extremely flammable trees, as the adjacent neighborhoods still do. However, one has to wonder if things can somehow be done better after the next fire.

The following suggestions are offered in an attempt to provoke discussion, among fire professionals and others, about the appearance of the post-fire landscape in urban areas:

- View ordinances should be suspended in fire zones, until the community has had a chance to thoroughly consider the issues involved. View ordinances tend towards maintaining a static landscape, which in the case of fire zones means almost no large or even moderate-sized trees.
- Communities should consider measures to promote more continuity in the landscape. Landscaping guidelines could require that at least one oak or other native tree be planted per property, for example. Such a measure would promote a sense of community without increasing fire hazard. Another possibility is for cities to strictly control street tree planting and species selection. If the individual homeowner chooses and installs street trees on a per-lot basis, the result is inevitably a wide mix of trees on each block.

- Wherever possible, at least some large trees should be planted. There is just no substitute for them in the urban landscape. In a landscape such as Oakland's, where the structures and other landscape are more fire-resistant than previously, it may be worth it to plant additional trees, even at the cost of some increase in fire risk. A certain level of fire risk may be the cost of living in a pleasant urban environment.

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Paul Cotton and Stefan Thuilot both provided invaluable instruction and assistance in using PhotoShop.

El Dorado National Forest Landscape Assessment Using GIS to Model Fire and Vegetation Risk, Hazard and Identify Values to Protect.

Scott Vail, David Bakke, Christie Neill, Chuck Mitchell, Dawn Lipton, Lester Lubetkin, Beth Paulson

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The fire regimes in long-needled pine forests of Sierra Nevada mixed conifer forest on the El Dorado National Forest in California have historically experienced frequent low-intensity surface fires at 1- to 25-year intervals. This cycle has been interrupted by several decades of fire suppression and timber harvest of pine, combined with drought as well as insect and disease outbreaks. Interruption of the cycle has contributed to shifts in species composition to species that are less fire resilient and to fuels accumulations that are at much higher levels than have historically occurred. This has shifted the fire regime from a low intensity surface fire regime to a high-intensity fire regime, drastically increasing risks to people, property, and natural resources. In recent years, the El Dorado National Forest has addressed the increasing fire risk and hazard to varying degrees. This analysis is an attempt to coordinate the efforts on a forest-wide basis and focus on some of the highest fire risk and hazard areas.

To determine the highest priority areas for vegetation treatment on the El Dorado National Forest, two GIS (geographic information system) based submodels, Fire and Vegetation, were developed to define the areas on the Forest that if treated will provide the greatest reduction in fire hazard and risk of ignition; and to identify areas on the Forest that are in need of treatment because they represent a substantial deviation from a historic fire regime, in terms of vegetation structure and content. The model is watershed-based, with results displayed by watershed. All lands within the Forest were considered, including private lands.

The results of these two models were combined, and the resulting map showed the zone considered to be of highest priority on the Forest for vegetation management. Three other GIS-based submodels were developed, showing where the high value resources existed: a wildlife habitat submodel, a watershed submodel, and a developments submodel. These three submodels were used to further define the reason for entering these watersheds in the priority zone and will be of benefit in determining priorities outside of the zone in future planning.

Fire Occurrence on Southern California National Forests-- Has It Changed Recently?

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Introduction

Fire is a common occurrence in southern California. The 4 National Forests in southern California, the Angeles (ANF), Cleveland (CNF), Los Padres (LPNF), and San Bernardino (SBNF), have recorded fire perimeters and sizes within the forest boundaries since about 1910. Although it is generally believed that fire exclusion during this century has altered current fire behavior in many western forest ecosystems, there is currently debate over the impact of fire exclusion on fire occurrence in chaparral (Minnich 1983, Strauss and others 1989, Zedler 1995). These previous studies have examined a portion of the fire occurrence record for the four National Forests in southern California. To our knowledge, the complete fire history record compiled by these forests has not been analyzed to determine if fire occurrence on National Forest land has changed in this century. This paper presents a preliminary analysis of the fire history record from 1910 until 1989 on the ANF, CNF, LPNF, and SBNF.

Methods

The fire history maps compiled since about 1910 by the ANF, CNF, LPNF, and SBNF have recently been digitized and stored in a geographic information system. Fire year and size for 2205 fires were extracted from this database. Fire size distributions were examined for each National Forest. Some fires burned on more than one National Forest because the forests share common boundaries. In these instances, the fire statistics were applied to each National Forest. The 80-year fire histories (1910-1989) were split into 2 40-year periods (1910-1949, 1950-1989) for each National Forest. We assumed that fire suppression became effective on National Forests following World War II with improvements in and availability of fire-fighting equipment and personnel. The minimum, mean, median, and maximum fire sizes were determined for each period for each Forest. Mean and median fire size for each time period were tested for change for each National Forest. An F-statistic was used to test equality of means and the Wilcoxon rank-sum test was used to test for shift in the median fire size. Fire size frequency distributions for each period were compared by using the Kolmogorov-Smirnov (KS) statistic. Fire size distributions were broken into six classes: 0 = <3.16 ha; 1 = 3.16 to 31.6 ha; 2 = 31.6 to 316 ha; 3 = 316 to 3160 ha; 4 = 3160 to 31600 ha; 5 = > 31600 ha.

Results and Discussion

Fire size ranged from 0.1 to more than 89000 hectares. Minimum, mean, median, and maximum fire sizes for each period for each National Forest were determined (Table 1). Median fire sizes were an order of magnitude smaller than mean fire size. Except on the CNF, maximum fire sizes were similar between periods. Based on these data, mean fire size for the two time periods differed only on the LPNF at the $\alpha = 0.05$ level (Table 2). The nonparametric test for shift in location (Wilcoxon) indicated shifts in the median fire size between the periods for both the ANF and LPNF at the $\alpha = 0.05$ level. The Kolmogorov-Smirnov test also indicated that the fire size frequency distributions differed by period for these two National Forests. The number of fires in class 1 (3.6 to 31.6 ha) on both LPNF and ANF differ substantially between the two time periods (fig. 1) compared to the much smaller differences in number of fires between time periods in other categories. The differences in this class are most likely the cause of the significant K-S tests.

Table 1. Individual fire size statistics for the four southern California National Forests for two 40-year time periods.

National Forest ¹	Period	Fire size statistics (in hectares)				
		Minimum	Median	Mean	Maximum	Count
ANF	1910-1949	4.3	131	1317	28871	191
	1950-1989	0.1	39	762	30911	435
SBNF	1910-1949	1.6	75	673	24333	263
	1950-1989	1.9	65	629	20887	358
CNF	1910-1949	12.1	178	1128	26052	276
	1950-1989	7.6	104	1420	70426	258
LPNF	1910-1949	15.3	223	1887	89051	343
	1950-1989	11.8	400	3452	70377	139

¹ ANF = Angeles National Forest, SBNF = San Bernardino National Forest, CNF = Cleveland National Forest, LPNF = Los Padres National Forest.

Table 2. Summary of statistical testing of fire size statistics for four southern California National Forests.

National Forest ¹	Mean ²		Median ³		Distribution ⁴	
	F	p	W	p	K-S	P
ANF	2.81	0.09	6.64	<0.001	3.976	<0.001
SBNF	0.16	0.68	1.80	0.07	1.169	>0.13
CNF	0.63	0.42	-1.84	0.07	1.296	0.07
LPNF	5.05	0.02	2.91	0.004	1.819	0.003

¹ ANF = Angeles National Forest, SBNF = San Bernardino National Forest, CNF = Cleveland National Forest, LPNF = Los Padres National Forest.
² F-statistic (test equality of mean fire size), Probability of > F.
³ Z statistic (normal approximation of Wilcoxon 2-sample test to test shift in median, Probability of > |Z|.
⁴ Kolmogorov-Smirnov statistic to test equality of fire size distributions, asymptotic probability of a greater K-S statistic

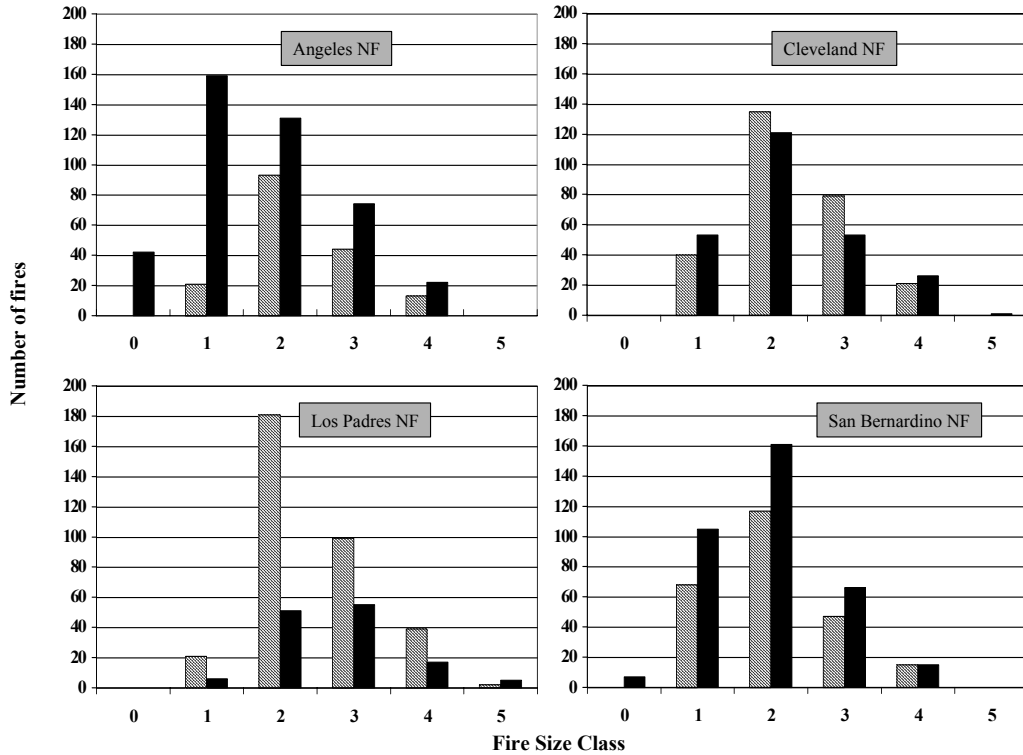


Figure 1. Classified fire sizes for 1910-1949 and 1950-1989 for the four southern California National Forests. The base 10 logarithm of fire size was computed and assigned to one of six classes: 0 = < 3.16 hectares; 1 = 3.16 ha to 31.6 ha; 2 = 31.6 to 316 ha; 3 = 316 to 3160 ha; 4 = 3160 to 31600 ha; 5 = > 31600 ha. Hatched bars = 1910-1949, solid bars = 1950-1989.

On the basis of these preliminary results, it is not possible to conclude that fire occurrence on southern California National Forests has changed uniformly in this century. The data indicate differences in mean fire size; however, the differences are not consistent. Fire size decreased on the ANF and increased on the LPNF. This result could be due to several reasons, including differences in data recording over time, a heterogeneous response of fire occurrence to fire suppression, or heterogeneous changes in mesoscale weather patterns that influence fire size. Our preliminary analysis does not support the hypothesis that fire suppression has changed fire size in this century on all southern California National Forests. Further analysis is planned to examine fire occurrence differences between vegetation types and between National Forests.

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