

THE SCIENCE OF PRESCRIBED FIRE: TO ENABLE A DIFFERENT KIND OF CONTROL

Timothy E. Paysen and Marcia G. Narog

U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Riverside Forest Fire Laboratory,
Riverside, CA 92507

Jack D. Cohen

U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Intermountain Fire Sciences Laboratory,
Missoula, MT 59807

ABSTRACT

A paradigm shift from fire suppression to fire suppression and prescription requires a shift in emphasis from simply controlling wildfire occurrence and spread to one that includes controlling characteristics of prescribed fire. Suppression focuses on preventing unwanted effects that might result from wildfire occurrence. Prescription promotes desired effects by precisely and properly implementing fire occurrence. The duality of these concepts requires a new research focus. Research must now determine how to control processes that constitute a specific fire event. Each fire event includes specific kinds of fire behavior and simultaneously activated ecosystem processes. Control of a fire event, to the degree needed to reach specific prescribed fire objectives, is complicated. It requires an understanding of many aspects of fire behavior and the complex processes that might be activated by the fire. It also requires knowledge of preconditioning factors that control both the nature of fire behavior and the response of a site to a particular fire event. Needed research is both multidisciplinary and interdisciplinary. It requires contributions from a wide range of backgrounds, including plant physiology, ecology, fire physics, and others. This new research focus will promote a broad array of investigations which address various levels of detail, and will advance the science of prescribed fire.

Citation: Paysen, Timothy E., Marcia G. Narog, and Jack D. Cohen. 1998. The science of prescribed fire: to enable a different kind of control. Pages 31–36 in Teresa L. Pruden and Leonard A. Brennan (eds.). Fire in ecosystem management: shifting the paradigm from suppression to prescription. Tall Timbers Fire Ecology Conference Proceedings, No. 20. Tall Timbers Research Station, Tallahassee, FL.

INTRODUCTION

catastrophe: any event that disturbs or overthrows the existing order of things.—Webster's Dictionary

Wildland fire research, as we tend to understand it, and the loosely connected set of research activities that have been directed toward prescribed fire, are founded on two distinct concepts of control. For the former, the concept has been overt: wildland fire research has been directed toward the control of wildfire and its effects. For the latter, the concept has largely been intuitive. Researchers have been working on solutions for a variety of problems related to prescribed fire for years. Many fire scientists have been working within the discipline of prescribed fire as we define it here. Yet, an incomplete concept of fire science has prevented a complete vision of direction for the discipline. During recent years, control of a fire event has become the defining objective for prescribed fire research. This has been a result of increasingly specific prescribed fire goals in wildland management.

Our objective for this paper is to outline the logic that defines the domain of prescribed fire research and to suggest requirements for practicing it. Our purpose is to change the perceptions of research and land managers by providing a clear framework for prescribed fire research and planning efforts. Prescribed fire research is not a subset of fire effects research, although

there is a connection between the two. Nor is it an afterthought in wildfire research, although there is also a relationship between the two. When a clear understanding of knowledge gaps that bear the name "prescribed fire" is achieved, then multidisciplinary science can fill gaps in prescribed fire science. The control of both wildfire and prescribed fire must be addressed by fire research in order to provide a balanced capability for addressing wildland fire concerns.

Historically, fire in a wildland setting was viewed, justifiably, as a catastrophic event. Anything that totally removes existing elements of a system or structure can be viewed as a catastrophe. Fire can be socially and economically catastrophic as well. A dramatic example is the Peshtigo, Wisconsin fire of 1871. This fire killed 1,500 people and burned 1.2 million hectares (3 million acres) (Zelker 1976). Other major conflagrations have burned millions of acres, destroyed thousands of structures, and killed hundreds of people during the last 200 years (Martin and Sapsis 1995). The Oakland Hills fire of 1991 is a recent case history (Ewell 1995). Few people want to see natural resources, much less human habitations, lost to a fire. The natural reaction to such calamities is to try to control them, to extinguish wildfires as quickly as possible, and to prevent them whenever possible. The Smokey Bear fire prevention campaign is an internationally renowned example of a comprehensive at-

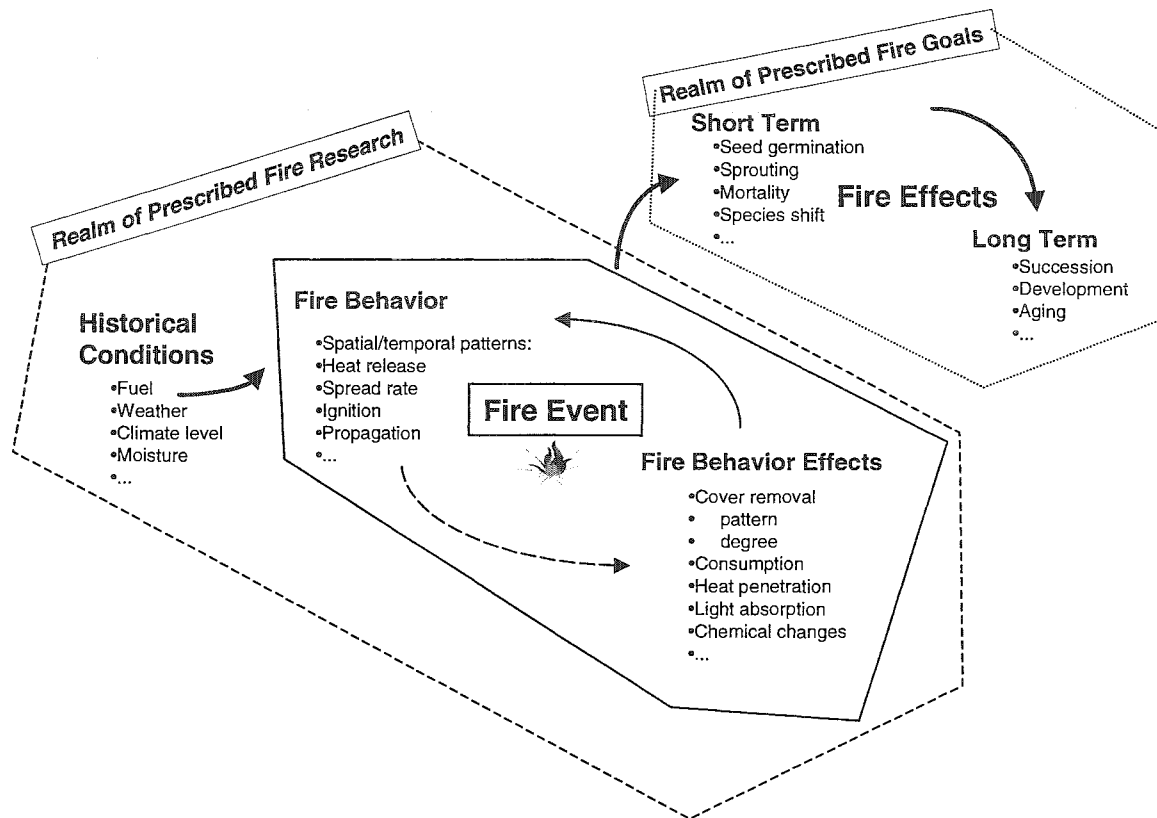


Fig. 1. The prescribed fire event and its components (fire behavior and direct fire effects) are affected by short- and long-term historical conditions of the environment. The fire event in turn affects short- and long-term fire effects. The effects constitute the realm of goals that are the objectives for prescribed burns. Prescribed burners must control fire events sufficiently to achieve the goals. The realm of prescribed fire research includes the fire event and prefire history.

tempt to prevent wildfire (Adams 1994). People wanted to control effects of fire upon the landscape, and if possible, control fire itself, regardless of any thought about beneficial effects of fire.

How people react to fire and view its role in the scheme of things have evolved during the last century. In recent decades, we have seen a more general acceptance of the idea that some effects of fire are desirable. In many ecosystems, we want to maintain fire as an environmental element, but cannot live with the potential effects of unchecked catastrophic wildfire (Mutch 1994). As a consequence, we want to selectively pick and choose the way that fire influences the landscape. We want to minimize catastrophic effects, and incorporate fire into our view of the existing order of things. We still want to control fire, but the modern idea of control now has more than one dimension.

Our current framework for managing wildland fire embraces two concepts. One is our historical concept of fire control; i.e., preventing or removing unchecked wildfire. In some ways, we are pretty good at this, but in many ways, we are lacking (Irwin 1995). The second is the concept of prescribed fire; i.e., the purposeful use of fire upon the landscape, at a prescribed time, in a prescribed place, under prescribed conditions, to meet a prescribed goal. Goals can include improved rangeland for cattle, hazard reduction, or improved habitat for endangered species (Price et al. 1995).

From the need for such a prescription emerges the need for focused research on a complex array of phenomena (Cohen 1990). That is, research directed toward enabling a manager to control a fire event for a specific purpose or outcome. Fire, whether wild or prescribed, is a disturbance that activates a set of responses according to the ecosystem condition at the time of burning. It is driven according to the sequence and characteristics of such factors as weather that affect not only the fire event, but also subsequent reactions to it.

THE FIRE EVENT

A fire event includes a fire and myriad processes that result from the fire's presence (Figure 1). The fire itself manifests an array of characteristics that constitute what we call fire behavior; i.e., characteristics that include both how fast it spreads and how long it burns in one place, the character of the radiant heat flux from a segment of its flaming zone, and its ability to propagate through various configurations of fuel. Other phenomena that occur during the fire, such as direct fire effects, are reactions to the fire that occur simultaneously as the fire is burning. These effects (heat penetration, chemical changes, and cover removal) lead to secondary effects, or what we conventionally

think of as fire effects (e.g., a shift in species dominance, improvement in pine reproduction, or an age class modification in chaparral). These secondary effects include many that we are aware of (Valette et al. 1994, Gillon et al. 1995), but perhaps do not fully understand. The fire, its behavior, and the processes activated by the fire (direct fire effects) constitute a fire event.

The job of a prescribed fire manager is to orchestrate a fire event and implement a prescribed fire that activates processes which lead to a specific goal. This requires an understanding of fire behavior and the ability to control it. It requires an understanding of the link between a particular kind of fire behavior and, through activated processes, an end result. The manager must be able to: 1) prescribe the physical/environmental conditions, including ignition technique if appropriate, that will allow a prescribed fire to meet necessary goals and objectives; and 2) assure that the fire is extinguished once these criteria have been met. These constraints apply to prescribed natural fire as well (i.e., an unplanned ignition, the characteristics of which meet a preplanned set of fire prescription parameters). The prescribed fire manager has controls available that can be brought to bear on a fire event. However, these controls are not absolute, and the manager will have to balance interactions between these factors to achieve a specific outcome. Broad areas of control are related to the physical structure and physiological condition of fuels and other environmental factors.

The physical structure of fuel gives character to a fire event by its effect on both fire behavior and the final outcome of the fire. For example, the condition and depth of forest understory litter can affect fire propagation, the length of time the litter will burn, and the nature of a heat pulse that might penetrate into the soil (Covington and Sackett 1990). This can in turn determine the effect of the fire on underground plant parts and soil nutrients. The density of a stand of trees can affect many aspects of fire behavior, including radiation, heat convection, and air movement, which can all be affected by stand density. These factors can affect forward and vertical propagation of the fire and degree of fuel consumption. Many such variables associated with the structure of a fuel array can determine the nature of fire behavior and its effect on the vegetation, thus affecting the nature of the fire event. The prescribed fire manager can, if feasible, modify this structure, or can control the application of prescribed fire to a limited set of conditions that will result in a desirable outcome.

The timing of a prescribed fire is another area of control that is theoretically available to the prescribed burner. This amounts to application in an ecological context (Biodini et al. 1989, Kalmbacker and Martin 1995). The state of the environmental variables that affect fire behavior can be prescribed (though not ordered at will). Selection of an area can be based on the condition of live and dead fuels, as well as the physiological state of pertinent biota (which can include the fuel elements themselves). If not so selected,

the environmental history of the area to be burned can at least be considered when determining the probable site response to burning. In short, the manager is able to choose the time and conditions for a prescribed fire, rather than being at the mercy of an unplanned ignition. Or, the manager should be able to evaluate the timing and conditions of an unplanned ignition to determine whether or not it falls within the bounds of a predetermined prescription.

Benefits presumed to emerge from this kind of control rely on a prescribed burner's understanding of the effect of current and historical environmental conditions on the nature of the fire event being prescribed. The manager must understand the effect of the most variable conditions (such as weather) on fire behavior, and on the combination of these and the historical sequence of such conditions on relevant fuel characteristics such as fuel moisture and dead material production (Paysen and Cohen 1990). These same conditions can also have an effect on the physiological state of the vegetation affected by the prescribed fire (Narog et al. 1991). Such events can in turn influence vegetation response to the fire. The latter can determine whether the goal of a prescribed fire will be met.

PRESCRIBED FIRE RESEARCH

There are many factors associated with successfully carrying out a carefully planned prescribed fire. Considerations range from the fields of physical science and chemistry, to those of biology and mathematics. In spite of years of research related to issues that emerge in the application of prescribed fire, knowledge needed to carry out prescribed fire activities with any level of sophistication is severely limited. The reason for this is that little research from the requisite fields has been directed specifically to the solution of prescribed fire problems. There are some exceptions in certain locales throughout the country, and for certain disciplines with specific goals, a process of discovery has led to satisfactory application of prescribed fire. However, it is not clear that, in the same locales, a new goal arising from a different discipline can be achieved with existing knowledge.

Fields of knowledge develop either as a result of directed curiosity that follows chance discovery, or under the direction provided by an understanding of the context of a problem area. In either case, knowledge development has a direction. Knowledge pertaining to prescribed fire is no exception. A conceptual understanding of the nature of a fire event, and its placement in time, can point to the kind of knowledge needed to prescribe the character of a fire event, to control it, and to achieve a desired goal. An inventory of current knowledge can reveal missing information, and suggest the disciplines needed to direct research toward an understanding of the fire event (Martin et al. 1979, Sandberg et al. 1979, Wells et al. 1979).

In the following sections, we will present samples of research issues. This is intended as a conceptual, rather than a comprehensive list. The examples were chosen because they illustrate the kinds of disciplines

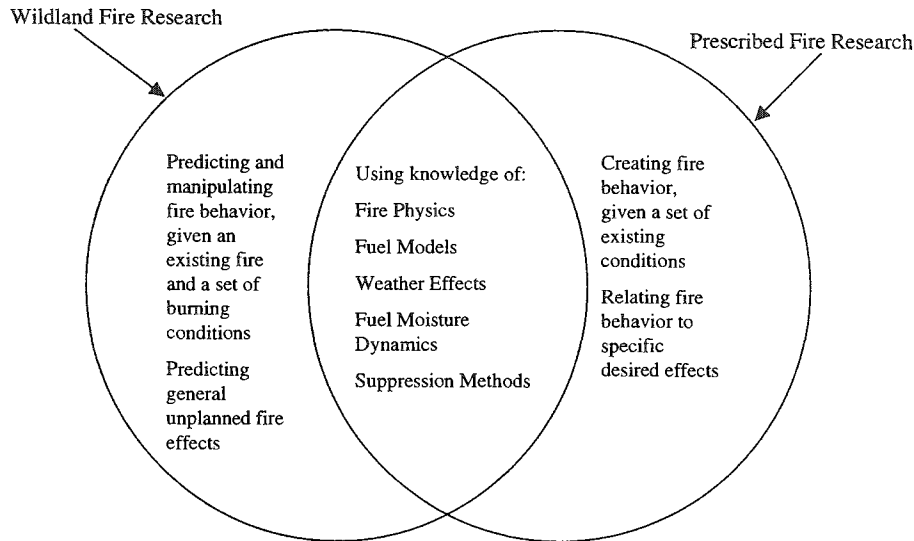


Fig. 2. A diagram illustrating the kinds of issues that wildland fire research and prescribed fire research must address. Overlapping research issues are found within the intersection of the two circles.

that must work jointly, or in concert, to provide the knowledge base required to control a particular fire event.

Prescribed Fire Behavior Research

Is this any different than standard fire behavior research? Well, it is fire behavior research; however, past fire behavior research focused on an understanding that does not address all aspects of wildland fire (Figure 2).

The management of our natural resources has primarily focused on utilization. Correspondingly, our research has been directed toward maintaining and improving utilization (Cohen 1990). Fire behavior research has not been an exception. It has largely directed its attention toward questions for fire suppression. Our current fire behavior information tools reflect this limitation. Predictions primarily address the characteristics of the propagating flame zone, from the standpoint of factors such as flame length and spread rate. These characteristics are important to fire suppression operations, but do not necessarily address ecological issues or operational prescribed burning needs.

Wildfire and prescribed fire present two different contexts for information requirements, and thus, potentially for research issues (Cohen and Bradshaw 1986). A wildfire manager already knows that an ignition will occur with subsequent fire spread. The wildfire manager is primarily interested in controlling the fire and limiting the fire-affected area. This requires information regarding the continued fire spread and intensity that impacts control activities. The prescribed fire context requires different information needs. With the exception of prescribed natural fires, prescribed burns are usually controlled to some degree by ignition techniques. Thus, management requires information about spread potential (the ability to get appropriate fire coverage), and the fire characteristics re-

sulting in fuel consumption and plant survival before and during burning operations (which should include the entire life of the fire).

Fire Propagation in Live Green Fuels

This problem has long been an issue for fire behavior practitioners. The question, "Will it burn or not?" has been a live fuel prescribed burning conundrum for years. Funds and time spent on trying to ignite a prescribed fire that will not sufficiently spread greatly reduces management effectiveness. Wildfires that burn through live green fuels often engender disbelief and compromise safety of people who thought that the green vegetation should not burn. The inability to recognize the conditions that produce fire spread, often with high intensities, affects all prescribed and suppression fire management operations. During a suppression operation in 1988, Beighley and Bishop (1990) characterized fire spread in conifer canopies (a type of live fuel) this way. "Fire spread rates and intensities were extremely sensitive to small variations in fire environmental factors, with quantum steps up or down in spread rate and intensity from small changes of relative humidity or wind." The prescribed fire manager working in live fuels can be caught in a small range of conditions bounded by no spread on one side and high intensity fire behavior on the other.

Thresholds

Experience and preliminary investigations by various people in research and fire management suggest that rates of fire spread in live green fuels occur at different thresholds. Dead surface fuels gradually increase fire spread and intensity as fire behavior factors increase in severity. In contrast, the live fuel strata can suddenly become involved, resulting in extreme fire behavior, whether in a wildfire or a prescribed burn.

No single fire behavior factor indicates how fire

spread will occur. One factor that has recently gained attention is live fuel moisture; however, we do not know how important live fuel moistures are to fire behavior (Weise et al. this volume). Because experience indicates a high degree of sensitivity to initial conditions, the spatial and temporal changes in the fuel particle and fuel bed geometry, fuel bed depth, proportion of dead fuel, fuel moisture contents, wind speeds, and slope steepness and configuration all contribute to the fire behavior threshold. Current fire models and analysis techniques cannot specifically identify the burning threshold. Adequately describing fire behavior in live fuels will likely require disciplines ranging from research engineering and physics, to mathematics and plant physiology.

Consumption

Consumption is conceptually related to fire propagation, but the degree of consumption during propagation is something we have virtually no understanding of at all. It is of vital concern to a prescribed burner, and is one thing that must be controlled during the fire event. People in the fire suppression community generally assume that consumption will exist if fire propagation occurs. If consumption is not complete, concerns about reburn potential immediately emerge.

The set of research disciplines that must address this problem is the same as that required to address most other problems in general fire behavior research. What sets prescribed fire behavior research apart is the need to interact with other disciplines so that the fire event can be more fully understood.

Research on Direct Prescribed Fire Effects

Mortality

Our reaction is that mortality is somehow related to fuel consumption and that this is a fire behavior problem. After all, if something is consumed by fire, it will die. But, mortality can occur without consumption. A fire can kill a tree or shrub without ever touching it with a flame. We are concerned with both the physical processes of heat transfer, and the physiological notion of mortality as a result of a heat overload. This problem is an example of needed research input from both the physical and biological sciences.

Heat-activated effects

Input of heat from the fire event that is not extreme enough to kill vegetation (outright or delayed) may activate both abiotic and biotic changes. Some soils affected by extreme heat can become hydrophobic (DeBano 1981). This affects soil hydration and can lead to severe erosion. Serotinous cones require heat treatment before releasing seeds that will then germinate. Species dominance and diversity can be altered in a postfire environment, presumably as a result of processes activated during the fire event.

It is hard to imagine research that would operate independently. Thus, physiologists, microbiologists,

biochemists, and physicists would have to integrate their work with that of ecologists, foresters, soil scientists, and geologists to correctly interpret the links between prescribed direct fire effects and the resulting short- and long-term fire effects.

Preburn History Research

This area is probably least thought about as an object of research, but aspects of it have been foremost in the minds of managers for many years. Most notable are the effects of preburn weather on fuel moisture, and of its seasonal patterns on the production of biomass. Still, our knowledge of the effects of these factors is elementary. We can only guess about cycles of weather, nutrients, and about the effects of age on the production of dead biomass. We can only wonder about the effects of protracted drought, or even a short one, on the effects of species survivability after fire. Are germination pathways altered? Will sprouting species be able to sprout? These questions and their answers are vital to the planning and implementation of prescribed burns. We can list numerous disciplines from the physical and life sciences that can contribute research towards the needed answers.

SUMMARY

Major research and development efforts have been made to improve suppression effectiveness on undesirable ignitions. These include enhancement of detection and attack methods, coupled with improved understanding of fire behavior, fire physics, and the general fire environment. Loss of property and life from wildfire can be reduced based on immediate response and analysis of the known fire behavior observed during a conflagration. Reliable knowledge enables fire managers to mitigate undesirable, and often unpredictable, postfire effects while also ensuring public safety as well.

Complementary to the above wildfire scenario are benefits that can be derived from a controlled prescribed fire event. With prescribed fire, control, predictability, and achievement of desired fire effects are imperative. Site history and critical environmental conditions must be known in advance. Deliberate application of fire during a specified window of opportunity should achieve desired reproducible effects (e.g., habitat improvement, hazard reduction, enhanced reproduction). Therefore, the use of prescribed fire requires specific knowledge of relations between fire behavior and site conditions, as well as the response of the environment to the fire. This is essential in order to create the appropriate fire event for achieving successful burns and postfire results. Ultimately, the consequences of the prescribed fire event must be arrived at in a deliberate, controlled, and safe fashion that was formulated from a knowledge base generated from careful research.

Presently, our knowledge base is neither exact enough nor broad enough to allow us to create fire conditions over the range of habitats that would benefit

from fire applications. Understanding the context of a prescribed fire event provides the framework needed to develop a unique research focus for a wide variety of disciplines. This focus is directed toward the control of the prescribed fire event. And, it defines the science of prescribed fire.

LITERATURE CITED

- Adams, D.L. 1994. The forests of the inland west. Pages 11–17 in *Proceedings of the conference on forest health and fire danger in inland western forests*. Harman Press, Spokane, WA.
- Beighley, M., and J. Bishop. 1990. Fire behavior in high elevation timber. *Fire Management Notes* 51: 23–28.
- Biodini, M.E., A.A. Steuter, and C.E. Grygiel. 1989. Seasonal fire effects on the diversity patterns, spatial distribution and community structure of forbs in the Northern Mixed Prairie, USA. *Vegetatio* 85:21–31.
- Cohen, J.D. 1990. Research has part of the answer. Pages 117–120 in *Proceedings of the conference on are forests the answer?: Society of American Foresters National Convention, Society of American Foresters*, Bethesda, MD.
- Cohen, J.D., and B. Bradshaw. 1986. Fire behavior modeling—a decision tool. Pages 1–5 in A. L. Koonce (ed.). *Prescribed burning in the Midwest: state of the art*. University of Wisconsin, Stevens Point.
- Covington, W.W., and S.S. Sackett. 1990. Fire effects on ponderosa pine soils and their management implications. Pages 105–111 in J. S. Krammes (technical coordinator). *Proceedings of the symposium on effects of fire management of southwestern natural resources*. General Technical Report RM-191, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.
- DeBano, L.F. 1981. Water repellent soils: a state-of-the-art. General Technical Report PSW-46, U.S. Department of Agriculture, Forest Service, Pacific Southwest Range and Experiment Station, Berkeley, CA.
- Ewell, P.L. 1995. The Oakland-Berkeley Hills fire of 1991. Pages 7–10 in D.R. Weise and R.E. Martin (eds.). *Proceedings of the Biswell Symposium: fire issues and solutions in urban interface and wildland ecosystems*. General Technical Report PSW-158, U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, CA.
- Gillon, D., V. Gomendy, C. Houssare, J. Marechal, and J. Vallette. 1995. Combustion and nutrient losses during laboratory burns. *International Journal of Wildland Fire* 5:1–12.
- Irwin, R.L. 1995. What do we do now, Ollie? Pages 17–21 in D.R. Weise and R.E. Martin (eds.). *Proceedings of the Biswell symposium: fire issues and solutions in urban interface and wildland ecosystems*. General Technical Report PSW-158, U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, CA.
- Kalmbacker, R., and F.G. Martin. 1995. Response of creeping bluestem to varying month of burn and soil water conditions. *International Journal of Wildland Fire* 5:101–111.
- Martin, R.E., H.E. Anderson, W.D. Boyer, J.H. Dieterich, S.N. Hirsch, V.J. Johnson, and H.W. McNab. 1979. Effects of fire on fuels. A state-of-knowledge review. Forest Service national fire effects workshop. General Technical Report WO-13, U.S. Department of Agriculture, Forest Service, Washington, DC.
- Martin, R.E., and D.B. Sapsis. 1995. A synopsis of large or disastrous wildland fires. Pages 35–38 in D.R. Weise and R.E. Martin (eds.). *Proceedings of the Biswell symposium: fire issues and solutions in urban interface and wildland ecosystems*. General Technical Report PSW-158, U.S. Department of Agriculture, Forest Service, Albany, CA.
- Mutch, R.W. 1994. Restoring forest health: do we have the will to apply science findings? Pages 18–22 in *Proceedings of the conference on forest health and fire danger in inland western forests*. Harman Press, Spokane, WA.
- Narog, M.G., T.E. Paysen, A.L. Koonce, and G.M. Burke. 1991. Burning irrigated and unirrigated chamise. *Proceedings of the Fire and Forest Meteorology Conference* 11: 352–356.
- Paysen, T.E., and J.D. Cohen. 1990. Chamise chaparral dead fuel fraction is not reliably predicted by age. *Western Journal of Applied Forestry* 5:127–131.
- Price, M.V., N.M. Waser, K.E. Taylor, and K.L. Pluff. 1995. Fire as a management tool for Stephens' kangaroo rat and other small mammal species. Pages 51–62 in J.E. Keeley and T. Scott (eds.). *Proceedings of brushfires in California wildlands: ecology and resource management*. International Association of Wildland Fire, Fairfield, WA.
- Sandberg, D.V., J.M. Pierovich, D.G. Fox, and E.W. Ross. 1979. Effects of fire on air. A state of knowledge review. Forest Service national fire effects workshop. General Technical Report WO-9, U.S. Department of Agriculture, Forest Service, Washington, DC.
- Vallete, J.C., V. Gomendy, F. Marechal, C. Houssard, and D. Gillon. 1994. Heat transfer in the soil during very low-intensity experimental fires: the role of duff and soil moisture content. *International Journal of Wildland Fire* 4:225–238.
- Wells, C.G., R.E. Campbell, L.F. DeBano, C.E. Lewis, R.L. Fredricksen, C.E. Franklin, R.C. Froelich, and P.H. Dunn. 1979. Effects of fire on soil. A state-of-knowledge review. Forest Service national fire effects workshop. General Technical Report WO-7, U.S. Department of Agriculture, Forest Service, Washington, DC.
- Zelker, T.M. 1976. Forest interpreter's primer on fire management. TT-53 (1660/2300), U.S. Department of Agriculture, Forest Service, Washington, DC.