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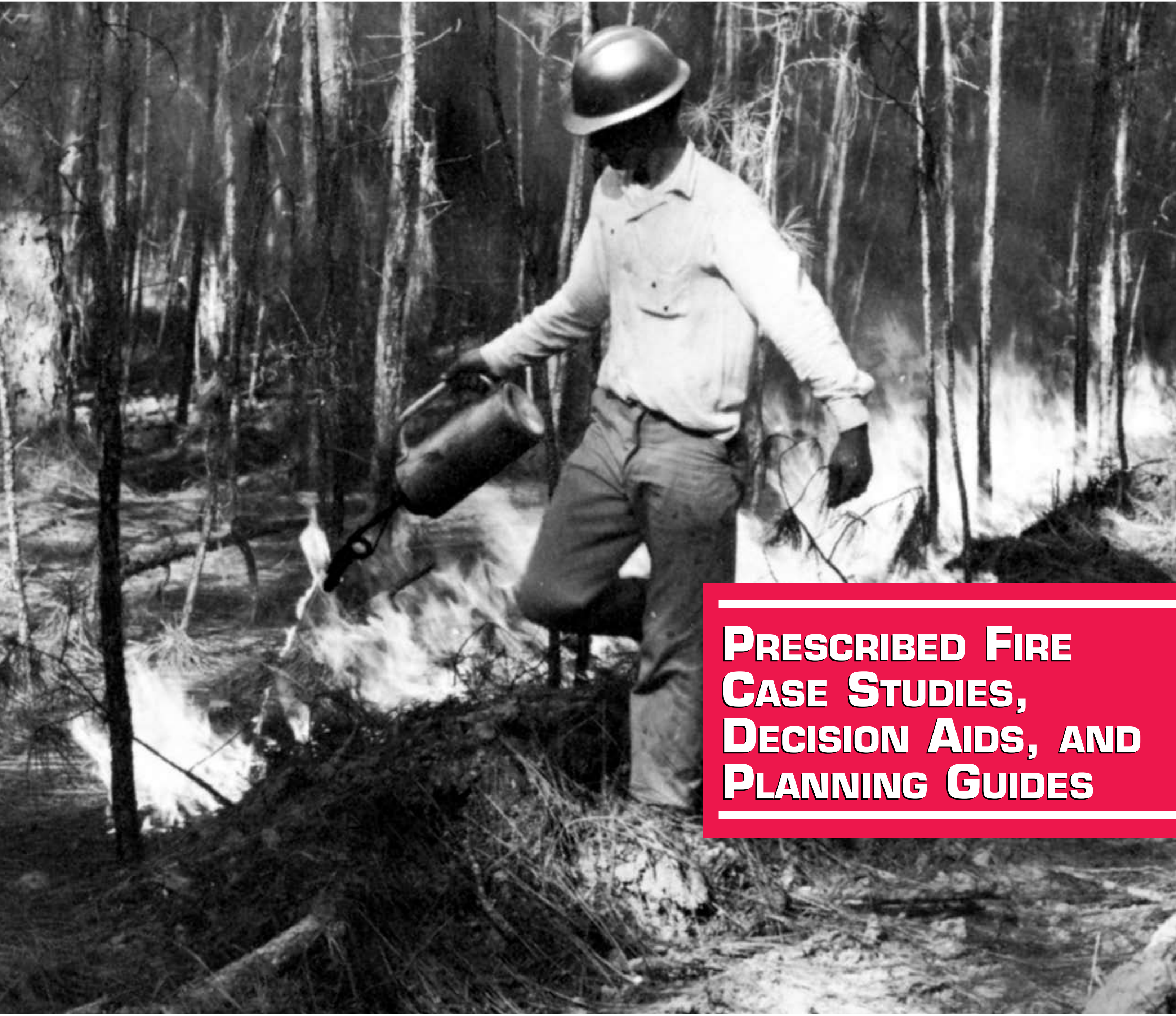

PRESCRIBED FIRE CASE STUDIES, DECISION AIDS, AND PLANNING GUIDES

United States Department of Agriculture
Forest Service

Dedication

This special issue of *Fire Management Today* devoted to prescribed fire is dedicated to all the individuals from around the world who have been killed or seriously injured while engaged in a prescribed burning operation. This would include fatality incidents in Australia, Canada, New Zealand, Portugal, the United States, and no doubt other regions of the world.

It is our sincerest hope that this publication will in some way contribute to an enduring culture where concern for the safety of personnel involved in prescribed burning is an integral part of the planning and operational procedures in the future.

Martin E. Alexander and David A. Thomas
Issue Coordinators

Editors' note: This issue of *Fire Management Today* reprints articles from early editions of the journal, some of them decades old. Although the articles appear in today's format, the text is reprinted largely verbatim and therefore reflects the style and usage of the time. We made minor wording changes for clarity, added intertitles and metric conversions where needed, and occasionally broke up paragraphs to improve readability. All illustrations are taken from the original articles.

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On the Cover:

Prescribed burning in southern pine in about 1970. The photo is from an article by Walter A. Hough ("Prescribed Burning in the South Surveyed, Analyzed" [*Fire Control Notes* 34(1): 4–5]), a research forester for the USDA Forest Service, Southern Forest Fire Lab, Macon, GA. The article describes the prescribed fire program in the 13 Southern States from 1964 to 1971, when more than 2 million acres were prescribe-burned each year on average, mainly in an arc from South Carolina to Louisiana and mostly for hazardous fuels reduction and site preparation. Photo: USDA Forest Service.

The USDA Forest Service's Fire and Aviation Management Staff has adopted a logo reflecting three central principles of wildland fire management:

- *Innovation:* We will respect and value thinking minds, voices, and thoughts of those that challenge the status quo while focusing on the greater good.
- *Execution:* We will do what we say we will do. Achieving program objectives, improving diversity, and accomplishing targets are essential to our credibility.
- *Discipline:* What we do, we will do well. Fiscal, managerial, and operational discipline are at the core of our ability to fulfill our mission.

Firefighter and public safety is our first priority.

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Fire activity following ground and aerial ignition of the 1,300-acre (525-ha) "Diamond L" prescribed burn unit on the Buffalo Ranger District, Bridger–Teton National Forest in northwestern Wyoming, October 1, 2005. Vegetation/fuel types consisted of trembling aspen, sagebrush, and mixed-conifer stands. The primary purpose of the burning was to enhance winter and transitional ranges for elk by using fire to stimulate aspen regeneration. Photos: Chris Vero, USDA Forest Service, Bridger–Teton National Forest, Jackson, WY, 2005.

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SHORT FEATURES

PRESCRIBED FIRE CASE STUDIES, DECISION AIDS, AND PLANNING GUIDES

M.E. Alexander and D.A. Thomas

Fire Management Today and its predecessors collectively have a 70-year record of publishing on all aspects of wildland fire management. While early on the emphasis was placed on subjects related to fire protection and fire suppression, it wasn't too long before articles dealing with prescribed fire began to appear. Bunton (2000) has identified and subject-indexed all the prescribed-fire-related articles published in *Fire Control Notes, Fire Management,* and *Fire Management Notes* between 1970 and 1999. The articles published on the subject of prescribed fire from 1936 to 1969 were not so handily cataloged, although summary indexes were published by *Fire Control Notes* in 1942, 1955, 1963, and 1969.

Starting with *Fire Management Notes* volume 57, number 1 (Winter 1997), all issues have been posted for downloading from the Internet at the journal's website (http://www.fs.fed.us/fire/fmt/). This action has greatly increased the exposure of the journal within the global wildland fire management community. The collection of downloadable issues now extends back to 1991. In time, the entire collection of all issues will be available for downloading from the *Fire Management Today* Website. This will be a very valuable resource to the wildland fire community.

The use of fire by humans has a long and storied history, as has been chronicled globally by noted fire historian Stephen Pyne.

Meanwhile, seeing the need for a compendium of relevant articles on prescribed fire, the authors prepared this special issue of *Fire Management Today*, selecting 28 previously published articles from past issues of *Fire Control Notes, Fire Management,* and *Fire Management Notes*. We chose case studies as well as pertinent decision aids and planning guidelines; and, because space limited our selection of articles, we sprinkled titles of others throughout the issue (beginning in the sidebar on page 6).

Prescribed Fire Defined

The term "prescribed fire" has also been referred to as "control burn" or "prescription fire." Although many different definitions of prescribed fire exist globally (e.g., BCRC 2004; CIFFC 2003; NWCG Incident Operations Standards Working Team 2005), they all have a central theme. Merrill and Alexander (1987), for example, defined prescribed fire as "any fire deliberately utilized for prescribed burning; usually set by qualified fire management personnel according to a predetermined burning prescription." They in turn defined prescribed burning, following Muraro (1975), as "the knowledgeable application of fire to a specific land area to accomplish predetermined forest management and other land use objectives."

Although subtle variations do exist in how the terms "prescribed fire" and "prescribed burning" are defined by different individuals and organizations, the most important points to remember are that, according to Wade and Lunsford (1989), prescribed fire is the application of prescribed burning:

- In a skilled manner,
- Under exacting weather conditions,
- In a definite place, and
- To achieve specific results.

The definitions above refer to traditional, planned-ignition prescribed fires versus chance- or random-ignition prescribed fires (Alexander

*Dr. Marty Alexander is a senior fire behavior research officer with the Canadian Forest Service, Northern Forestry Centre, and an adjunct professor of wildland fire science and management in the Department of Renewable Resources, University of Alberta, Edmonton, Alberta, Canada (at the time of this writing, he was on assignment as a senior researcher with the Wildland Fire Operations Research Group, Forest Engineering Research Institute of Canada, Hinton, Alberta, Canada); and Dave Thomas recently retired as the regional fuels specialist for the USDA Forest Service, Intermountain Region, Ogden, UT. The authors also served as issue coordinators for a special three-part series of previously published articles on the subject of wildland fire behavior—*Fire Management Today *63(3) [Summer 2003],* Fire Management Today *63(4) [Fall 2003], and* Fire Management Today *64(1) [Winter 2004].*

Additional References on Prescribed Fire

The following articles related to prescribed fire, published in *Fire Control Notes* and its successors, could not be reprinted in this issue of *Fire Management Today* due to space constraints. Similar lists are sprinkled throughout this issue (see pages 34, 37, 40, 46, 53, 59, 61, 68, 78, 82, 89, and 100).

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and Dube 1983). In some cases, naturally ignited wildland fires can produce beneficial results in terms of attaining land management objectives, and they are sometimes allowed to burn with limited intervention, provided they meet predefined criteria (Parsons and others 2003). In the United States, such events or incidents are called "wildland fire use" (NWCG Incident Operations Standards Working Team 2005).*

Prescribed Fire Uses

The use of fire by humans has a long and storied history, as has been chronicled globally by noted fire historian Stephen Pyne (1982, 1991, 1995, 1997, 2001, 2004). However, the fact that fire is both a management tool and a process was generally unappreciated until about 30 years ago; and, to a certain extent, full recognition of this point is still lacking today. Wright and Heinselman (1973), for example, outlined the principles of fire as an ecosystem process in fire-dependent northern conifer forests:

- Fire influences the physical–chemical environment (e.g., by volatilizing some nutrients, directly releasing mineral elements as ash, and reducing plant cover and thereby increasing insolation and, in turn, soil temperatures);

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* In keeping with the definition adopted by the National Wildfire Coordinating Group in the United States—and therefore with usage required in *Fire Management Today*—this article refers to planned-ignition prescribed fires simply as "prescribed fires."

A prescribed fire can, if properly executed, accomplish many beneficial purposes.

- Fire regulates dry-matter accumulation (i.e., in terms of fuel consumption and production);
- Fire controls plant species and communities (at the individual and stand level as well as at the landscape scale);
- Fire determines wildlife habitat patterns and populations (indirectly through vegetation as opposed to fire-induced mortality);
- Fire influences forest insects, parasites, fungi, etc. (directly by sanitization and indirectly by regulating vegetation); and
- Fire controls major ecosystem processes and characteristics (e.g., nutrient cycles and energy flow, succession, diversity, productivity, and stability).

Several authors have applied this broad framework with specific examples to various ecosystems (e.g., Alexander and Euler 1981; Wade and others 1980).

Wade and Lunsford (1989) considered the following as the most common reasons for using prescribed fire in forest resource management in the Southern United States:

- Reducing hazardous fuels;
- Preparing sites for seeding and planting;
- Disposing of logging debris;
- Improving wildlife habitat;
- Managing competing vegetation;
- Controlling insects and disease;
- Improving forage for grazing;
- Enhancing appearance;
- Improving access;
- Perpetuating fire-dependent species (ecosystem restoration);
- Cycling nutrients; and
- Managing endangered species.

These objectives are similar to those in other regions of North America (e.g., Beaufait 1966; Green 1981; Martin and Dell 1978; Sando and Dobbs 1970) and globally. To this list we could add, for example, increasing water yields (Green 1977; Pase and Granfelt 1977).

Experimental outdoor or prescribed fires have also been undertaken exclusively for the purpose of generating fire behavior data in relation to prevailing environmental conditions in order to develop new predictive models or guides (e.g., Bruner and Klebenow 1979; Davis and Dieterich 1976) and/or validate existing ones (Alexander and Quintilio 1990). Such fires might also be set to examine fire suppression effectiveness (e.g., Crosby and others 1963; Johansen 1965; Murphy and others 1991).

Prescribed burning can also serve as a valuable aid for training firefighting personnel. Many new firefighters are unfamiliar with fire control methods and need training in fire suppression. Prescribed fires can provide an excellent opportunity to learn about fire behavior, equipment operation, and suppression crew organization. Mopup on prescribed fires is essentially the same as on wildfires, so new personnel can be made familiar with problems before their first wildfire by using them on prescribed-burning operations. Such training should probably be viewed as a secondary objective of all prescribed fires, but it might become the primary objective (Alexander 1999; Cheney 1994).

A prescribed fire can, if properly executed, accomplish many beneficial purposes (see the sidebar below). On the other hand, it can actually be damaging, depending on the fire's intensity and timing in terms of the season or time of year (Robbins and Myers 1992). The key is to develop the right burning or fire prescription during the planning process (Miller 2004).

Prescribed Fire Planning Process

Figure 1 (from Kayll 1980) shows a basic framework for employing prescribed fires in forest vegetation management. The most important element in the flow process is the explicit provision of "feedback loops" (i.e., mechanisms or proce-

Fire's Dichotomous Role in Land Management*

Prescribed fire can:	Or it can:
• Reduce flammable fuels	• Eventually increase fire hazards
• Remove organic matter	• Contribute more organic matter
• Expose mineral soil	• Permit soil to erode
• Kill viable seeds in duff	• Stimulate germination
• Kill understory species	• Cause their roots to sprout
• Reduce insect numbers	• Enhance the insect environment
• Kill pathogens	• Provide entry for soil fungi
• Increase soil nutrient availability	• Reduce soil water-holding capacity
• Open serotinous cones	• Destroy other seed sources
• Thin overstocked stands	• Promote overstocking

* From Beaufait (1962).

dures whereby one can determine why or why not managerial objectives have been met). The five-step process is as follows:

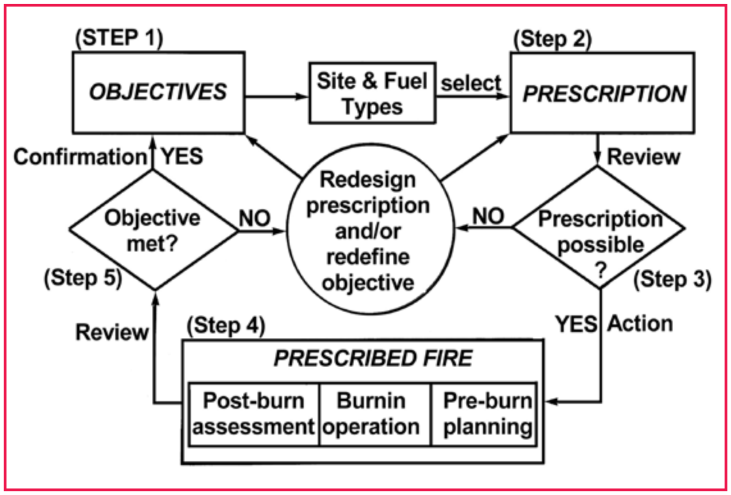

Figure 1—*Simple flowchart for employing prescribed fires in wildland vegetation management (from Kayll 1980).*

Step 1: After making the decision to use fire (fig. 2), the first and most important step is to set (and declare) the objectives relative to the site(s) and fuel type(s) you are attempting to manage.

For example, if the general objectives are wildfire hazard abatement (Muraro 1968) and improved tree-planting performance (Vyse and Muraro 1973), then the specific objectives of the prescribed burn would probably be stated in terms of the quantity of down–dead woody fuel (by roundwood size class distribution) and organic matter to be consumed (Hawkes and others 1990; Muraro 1975).

Step 2: Having defined the objectives, determine a burning prescription for achieving them expressed in terms of fire danger ratings, fire weather conditions, season, time of day, ignition pattern, etc. (see the sidebar on page 9, lower left) based on the best possible information available, such as operational case studies, research publications, decision aids and guides, expert opinion and past experience (fig. 3) or other approaches (e.g., Reinhardt and others 1992).

It is worth noting that case studies undertaken in one country can be applied to another, if fuel-type characteristics are relevant, by interpreting burning conditions through the other country's fire danger rating system (e.g., Alexander 1982, 1984; Alexander and Sando 1989).

Step 3: Is the "prescription" possible? That is, are there enough suitable days in an average fire season

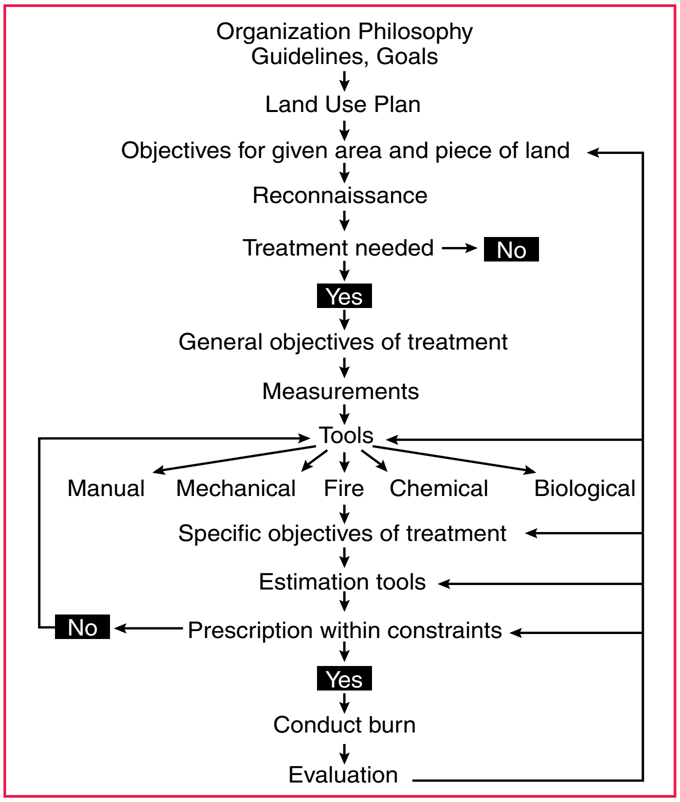

Figure 2—*The mental and management steps leading to the use of prescribed burning (from Martin 1978).*

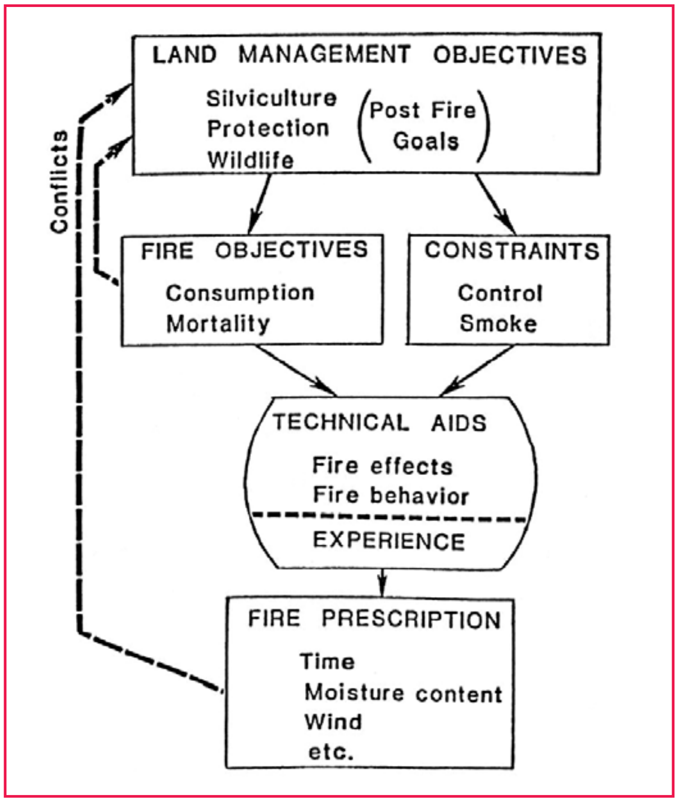

Figure 3—*Flow of information in designing prescribed burning prescriptions (from Brown 1975).*

and at the right time of the season to make it a reasonable prescription (Bradshaw and Fischer 1981; Martell 1978)? If not, then follow the feedback loops to redefine the prescription and/or the objective.

This might involve several iterations with slight changes in the range of the variables or parameters, including enlarging the ranges, before arriving at acceptable ranges that would still achieve the desired fire behavior and impact (Martell 1978). A common mistake is to include too many variables, because the probability of their simultaneous occurrence is generally quite low.

Step 4: If the prescription is possible, then proceed with the detailed planning for the operational execution of the prescribed burn, including smoke management considerations (Gorski and Farnsworth 2000; Hardy and others 2001); prepare the prescribed fire plan (see the sidebar to the right); and, as appropriate, execute the plan (see the sidebar on page 10).

A plethora of prescribed-fire-planning guidelines and guidebooks are available, including manuals on costing (Manol and others 1996) and complexity rating (NFES 2004). See, for example, Allen and others (1968), Kiil (1969), Fischer (1978), Martin and Dell (1978), NWCG Prescribed Fire and Fire Effects Working Group Team (1986), Wade and Lunsford (1989), and The Nature Conservancy (1991).

Step 5: Review performance to determine whether the stated objectives were achieved, and, most importantly, why. If the stated objectives were not achieved, it is equally important to determine why and thus close the loops. The level of detail that can be achieved in monitoring weather conditions and aspects of fire behavior during the actual burning operations will depend on ease of access and safety considerations, availability of personnel and equipment, size of the burning unit, and firing pattern (McRae and others 1979; NWCG Prescribed Fire and Fire Effects Working Group Team 1982; Rothermel and Rinehart 1983). The documentation made prior to, during, and immediately after the fire (e.g., postburn sampling) should directly link to the burning prescrip-

Three Examples of Burning Prescriptions Based in Part on the Canadian Forest Fire Weather Index System*

Open, montane lodgepole pine stand—ecosystem restoration (Dube 1977):

- Dry-bulb temperature: 61–73 °F (16–23 °C)
- Relative humidity: 25–40 percent
- 10-m (33-ft) open windspeed: 5–15 miles per hour (8–24 km/h)
- ISI: 5–12
- BUI: > 20
- FWI: 10–12

Lowland black spruce stand following harvesting—seedbed preparation (Chrosciewicz 1976):

- FFMC: ~ 91
- DMC: 22–46
- BUI: 21–45
- 10-m (33-ft) open windspeed: 5–10 miles per hour (8–16 km/h)

White and red pine stand—seedbed preparation and understory vegetation control (Van Wagner and Methven 1978):

- FFMC: 90–95
- ISI: 8–16
- BUI: < 52
- FWI: 12–24
- Time of year: May–June (ideal)

* The Fire Weather Index System components consist of three fuel moisture codes and three fire behavior indexes (Canadian Forestry Service 1984): the Fine Fuel Moisture Code (FFMC); Duff Moisture Code (DMC); Drought Code (DC); Initial Spread Index (ISI); Buildup Index (BUI); and Fire Weather Index (FWI).

Elements of a Prescribed Fire Plan*

1. Required signatures/approvals
2. Burn unit description
3. Vicinity map
4. Project map
5. Goals and objectives
6. Source of funding and estimated cost
7. Equipment and personnel
8. Fire prescription
9. Weather information
10. Preparation work
11. Protection of sensitive features
12. Smoke management
13. Preburn coordination and public involvement
14. Burn day notification
15. Public and personnel safety
16. Communication
17. Briefing guidelines and "Go/No Go" checklist
18. Test fire
19. Firing, holding, and mopup/patrol
20. Contingency
21. Monitoring and evaluation
22. Rehabilitation
23. Management of multiple prescribed fires
24. Necessary support documentation

* From NWCG Prescribed Fire and Fire Effects Working Team (1986).

tion relative to what was achieved or accomplished versus the objective(s) of burning. In other words, there are lots of things to potentially document on a prescribed fire, but one should ensure that the basics are covered off first.

Postburn monitoring can range from simple repeat photography (Magill 1989) to more detailed studies (USDI Fish and Wildlife Service 2004; USDI National Park Service 2003). A pre- and postburn fuel photo series, especially if coupled with quantitative measurements, is an invaluable tool for future prescribed-fire planning and burning-prescription formulation (e.g., Scholl and Waldrop 1999; Wade and others 1993; Wearn and others 1982). Detailed, research-level documentation and monitoring are probably justified when burning in a new fuel or vegetation type (Gilmore and others 2003). Occasionally, prescribed fires attract the attention of wildland fire researchers who are able to "piggyback" their activities onto the operational burning without causing undue interference (e.g., Stocks and McRae 1991).

Prescribed Fire Training

Three national prescribed-fire training course packages are now available through the U.S. National Wildfire Coordinating Group's National Fire Equipment System based at the National Interagency Fire Center in Boise, ID (NFES 2005):

- Prescribed Fire Burn Boss (Rx–300),
- Introduction to Fire Effects (Rx–340), and
- Smoke Management Techniques Rx–450).

For a listing of course offerings, visit the Wildland Fire Training website (http://www.nationalfiretraining.net). The National Advanced Fire and Resource Institute in Tucson, AZ (http://www.nafri.gov/index.htm) also offers the "Applied Fire Effects" course (Rx–510) on an annual basis.

Two prescribed-fire training centers have been in operation in the United States since 1998. The Southwest Fire Use Training Academy located in Albuquerque, NM, is an interagency program that offers a unique blend of formal classroom training and hands-on prescribed-burning field experience over the course of a 7-week period (http://nationalfiretraining.net/sw/futa/). The National Interagency Prescribed Fire Training Center located in Tallahassee, FL, offers a similar program oriented towards the southeastern United States (Fort and others 2000). University-level courses in fire ecology that include a prescribed-fire component and orientation are even available on the World Wide Web (Walstad and others 2003).

Prescribed-Fire-Related Information Sources

There is no shortage of technical information on prescribed fire and prescribed burning. Several books (e.g., Agee 1993; Biswell 1989; DeBano and others 1998; Kozlowski and Ahlgren 1974; Pyne and others 1996; Walstad and others 1990; Whelan 1995; Wright and Bailey 1982) and bibliographies (e.g., Crow 1982; Cushwa 1968; Greenlee 1995; Kumagai and Daniels 2002) exist, plus online sources such as the Encyclopedia of Southern Fire Science (http://forestencyclopedia.net/Encyclopedia/Fire%20Science). Numerous conference and symposium proceedings devoted to a wide range of prescribed-fire topics have also been published (e.g., Baumgartner and others 1989; Bidwell and Burke 1993; Bryan 1997; Hardy and Arno 1996; Koonce 1986; Lotan and Brown 1985; Sanders and Durham 1985; Trowbridge and Macadam 1983; USDA Forest Service 1971, 1977; Wade 1985; Wood 1981). Other excellent sources of information include fuel- or vegetation-type-specific prescribed-fire guidelines (e.g., Archibald and others 1994; Bunting and others 1987; Cheney 1978; De Ronde and others 1990; Green 1977;

The Fourteenth Prescribed Fire Situation that Shouts, "Watch out!"

Maupin's (1981) *thirteen prescribed fire situations that shout watch out!* are listed on the back inside cover of this issue. Based on past experiences (e.g., USDA Forest Service 2003), we would add a fourteenth situation to this list:

Conducting a prescribed fire without having a temporary onsite or nearby fire weather station.

This applies to some specified time prior (depending on the fuel type and representativeness of the permanent, "offsite" fire weather station(s) for startup values), during, and immediately following the prescribed fire.

There are lots of things to potentially document on a prescribed fire, but one should ensure that the basics are covered off first.

Gruell and others 1986; Kilgore and Curtis 1987; Norum 1977; Wright and others 1979).

One of the most notable sources on prescribed fire is the proceedings of the Tall Timbers Fire Ecology Conference series organized by the Tall Timbers Research Station (Fischer 1980); the 23rd event, devoted to "fire in grasslands & shrubland ecosystems," took place in October 2005 in Bartlesville, OK. The Tall Timbers Research Station has also published other prescribed-fire-related monographs (e.g., Biswell and others 1973; Robbins and Myers 1992) and has created a computerized Fire Ecology Database on its Website (http://www.talltimbers.org/info/fedbintro.htm).

Several fire effects summaries have been prepared (e.g., Miller 1995). Perhaps one of the most up-to-date information sources on fire effects is the USDA Forest Service's "Rainbow Series," which covers the effects of fire on flora, fauna, air, soil and water, cultural resources and technology, and nonnative invasive plants. Four of the six planned publications in the series are currently available (Brown and Smith 2000; Neary and others 2005; Sandberg and others 2002; Smith 2000). The Fire Effects Information System (Fischer and others 1996) also developed by the USDA Forest Service is a computerized system that provides up-to-date information about fire effects on plants and animals (http://www.fs.fed.us/database/feis/). In addition, a Fire Effects Planning Framework has recently been developed (Black and Opperman 2005).-

Several prescribed-fire-related models exist. For example, FOFEM, a national fire effects model, predicts tree mortality, fuel consumption, smoke production, and soil heating (Reinhardt and others 1997). CONSUME also predicts the amount of fuel consumption and emissions from the burning of logged units, piled debris, and natural fuels for most vegetation types in North America (Ottmar and others 1993). With respect to modeling fire behavior, a few empirically based, fuel-type-specific models exist (e.g., Bruner and Klebenow 1979; Cheney and others 1992; Davis and Dieterich 1976; Muraro 1975; Sneeuwjagt and Peet 1985). BEHAVE, a semiphysically based fire behavior model applicable to surface fuelbeds (Andrews and Bradshaw 1990), has been formatted for prescribed-fire applications (e.g., Grabner and others 2001). Even decision support aids intended for assessing wildlfire potential, such as the Canadian Forest Fire Behavior Prediction System (Taylor and others 1997), have value in escaped-fire assessments and contingency planning.

One of the immense challenges facing prescribed burners of the future will be acquiring the skills needed to professionally sort out the staggering amount of "information" available in all the areas they are supposed to have expertise in—disturbance ecology, fire meteorology and climatology, fire behavior modeling, and decisionmaking, just to name a few. They are supposed to have not only a working knowledge of these academic disciplines, but also the ability to readily carry them out in a field setting under quickly changing environmental conditions. Many fire managers feel out of control and anxious over the sheer amount of information and data they are supposed to deal with. They may suffer from "information anxiety," defined by Wurman (1989) as the feeling of being overwhelmed by the amount of information available on a given topic. Wurman notes that even if we find the information we think we need, we might not be able to understand or evaluate it.

Inherent Risks in Using Prescribed Fire

The biggest challenge for fire managers faced with a steadily rising prescribed-burn targets is lack of practical experience within their fire organizations. Interestingly enough, this is not a new issue (Beaufait 1966). Given the decline in commercial harvesting, the generation of burn bosses that grew up igniting hundreds of logging slash units in an individual career has been lost to retirement, resulting in a huge prescribed-fire experience gap. It is common, for example, on many national forests in the Western United States to have staff that are involved in only one or two prescribed burns per year. Obviously, developing prescribed-burning expertise in this manner is slow. Perhaps recent retirees should be brought back on contracts as coaches or mentors.

Even though prescribed fire is one of the most important tools for managing fire-dependent ecosystems, little attention has been given, until recently, to understanding the lessons to be learned from past prescribed burns or the organizational psychology of the prescribed-burn team responsible for safely igniting a block of flammable vegetation. This lack of attention to burning operations is somewhat surprising, because the decision to "light the match" is always inherently risky, from both a personal and a social standpoint. (Ask any burn boss who regularly ignites prescribed fires or has been involved with an escaped fire that has resulted in a national review team looking at every judgment and decision made in the planning and execution of the prescribed fire.)

Escaped fires are a very real possibility in prescribed burning (Stock and others 1996), as a number of incidents have shown in recent years. For example:

- In May 1980, the Mack Lake Fire in northern Lower Michigan burned 29,000 acres (9,300 ha) and 39 homes (Borie 1981; Simard and others 1983);
- In August 1995, the Carmody Township Fire in north-central Ontario burned 19,296 acres (7,810 ha), with no structural losses (OMNR 1995);
- In July 1999, the Lowden Ranch Fire in central California burned 2,000 acres (800 ha) and 23 homes (USDI Bureau of Land Management 1999);
- In July 2001, the North Shore Kenai Lake Fire in southeastern Alaska burned 2,220 acres (899 ha), with no structural losses (USDA Forest Service 2002);
- In September 2003, the Cascade II Fire in north-central Utah burned 7,828 acres (3168 ha), with no structural losses (USDA Forest Service 2003); and
- In March 2004, the Impassible 1 Fire in northern Florida burned 34,660 acres (14,028 ha), with no structural losses.

However, probably the best known example of an escaped fire is associated with the Upper Frijoles Prescribed Fire on Bandelier National Monument in northern New Mexico during May 2000. The resulting Cerro Grande Fire eventually burned some 47,650 acres (19,284 hectares), including 235 homes in and around the community of Los Alamos (Paxon 2000; USDI National Park Service 2000).

At a recent workshop on high-reliability organizations (HROs) regarding wildland fire use and prescribed fires (Keller 2004), participants completed a staff ride of the Cerro Grande Fire. Under the tutelage of Drs. Karl Weick and Kathleen Sutcliffe, two experts on HROs from the University of Michigan Business School, staff ride participants used the concepts of HROs to analyze the prescribed burn and associated wildfire. According to Weick and Sutcliffe (2001), five key processes, or organizational principles, govern organizations that actively promote an HRO environment:

One of the most notable sources on prescribed fire is the proceedings of the Tall Timbers Fire Ecology Conference series.

- *Preoccupation with mistakes/failures:* Take every opportunity to use near-misses, even so-called "minor mistakes," to see if they might indicate the beginnings of a major breakdown in prescribed burn operations.
- *A reluctance to simplify:* A prescribed burn crew should be constantly vigilant to simplifying mistakes into cause-effect relationships. They should strive to view mistakes from multiple angles in a culture that supports robust conversations.
- *Sensitivity to operations:* In prescribed-burning operations, a high-reliability work culture would be extremely sensitive to the people in the field who "light the match" and control the ensuing fire. They would not drown out what is going on at the ground level with an overemphasis, for example, on national or regional policy.
- *A commitment to resilience:* A prescribed fire organization that is highly reliable creates a work environment where personnel can easily talk about their "mistakes" and, after larger mistakes have occurred, can quickly adjust and get back to work in a timely fashion.
- *A deference to expertise:* A highly reliable burn organization pays keen attention to those who make critical decisions, regardless of their position on an organization chart.

The attentive prescribed-fire manager will hopefully use each of these five principles of HROs in order to safely and effectively conduct prescribed fires in the future (see the sidebar above). However, as Lepine and others (2003) duly note, "Regardless of how many precautions are taken, it is impossible to eliminate the risk of fires escaping from prescribed burning."

Prescribed Fire Safety

It would be fairly easy to conclude that prescribed-fire operations are not inherently dangerous. After all, major activities on a prescribed burn are completely preplanned, with all contingencies carefully thought out. In other words, every task involved with a prescribed-fire operation is "under control." Unlike a wildfire event, the prescribed burner is not at

The “Art and Science” of Prescribed Burning*

A successful prescribed fire is one that safely and effectively achieves the land and resource management objectives for which it was conducted. Such fires do not happen by accident: they are the result of careful and intelligent planning.

To plan a successful prescribed fire the planner must clearly define why he wants to burn a site and what he hopes to accomplish. He must also describe the physical and biological characteristics of the site to be treated. He must then blend this information with an understanding of the relationships between fuel, weather, topography, fire behavior, fire effects, and burning techniques. Finally, the actual fire must be evaluated in order to improve the performance of subsequent plans.

* Quoted from Fischer (1978).

the mercy of an unexpected weather event, for he can ignite his burn when the weather is favorable—or, at least, when it is expected to be favorable. But even with all this preburn control and expert weather forecasting, fatalities have resulted from burnovers and entrapments on escaped prescribed fires (Thomas 1998). The better known examples include:

- August 1979—seven fatalities on the Geraldton PB-3/79 Prescribed Fire in north-central Ontario, Canada (McCormack and others 1979) (see the sidebar on page 14);
- February 1980—two fatalities on the Willow Flat Prescribed Fire, North Island, New Zealand (Millman 1993);
- May 1980—one fatality on the Mack Lake Fire resulting from an escaped prescribed fire in northern Lower Michigan (Borie 1981; Simard and others 1983);
- April 1993—one fatality on the Buchanan Prescribed Fire in north-central New Mexico (USDA Forest Service 1993);
- June 2000—four fatalities in Kurring-gai Chase National Park, New South Wales, Australia (New South Wales National Parks and Wildlife Service 2001); and
- May 2003—one fatality on the Fort Apache Indian Reservation in northern Arizona (USDI Bureau of Indian Affairs 2003).

Furthermore, aviation-related fatalities are not limited to wildfires. On March 10, 2005, two fire managers and a pilot died when a Bell 206B-III helicopter they were in crashed while conducting a prescribed burning operation on the Sabine National Forest in East Texas (NTSB 2005).

The reality is that individuals involved in prescribed burning are exposed to the same natural and manmade hazards as those involved in fire suppression operations. For example, an interagency hotshot crew member was killed in 2004 when he was hit in the head by the top of a burning snag (USDI National Park Service 2004). Thus, the realization that fatalities can occur on prescribed fires should not be overlooked, especially in light of an escalating use of prescribed burning in many regions of North America and elsewhere (Alexander 2003). It is worth emphasizing that members of the general public have also been killed while engaged in using fire as a land management tool on their private properties (Millman 1993; Viegas 2004).

The ability to predict fire behavior is essential to the safe and effective control of wildfires as well as the use of fire (Countryman 1972). In this regard, one shouldn’t overlook the importance that human factors have played in past wildland firefighter fatalities (Butler and Alexander 2005). Some of the same principles associated with wildfire situations could equally apply to prescribed fires (e.g., complacency).

When one couples a general lack of burning experience with the organizational pressure to prescribe-burn more area each year, often under more severe burning conditions and on a landscape scale, a future scenario begins to unfold of increased risk of escape and potential safety problems. Even though prescribed-fire fatalities are relatively rare, deaths directly associated with prescribed burning have occurred, as outlined here.

One of the cardinal principles of HROs is “mindfulness” (Putnam 2005). Applied to prescribed burning, mindfulness involves a conscious effort by the burn boss to stop concentrating on things in the fire environment that confirm his hunches or make him feel good about what the fire is doing and to start concentrating on things that discount or contest his feelings.

It is fairly easy to start a short list

The biggest challenge for fire managers faced with a steadily rising prescribed-burn targets is lack of practical experience within their fire organizations

Application of Barry Turner's Disaster Model to a Prescribed Fire Fatality Case Study

On August 22, 1979, seven seasonal employees (three females and four males; six of the individuals were only 16–17 years old) of the Ontario Ministry of Natural Resources (OMNR) were killed on a prescribed fire (PB–3/79) that took place in logging slash near the community of Geraldton in north-central Ontario, Canada. An OMNR fire technician was also severely burned.

An accident is generally regarded as occuring when existing or known safety precautions haven't been followed (Whitlock and Wolf 2005). The chain of events leading to a disaster, on the other hand, is more ambiguous and less easily reconstructed. In its simplest form, a disaster occurs when the precautions that had previously been thought to be satisfactorily adequate turn out to be inadequate. A disaster nearly always catches an organization by surprise.

Fire managers in the United States have used British sociologist Barry Turner's manmade disaster model to analyze prescribed-fire fatalities, including the Geraldton PB–3/79 incident (Mutch 1982). Turner's (1976) six stages to a disaster applied to prescribed fire are as follows:

High-intensity fire behavior associated with the Geraldton PB–3/79 prescribed fire in north-central Ontario on the afternoon of August 22, 1979. Photo: McCormack and others (1979).

- **Stage I—Predisaster Starting Point:** The social, political, and environmental framework in which the prescribed-burn organization is working help set up the disaster.
- **Stage II—Incubation Period:** For a period of time, often years, small mistakes occurring in the prescribed-fire work environment become large and dangerous.
- **Stage III—Precipitating Undesirable Event:** Small mistakes accumulate during the incubation period until a major collapse occurs. In prescribed-burn operations, a "precipitating undesirable event" is often an escaped fire.
- **Stage IV—Onset:** The prescribed burn escapes and causes major damage to property and/or human life.
- **Stage V—Suppression, Rescue, and Salvage:** Control of the escaped prescribed fire begins, with primary emphasis on protecting human life and property. Towns might be evacuated and structural firefighters suppress house fires.
- **Stage VI—Full Cultural Readjustment:** After the escaped prescribed fire, new procedures and policies to prevent future escapes are adopted. If fatalities have occurred, it takes time for the burn crew and the community surrounding the escaped fire to come to terms with what has happened. Often, this is a period of grieving and healing, and it can take decades to complete.

Of the six stages of a disaster, the incubation stage is the most interesting for prescribed-fire managers. During this stage, which may go on for years, small "discrepant events" begin taking place in the prescribed-burn work environment, and they go largely unnoticed by fire personnel. Small errors are seen as normal. When these events accumulate to a critical level, an "undesirable event" (such as a major prescribed fire escape) can occur. It causes a major cultural shift in the way an organization completes future prescribed burns.

Aerial view of the Esnagami memorial near the fatality site honoring the seven individuals associated with the Geraldton PB–3/79 prescribed fire. Photos: Terry Popowich, Ontario Ministry of Natural Resources, Dryden, Ontario, 2004.

Based on the board of review report for the Geraldton PB–3/79 prescribed fire incident (McCormack and others 1979), Mutch (1982) suggested that the associated fatalities constituted a "disaster" in Turner's terminology. Mutch (1982) described five major factors that might have played a role in the incident, including target accomplishment, haste, overconfidence, span of control, and deviation from plans. For more information on Turner's disaster model, see Turner and Pidgeon (1997).*

* Terry Popowich (2005) indicates that the OMNR "has taken many different visitors to the site of the Geraldton PB-3-79 incident in recent years to discuss and understand the true tragedy and how lapses in standard operating procedures will cascade and exponentially bring safety to the brink, and then of course fatalities." At the time of the incident, Popowich was a senior fire technician in the Geraldton District and the fire duty officer on the day of the PB-3-79 burning operation.

of items that might lead to things going wrong on a prescribed fire. For example:

- Burning aluma-gel from helitorch operations splashing on hunters within the ignition zone of a landscape-scale prescribed fire;
- Continuing to use the excuse of an "unexplained" wind event as the primary cause of prescribed fires escaping;
- A burn boss covering up his lack of experience because of pride;
- Unrealistic burning targets placed on field organizations; or
- Allowing the prescribed-fire plan to become so thick that it is nearly useless as a field guide to its execution.

It is interesting to note that even technological advances in prescribed fire have been a "double-edged sword" when it comes to safety. Take, for example, ignition devices. A vehicle-mounted terra torch requires far more vigilance that a conventional handheld drip torch (Bradshaw and Tour 1993). The introduction of the aerial drip torch or helitorch, originally conceived by Muraro (1976), has certainly increased the prescribed fire manager's firing capability (McRae 1997). Safety one was of the prime considerations in developing the helitorch, because it eliminated the need to expose ground personnel to hazardous situations such as steep terrain and/or heavy fuel concentrations (Muraro 1977). However, as noted above and elsewhere (Mutch 1985; Thomas 1998), the helitorch has also introduced a whole new set of safety problems and concerns.

Prescribed Fire Economics

Under the impetus of the Healthy Forests Initiative and the National Fire Plan, Federal natural resource management agencies have been given annual fuel management work goals to treat from 2 to 3 million acres (0.8–1.2 million ha) of Federal land per year. These annual acreage treatment targets are expected to grow.

Near the wildland/urban interface (WUI), some prescribed burning will be undertaken but machine work (e.g., thinning, chipping, or dozer-piling) will continue to be the standard method of fuel treatment. WUI treatments will generally have higher costs (Berry and Hesseln 2004). Outside the WUI, prescribed fire will be the most common method used to treat large fire-prone landscapes. Generally speaking, on a per-acre basis, prescribed fire is less expensive than machine work (Gonzalez-Caban 1997). In the Western United States, for example, average per-acre cost for prescribed fires ranges from $25 to 125 ($62–309/ha), whereas for machine work it reaches about $450 ($1,112/ha), with some areas reporting costs as high as $2,700 per acre ($6,669/ha).

Although additional research is needed (Hesslen 2000), fire managers must hone their skills to efficiently and economically accomplish ever-increasing restoration/fire hazard abatement targets. They must constantly strive to become more professional at regularly igniting, holding, and monitoring prescribed fires.

Parting Thoughts

Deep collaboration at the community level is absolutely essential to a successful prescribed-burning program. Collaboration is sometimes humorously referred to as the "C" word, because it is now used so often that its original meaning of working together to solve common natural resource problems has been lost. Prescribed-fire managers often blame regulatory constraints, such as those associated with smoke management, for not allowing them to prescribe-burn more land. We believe that the biggest obstacle (and challenge) for the future will be to effectively communicate to our local constituencies the risk and long-term consequences of *not* burning an area. There is no shortage of difficult fuel situations to tackle (Leuschen and others 2000). That said, we must also be realistic about the limitations of using prescribed fire for fire hazard reduction (see the sidebar on page 16). Prescribed burning is not a substitute for effective fire suppression (Brackebusch 1973).

We can neither take all of the risk out of prescribed burning nor eliminate the smoke, for risk is inherent in the very nature of the burning job and, unfortunately, smoke is a byproduct of the activity. What we can do, however, is become better at cooperating with our local communities and understanding the social dimension of prescribed burning while constantly working to collaboratively design risk scenarios that are supported or at least understood by our stakeholders (Brunson and Evans 2005; Loomis and others 2001; Schindler and Toman 2003; Wade 1993; Weisshaupt and others 2005; Winter and others 2002, 2004). Successful prescribed burning programs generally have few conflicting resource values, strong public education programs, and/or the support of the communities with close ties to and an understanding of the land (Taylor 1997).

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Effectiveness of Prescribed Burning on Fire Hazard Reduction*

Wildfire hazard abatement is one of the major reasons to use prescribed burning. Computer simulation, case studies, and analysis of the fire regime in the presence of active prescribed burning programs in forest and shrubland generally indicate that this fuel management tool facilitates fire suppression efforts by reducing the intensity, size, and damage of wildfires. However, the conclusions that can be drawn from the above approaches are limited, highlighting the need for more properly designed experiments addressing this question. Fuel accumulation rate frequently limits prescribed fire effectiveness to a short post-treatment period (2-4 years). Optimisation of the spatial pattern of fire application is critical but has been poorly addressed in research, and practical application management guidelines are lacking to initiate this. Furthermore, adequate treatment efforts in terms of fire protection are constrained by operational, social, and ecological issues. The best results of prescribed fire application were likely to be attained in heterogeneous landscapes and in climates where the likelihood of extreme weather conditions is low. Conclusive statements concerning the hazard-reduction potential of prescribed fire are not easily generalized, and will ultimately depend on the overall efficiency of the fire management process.

* Quoted from Fernandes and Botelho (2003).

The reality is that individuals involved in prescribed burning are exposed to the same natural and manmade hazards as those involved in fire suppression operations.

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PRESCRIBED BURNING IN THE FLORIDA FLATWOODS*

C.A. Bickford and L.S. Newcomb

Fire protection has changed many open longleaf pine forests into more dense forests dominated by slash pine—and with higher fuel hazards.

This discussion of prescribed burning is based on experience and studies of the use of fire as a tool in the elimination of hazardous fuels in the longleaf pine–slash pine forests of the flatwoods section of Georgia and Florida. It does not cover other uses of fire in the silvicultural control of diseases in pure longleaf pine and other southern forest types. Most of the practices described will, however, be found applicable to other types of prescribed burning.

By definition, prescribed burning is a distinctly technical measure and a potentially dangerous tool. Mr. Arthur W. Hartman, Chief of Fire Control in the Southern Region, sounds a note of caution when he says this employment of burning is "the application of fire to land under such conditions of weather, soil moisture, time of day, and other factors as presumably will result in the intensity of heat and spread required to accomplish specific silvicultural, wildlife, grazing, or fire hazard reduction purposes." Consequently, fires set for any other purposes or set without expert knowledge of fire behavior under existing conditions of weather, soil moisture, time of day, probable wind, etc., are definitely to be avoided. Uninformed and misguided efforts to burn are almost certain to produce disastrous results.

Hazardous Fuel Buildups

Successful fire protection in the longleaf pine–slash pine forests of the southeastern flatwoods markedly changes the composition of the stand. Under protection, slash pine, instead of remaining confined to ponds and swamp margins, reproduces vigorously and invades drier sites formerly occupied almost exclusively by open stands of longleaf pine. The stand is thus converted from nearly pure longleaf pine to one in which slash pine predominates. This change in composition is sought and welcomed by most owners and operators of forest land because of the rapid growth of slash pine and its high value for naval stores and other products.

Unfortunately, increase in fire hazard accompanies this beneficial conversion to slash pine. Under fire exclusion the grass roughs become heavy. Needles and twigs add to the inflamma-

Dense slash pine 15 years of age on the Osceola National Forest, FL. Note dead needles drapted over gallberry undergrowth and dead lower limbs. Wildfire in such a stand almost always results in a complete kill.

When this article was originally published in 1947, C.A. Bickford was a forester for the USDA Forest Service, Northeastern Forest Experiment Station; and L.S. Newcomb was a forester for the USDA Forest Service, Naval Stores Conservation Program.

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To decrease the threat of large fires in slash pine, many foresters and landowners have resorted to prescribed burning of accumulated fuels.

bility, while the gallberry and palmetto undergrowth increases in size and density. Conditions often become particularly hazardous in dense stands of slash pine 10 to 15 years of age, where dead needles may be draped over the high gallberry undergrowth and the lower dead branches in an almost continuous screen from the ground to the living crown 15 to 20 feet (5–6 m) above.

When a fire starts in stands unburned 10 or more years, it spreads rapidly and is hard to control. Such fires often cause extensive and severe damage and become so much of a threat to landowners that they give up the idea of growing timber on their land.

Managing Fuels

To decrease the threat of such fires, many foresters and landowners in this section have resorted to prescribed burning of accumulated fuels at intervals under carefully selected weather conditions. Slash pine about 6 feet (1.8 m) in height and longleaf over 1 year in age can stand slow-burning prescribed fires during the dormant season. Experience demonstrates that burns carefully planned and executed in this season may temporarily eliminate the hazard of accumulated fuels without serious injury to the timber stand.

Prescribed burning to reduce fire hazards affects fire prevention, detection, suppression, and other fire control activities. Its justification depends on reducing the total costs of fire control, in which incidental damage caused by the burning is considered an item of cost.

This paper describes methods of prescribed burning developed and used on the Osceola National Forest in northeast Florida, a tract of 168,000 acres (68,000 ha) typical of managed forests in the southeastern flatwoods. On this area, fuel accumulated in dangerous quantities for 15 years, during which time the presence of small slash pine throughout the forest made fire treatments impractical. As the slash pine began to reach a size where damage from slow-burning fire would be minor, trial burns were made. On the basis of these trials and other observations, plans were laid in 1943 to prescribe-burn approximately 100,000 acres (40,000 ha) of longleaf pine–slash pine in the following 3 years.

In the first year, 39,130 acres (15,835 ha) were treated at a cost of 7.9 cents per acre, of which 0.7 cent was for planning, 3.2 cents for preparations (chiefly plowing firelines), and 4.0 cents were direct costs of burning. Costs the second year for 33,100 acres (13,395 ha) were 6.6 cents per acre treated; planning 0.7 cent, plowing 3.7 cents, and direct cost 2.2 cents.

Damage from the first year's operations was estimated at 31.4 cents per acre treated, and in the second year at 8.7 cents. Because of general drought and few periods of ideal burning weather, the damages sustained during the first year were greater than anticipated. Damages during the second year were reduced somewhat by the added skill and experience of the men conducting the work, but primarily by the more favorable ground water and weather conditions prevailing. By treating a maximum area during good burning years and a minimum during unfavorable years, future damage should be held to 8 cents per acre or less.

Forest managers throughout the South, who, after careful analysis, determine that the use of fire for some specific purpose is desirable, will find the methods used on the Osceola National Forest helpful in planning and organizing their prescribed burning.

Methods Used

Prescribed burning, to give maximum benefits at the least cost and damage, involves the following steps: analysis, planning, preparation, burning, and appraisal. Each step is important and necessary.

Analysis. To arrive at a satisfactory decision whether to use fire, an analysis of forest conditions must be made, permitting a sound comparison between the probable costs and damage and the expected benefits. Direct costs can be satisfactorily determined from data such as those given above and from similar operations in the same forest type.

In the flatwoods, benefits are mainly in the reduction of hazards and the consequent reduction in the possibility of large and destructive fires. Damage will depend to some extent on the weather during the burning season, but most of all on the training, skill, and experience of the personnel. Although prescribed burning in this section will be most important to fire protection, its influence on grazing, silviculture, logging, game, turpentining, and other forms of land use must be carefully considered. The advantages and disadvantages of the practice vary widely from property to property, and no simple and precise method of evaluation can be suggested. The practice should be undertaken, however, only after a careful analysis has convinced the owner of the need or desirability of the practice on all or part of his holdings.

After analyzing a property and decided to burn, the owner must determine which areas to treat. Areas burned should ordinarily be distributed so as to serve as temporary firebreaks. Prescribed burning of areas of high fire incidence is a double gain, for the areas not only become safe themselves but also act as firebreaks. The detailed location of burning units should be decided only after field examination, as described in the following section.

Planning. The prescription or plan is a most important phase of prescribed burning, distinguishing it from the unorganized and often destructive use of fire. The prescription is prepared in the field at the time of examination. It specifies when and how to spread fire to achieve the greatest benefit.

The first step in planning is to make a field examination to secure the necessary data. On the Osceola National Forest, experienced and responsible forest guards made the examinations under the direction of the district ranger. In planning the use of fire in extensive areas, maps are prepared to show natural fire barriers, fireline locations, burning direction, areas to be excluded, usable roads and trails, and other useful information. The examiners on the Osceola used aerial photographs for base maps on which to record such information. On small properties, detailed examination and mapping may be unnecessary.

Slash pines gradually seeding in a former longleaf pine "ridge" on the Osceola National Forest, FL. Such stands cannot be treated successfully under prescribed burning because of excessive mortality in the crop trees below 6 feet (1.8 m) in height.

Forest managers throughout the South will find the methods used on the Osceola National Forest helpful in planning and organizing their prescribed burning.

The size, abundance, and distribution of crop trees* determine where and how fire can be used. Small slash pine is easily fire-killed, and extensive areas of slash pine crop trees less than 6 feet (1.8 m) high should not be burned. When the crop trees are slash pine 1 to 3 inches (2.5–7.5 cm) in diameter at breast height, or longleaf pine from 1 to 3 inches (2.5–7.5 cm) in diameter at breast height, a backfire—that is, fire set to spread only against the wind—in the dormant season under proper weather conditions may be safely used.

With crop trees 4 inches (10.2 cm) in diameter at breast height, or more, a flankfire is safe. A flankfire—set to burn at right angles to the wind—spreads faster and burns hotter than a backfire. Flankfires in such stands are cheaper to use and generally cause less damage than backfires. In the Florida/Georgia flatwoods, where young slash pine is common, a backfire is the usual prescription. On the Osceola, many stands otherwise suited for a flankfire contain scattered groups of slash pine crop trees 1 to 3 inches (2.5–7.5 cm) in diameter at breast height, usually making it necessary to prescribe a backfire.

Small patches of slash pine crop trees less than 6 feet (1.8 m) high are often found in stands otherwise suited for burning. Whether to burn them with the rest of the stand or plow around them and exclude fire

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* In this work, the best trees at an average spacing of 10 feet (3 m) were considered crop trees, and smaller intermediate or suppressed trees were disregarded in planning the burning and in evaluating the results.

depends on the size of the patch, the number of small slash pine crop trees it contains, and its nearness to the firelines needed to burn the rest of the stand. Table 1 shows the smallest size patch found worth excluding on the Osceola National Forest. Smaller areas were often excluded when only a slight change was needed in the location of a plowed line.

The prescription first specifies type of fire, for all other steps depend on it. It then recommends preparatory work, mainly plowed lines to control the spread of the fire. Exterior barriers must be provided for all burning units; roads and streams should be used where possible to reduce plowing cost. A flankfire requires interior parallel lines about one-half mile (0.8 km) apart to avoid too long a flank. A backfire requires a similar series of parallel lines close enough together that the area between them will burn out in the burning period. A backfire spreads about 1 foot (0.3 m) per minute, and so 600 feet (180 m) is the maximum distance between such lines unless more than 8 to 10 hours of burning are planned. Since northerly winds are least variable, these interior lines are usually plowed in an east/west direction.

For most purposes, the season for using fire is the late fall and winter after the first frost (about November 15) and before the beginning of needle growth in the spring. Prescribed burning should be completed before the start of the spring fire season, about March 1. It is desirable to burn as much as possible in wet years when the ponds are full of water. Day burning is easy to supervise and to do correctly, but night burning is necessary when minimum fire intensity is required.

> Any decision to use fire should be based on a sound comparison between the probable costs and damage and the expected benefits.

Plan to burn only when constant wind direction is forecast. As wind shifts and breakovers are the greatest source of damage, good burning conditions are found when there is a 3- to 10-mile (4.8–16 km) northerly wind in clear weather immediately after rain. Wind direction is commonly variable in the unsettled weather previous to rainfall. Wind shifts are also likely around noon and sunset. On the Osceola, the northerly winds that prevailed 1 to 3 days after rains were the most reliable.

The prescription should also cover the size of crew and equipment needed. Motor equipment is used mainly to plow lines and to transport men and tools. Spreading and mop-up tools are needed for the burning job, and ample fire suppression tools should be available in case of breakovers.

Table 1—*Patch sizes worth excluding from prescribed burning.*

	Number of slash pine crop trees under 6 feet (1.8 m) tall	
Maximum area to exclude	**per acre**	**per hectare**
6 acres (2.4 ha)	50	124
5 acres (2 ha)	70	173
4 acres (1.6 ha)	95	235
3 acres (1.2 ha)	135	333

Crew size is influenced principally by considerations of cost and safety. It is seldom safe to attempt prescribed burning with fewer than 3 men. Reasonable cost in relation to benefits requires that at least 10 acres (4 ha) be treated per man-hour; thus, a crew of five, including the leader, should treat at least 400 acres (160 ha) in an 8-hour day. Such a crew on the Osceola National Forest burned 500 to 1,000 acres (200–400 ha) per day—12.5 to 25 acres (5–10 ha) per man-hour—setting as much as 10 miles (16 km) of backfire and providing the needed mop-up and patrol. This crew was large enough to vary duties to meet particular fuel and weather conditions.

At night, with no patrol, smaller crews may be superior, while if mop-up is needed, it is better to have extra men than to take some away from the work of spreading fire. Continuous day and night burning can be used, if relief crews are available, to lower costs under exceptionally favorable conditions of weather, fuel, and stand. Good prescribed burning requires that crews be relieved after 8 hours of work.

All preliminaries and plans for burning should be completed by early fall to eliminate haste and consequent poor results.

Preparation. Preparation for burning consists mainly in plowing the lines provided for in the plan.

Enough lines are plowed in advance to permit choosing one of several units on the burning day; yet, to prevent fallen needles and leaves from weakening the lines, plowing ordinarily should precede burning by not more than two weeks.

Lines should be carefully located to minimize breakovers from hazardous fuels such as snags and thickets of gallberry. A two-disk plow, drawn by a light tractor, will prepare a line about 6 feet wide (2 m) at a cost of about $3.25 per mile. With several hundred miles of line to plow, such equipment is indispensable. Plowing and burning in one operation is inefficient, since a line can be fired three times as fast as it can be plowed.

Burning crews should be selected and trained well before the start of operations. The plow operator needs to know how to read maps and aerial photographs and where lines should be located as well as how to operate and service his plow and tractor. Crewmen must be taught how to fire in relation to plowed line and hazardous fuels. Mop-up standards, changes to meet wind shifts, provisions in emergencies, etc., should be clearly understood by all. This training should be continued as long as necessary after burning starts. The continuity afforded by having the crew foreman examine, map, plan, and plow is desirable but seldom possible.

Reliable weather forecasts improve the quality of burning, and arrangements should be made to receive daily forecasts of wind direction and velocity, relative humidity, precipitation, and general state of the weather. Forecasts twice daily at 12-hour periods are best; the first should be received by 8 a.m., before departure of the work crews, and the second before the usual quitting time.

Burning. Each day during the burning season, the manager, guided by weather forecasts and experience, decides whether or not to burn and selects the best unit for conditions expected. With favorable weather, low costs are achieved by spreading fire rapidly to increase area burned per man-hour.

> The prescription or plan is a most important phase of prescribed burning, distinguishing it from the unorganized and often destructive use of fire.

To complete the burning job, the area should be mopped up to prevent breakovers. The extent of mop-up will depend on the amount of dangerous fuels and on weather conditions.

Appraisal. Appraisal following burning may consist simply of field checks, or it may be a careful evaluation of both injury and benefits for the whole area. When crowns are not scorched above half their height, damage is minor: a few small trees are killed and growth on others is slightly reduced for a year or two. Scorching more than four-fifths of the crown results in excessive mortality and a sharp temporary reduction in growth rate of the survivors.

Recommendations

Prescribed burning methods used on the Osceola National Forest have been briefly described; the most important suggestions follow:

1. Use fire only when analysis reveals benefits should clearly exceed cost and damage.
2. Correlate prescribed burning with silviculture, grazing, game, crops, logging, turpentining, etc.
3. Prepare in advance (examine, map, plan, plow, etc.) so as to be ready when burning conditions are right.
4. Arrange for weather forecasts, especially of wind direction. A steady wind during the 8 to 10 hours required to burn a unit is of first importance in minimizing cost and damage; burn only when a constant direction is forecast for at least 12 hours.
5. Reduce costs when burning conditions are especially favorable by (1) spreading backfire rapidly to have 10 miles or more (16+ km) burning at one time, and (2) using relief crews to take full advantage of favorable burning weather.
6. A competent crew is essential; it should be small and composed of reliable local men experienced in fire behavior and control.
7. The forester, to achieve efficient and successful prescribed burning, must use intelligence, courage, patience, and determination. ■

VEGETATION TEMPERATURE AND FIRE DAMAGE IN THE SOUTHERN PINES*

George M. Byram

It has long been known that pine stands in the South are more severely damaged by late spring or summer fires than by winter fires. The usual explanation is that a stand is most susceptible to fire injury during the growing season, or that dormant trees during the winter season are least susceptible. It is also thought that summer fires are hotter than winter fires.

Summer fires probably do have a somewhat higher intensity than winter fires. It is also likely that pines may be slightly more susceptible to injury during certain periods of the growing season. However, a theoretical analysis of the factors contributing to fire damage has shown that other factors may be considerably more important than the two just mentioned. The details of the analysis are outside the scope of this discussion, which will concern the results of the analysis rather than the technical aspects of its development.

Lethal Temperature

The lethal temperature for plant tissue is in the neighborhood of 140 °F (60 °C). It may be assumed that the buds, needles, and branch endings of a pine will die if heated to a temperature exceeding 140 °F (60 °C). An analysis of the lethal effects of fire, therefore, reduces to an analysis of those factors which directly or indirectly affect the temperature of the susceptible parts of a tree.

Of these, the initial vegetation temperature may be one of the most important. The temperature of the foliage of a pine in bright sunlight may exceed 105 °F (40.5 °C). Therefore, an increase of only 35 °F (19.4 °C) would be required to reach the lethal temperature, and the absorption of a relatively small amount of heat by the foliage would accomplish this.

On the other hand, the foliage temperature might be only 35 °F (2.7 °C) or 40 °F (4.4 °C) during a cold period in winter. Under these conditions, considerable heat would be required to raise the temperature up to the lethal value of 140 °F (60 °C). A fairly intense fire during cold winter weather might therefore do no more damage than a low-intensity fire in hot summer weather. The same comparison might be made between hot and cold spells both occurring in the winter, or both occurring in the spring.

Theoretical curves in figure 1 show the relative fire intensities that longleaf, slash, and loblolly pine should tolerate at different temperatures. At a temperature just above freezing, any one of these pines should tolerate a fire more

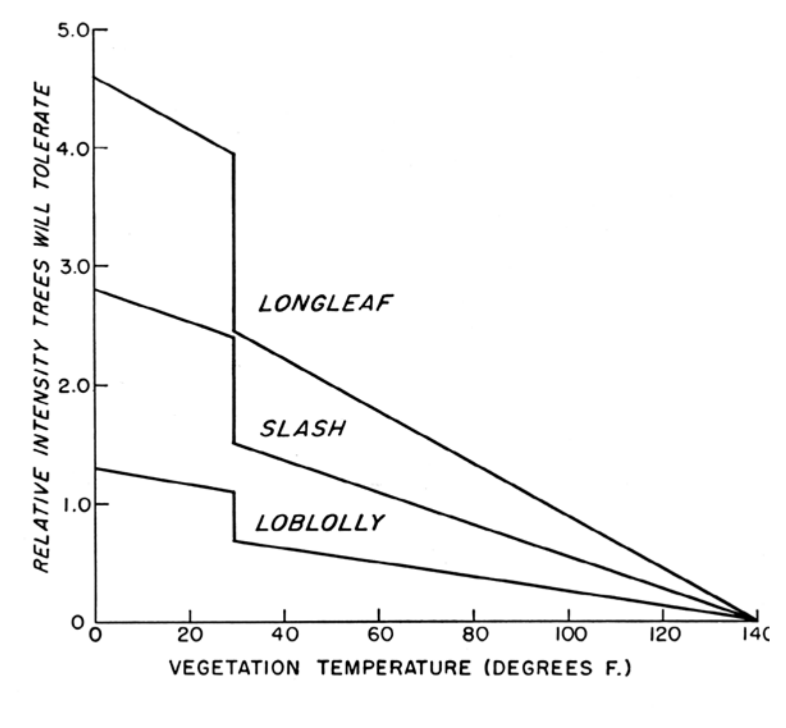

Figure 1—*The theoretical relation between vegetation temperature and a tree's heat tolerance. Heights of these curves represent the relative fire intensity that slash, longleaf, and loblolly pine will tolerate at different vegetation temperatures. The three species of trees are assumed to be of the same size.*

When this article was originally published in 1948, George Byram was a physicist for the USDA Forest Service, Fire Research, Southeastern Forest Experiment Station.

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than twice as intense as it would on a warm day when the vegetation temperature is 95 °F (35 °C).

One of the most noticeable features about the curves is the sudden increase in a pine's heat tolerance at temperatures below 29 °F (1.7 °C). At this temperature, since most of the water in the needles and buds would be frozen, large quantities of heat would be required to convert the ice back to water. At a temperature of 29 °F (1.7 °C), pine foliage should tolerate a fire about four times as intense as at a temperature of 95 °F (35 °C). Some field men have noticed that cold-weather fires have resulted in much less damage than might be expected.

Curves for hardwoods should be very similar to those for pine, except that their heat tolerance would be lower. In stands managed for the perpetuation of pine, hardwood sprouts could probably be girdled most effectively by burning in hot, sunny weather.

Morphological Factor

Another important factor associated with temperature changes in the crown of a tree concern the morphological characteristics or "geometry" of the needles, buds, and branch endings. The rate of temperature rise in these susceptible parts is inversely proportional to their size. When they are massive and heavy, they will not reach as high a temperature as when they are thin and light.

This may explain why suppressed trees, the susceptible parts of which are dwarfed and of small volume, are more easily killed by fire than vigorous trees of the same size. It may also explain why longleaf pine is less susceptible to fire than other species of pine. Also, the terminal buds of longleaf are surrounded by a protective sheaf of needles that retards a temperature rise in the bud.

Table 1 shows the diameter of the terminal buds on longleaf, slash, and loblolly pine. Susceptibility ratings are given in the third column. These ratings are found by taking the reciprocals of the values in the bud diameter column.

The relative positions of the three curves in figure 1 were determined by the diameters of the terminal buds in the three species.

Table 1—*Terminal bud diameter and fire susceptibility for three species of pine.*

Species	Bud diameter	Fire susceptibility
Longleaf pine	0.46 inches (1.16 cm)	0.88
Slash pine	0.28 inches (0.72 cm)	1.39
Loblolly pine	0.13 inches (0.33 cm)	3.00

Wind Factor

Wind is another important factor affecting the temperature of vegetation exposed to radiant heat. Wind has a conductive cooling action on buds and needles, which reduces the rate of temperature rise. Men who have done much work with prescribed burning usually consider wind the most important factor in the amount of scorch they are likely to get. Unlike temperature, many of the effects of wind can be readily observed. A sudden shift in the wind can convert a low-intensity backfire into a high-intensity headfire in a few minutes.

Some of the effects of wind are not yet well understood. It is known that scorching is severe when a fire burns in calm air. In this case, lack of turbulence permits the hot gases to pass straight upward in a more or less streamline flow.

However, recent thermocouple measurements indicate that there may be additional reasons for the scorching in calm air. When a line of fire passes under a tree, the foliage is subjected to two peaks of intensity. One peak is the result of radiant energy from the approaching fireline; the other is caused by convective heat from the burning gases. For a backfire, the peak for radiant heat comes first, and for a headfire the peaks occur in reverse order. In calm air they occur simultaneously.

Interrelated Effects

It is difficult to compare the relative importance of wind and temperature because their effects are interrelated. In a headfire, wind increases the fire intensity by speeding up the combustion process. This is partially offset by turbulence, which retards the upward flow of heat. In addition, wind exerts a conductive cooling effect on buds and needles.

Basic studies are now in progress on the Francis Marion National Forest to obtain experimental checks on the results of the theoretical work discussed in this paper. In addition, these studies should yield information for determining the proper place of fire in the management and protection of loblolly pine. This information should also be applicable in large part to other species of pine, such as slash, longleaf, and possibly even shortleaf. ■

BROADCAST SLASH BURNING AFTER A RAIN*

Robert Aufderheide and William G. Morris

Original editor's note: Slash burning after clearcutting in the Douglas-fir region has been previously discussed in pamphlets published by the Oregon State Board of Forestry, Washington Forest Fire Association, West Coast Lumbermen's Association, Western Forestry and Conservation Association, and the United States Forest Service and in several trade journal articles. The authors claim no originality for the material in the following article but believe the points discussed are worth reconsideration. Some of the suggestions will probably be new to readers who have not closely studied the methods of slash burning used in different parts of the Douglas-fir region. The origin and adoption of the policy to burn slash as soon as it becomes inflammable during the clearing weather immediately after a rain instead of waiting until just before the next rain is expected has not yet been definitely dated. The State Forester of Oregon states that his organization has followed it in the Douglas-fir region for a number of years. Several of the national forests in the Douglas-fir region have followed this policy in recent years.

Broadcast burning of slash in the Douglas-fir region is often done just before an expected heavy fall rain. If the rain occurs in sufficient quantity at the right time, no work is necessary to confine the fire to the slash area. If the expected rain does not occur, it is often difficult to confine the fire to the slash area. Furthermore, burning just before a rain is open to other criticisms. In contrast, recent experience shows that burning after a rain, as soon as slash is dry enough, has several advantages.

Burning after a fall rain should not be attempted until about 3 inches of rain have occurred.

The forestry objectives in burning slash are:

- To remove flashy small material in which dry-weather fires spread with such speed and heat that they can seldom be controlled inside of the slash area;
- To burn apart crossed and closely lying logs, separating them where great heat can be developed and thus make an accidental fire more intense and difficult to control;
- To check the growth of brush that sprouts from roots established before logging and competes with tree seedlings;
- To remove excessive debris that would prevent tree seeds from reaching a suitable seedbed; and
- To accomplish, as far as possible, the foregoing aims without scorching adjacent standing timber or causing undue heat injury to the soil and seed trees within the slash area.

Advance Planning

With such objectives, slash burning helps keep forest lands productive. It is not just a clean-up job to be done after the cutting under any conditions the operation may create; it is an important part of the cutting operation and, like other phases, should be efficiently coordinated. Plans for broadcast slash burning should be started long before the burning season. Some of the greatest difficulties and risks can often be eliminated if the slash-burning job is carefully considered in the cutting plans.

Good planning will avoid the following difficulties and risks:

1. Slash areas too big to be burned in 1 or 2 days by firing successive narrow strips along the contours, beginning at the top of the slash area. A slash fire that runs unchecked a long distance up a slope usually creates excessive heat. (Staggered settings of 80 acres (32 ha) or less facilitate slash burning, especially when periods of good burning weather are short.)

When this article was originally published in 1949, Robert Aufderheide and William Morris were foresters for the USDA Forest Service, Pacific Northwest Forest and Range Experiment Station.

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A slash fire burning with moderate intensity when the ground is still moist from a preceding rain leaves unburned beneficial humus in the topsoil.

2. Equipment and logs situated alongside considerable slash with no firebreak to isolate them at the time of the first burning season.
3. Current slash joined with that of another owned.
4. Tops felled into the adjoining green timber.
5. No firebreaks, such as ridges, streams, rock outcroppings, or roads, around the slash.

Advance work should also include a detailed plan of the burning jobs, outlined on paper well ahead of the burning date. This should provide:

1. A description of the weather and fuel moisture conditions desired.
2. Desirable time of day to begin setting fires.
3. A sketch of the area showing topographic features, boundaries of the area to be burned, and the order in which different parts of the fire will be set if the prevailing wind direction for the locality occurs. An alternate order of setting for another wind direction may be desirable.
4. Number of men needed to do a good job, and their specific assignments.
5. Estimated length of time to set the fire and to patrol and mop it up.
6. Number of torches, amount of oil, and other firing equipment.
7. Placement of portable pumps and tank trucks for fire control use.
8. Hand tools and bulldozer (on the job) for emergency use.
9. Communication and arrangements for extra fire control help if needed.

Finally, two parts of the slash-burning job should be done, if possible, before the burning season. All snags inside the slash area and any outside but near the area boundary should be felled. A fire trail should be built along adjoining cut-over areas, certain open types of standing timber, and other critical edges.

> In selecting the best day, the dampness of the duff should be determined at several points by digging into the duff with the hands.

The decision on the need for advance firelines will depend largely upon the nature of slash, the topography, adjacent timber conditions, and availability of adequate manpower for mop-up. Bulldozer firelines, particularly on sidehills, have the disadvantage of mixing much dirt with the slash to be burned; this causes fire to smolder a long time on the edges of the slash area. If a bulldozer is used, the dirt and debris should be pushed away from the slash area to avoid a smoldering fire at the line.

Choosing the Slash Moisture Conditions for Burning

Since one objective of broadcast slash burning should be to avoid undue heat injury to the soil, seed trees, and adjacent timber, the soil should be moist in both the slash area and adjacent areas. Yet, to allow economical fire setting, the fine material should be dry enough to carry fire and be easily kindled. In the light of these requirements, fall burning just before an expected rain presents several disadvantages:

1. The soil, duff, and logs in the slash area will usually be dry. Such slash generally burns too intensely, and a hard burn is destructive to soil structure, soil humus content, and seed trees.
2. If the slash is very dry, the adjacent areas also will be dry. Under these conditions, numerous spot fires and breakaways can be expected; this increases the cost of control and causes loss of adjacent timber, equipment, or other values. Even though timbered areas may be fairly damp, the exposed edges for several hundred feet inward may be almost as dry as the slash area. Hemlock and spruce, which are particularly susceptible to fire damage, will die from the effects of a ground fire around their bases.

3. The timing and intensity of a rainstorm in a given small area are difficult to forecast.
4. Most storms are preceded by strong winds; this will increase the danger of breakaways and damage.
5. If the rain begins sooner than expected, there generally is an urge to fire the slash rapidly. When this happens, a hard burn is the usual result, and frequently uncut timber around the edges is scorched. Sometimes the slash quickly becomes too wet for the set fires to spread. Instead, they smolder and burn in the concentrations without completely dying out; real danger may occur later with a change to low humidities and increased wind velocities.
6. The expected rain may not occur. A serious fire problem may confront the burner in this situation, depending upon adjacent timber conditions and subsequent weather.

Trend Since 1942

Since about 1942 there has been a trend toward doing fall slash burning immediately after a rain. This method has definite advantages in avoiding heat injury and providing good conditions for burning:

1. As fast as the fine slash and surface of the coarse slash become dry after the rain, the slash is burned. Since the duff is still wet below the surface, it is completely burned only in the spots beneath logs or piles of hot burning fuels. In the remaining area, the fire destroys the light and flashy fuels but dies out before consuming the duff and humus in the soil.
2. The fine slash will dry out first while the fuels in the adjacent green timber are still wet. The wet duff and damp litter in the timber will lessen the danger from spotting and breakaways. In many instances when slash is burned under these conditions, advance firelines are unnecessary.
3. The first few clear days following the rain are usually calm and offer ideal conditions for controlling the burn.
4. The materials in which the fire spreads can be burned out before dangerous weather develops.
5. Under this method, it is possible to do the slow burning that does the least damage to forest soils, seed trees, and surrounding timber. More time is usually available for setting the fire in successive contour strips down the hill. This avoids a sweeping and excessively hot fire.
6. Where one person or one crew has responsibility for burning a number of slash areas, this system offers a longer period in which to do the job. In this way, experienced slash-burning personnel can cover more ground, and better burning results are probable.

When the weather begins to clear after a rain, slash in a clearcutting will become dry enough to burn while the litter in the green timber is still moist.

In any broadcast slash burning, good judgment in picking the right time to burn is essential to success. The decision on whether to burn early or late in the season will be determined by the general location of the slash area and the burning conditions in and adjacent to the slash area.

Wait Until 3 Inches of Rain

Burning after a fall rain should not be attempted until about 3 inches (8 cm) of rain have occurred. This will usually be after two or more storms. There should be reasonable certainty that timbered areas will not again dry out that year. Fall rains occur on varying dates and usually begin earlier in the northern part of the Douglas-fir region than in the southern. Coastal slopes also become wet earlier than inland areas. Good burning conditions ordinarily occur in inland areas between October 1 and 20, and along the coast between September 10 and October 1.

A large slash area adjacent to other highly inflammable areas is more dangerous to burn early in the fall than a small slash area surrounded by green timber. Where high-risk burning chances occur, it is advisable to burn late. However, good slash-burning results cannot be expected consistently on such chances regardless of the time of burning. By planning the logging operation well, however, many of the risks can usually be eliminated or minimized. The poor slash burning results obtained in most dangerous slash areas happen largely because management permits difficult situations to occur.

In stream bottoms and on north slopes on the coast fog belt, where dense brush grew before logging, slash should be burned fairly early in the season after the first fall rains occur and under fairly dry burning conditions. This is done to obtain the best possible regeneration of conifers. One purpose of such burning is temporarily to set back the brush in order to give natural regeneration or planted stock a chance to become established. The coastal brush is more of an obstacle to adequate natural reproduction than is commonly appreciated. Unless burned with sufficient heat to kill the tops and injure the root crowns, this brush springs up rapidly when exposed to full light following logging. It will then hold the area it occupies and exclude conifer seedlings.

The Day to Burn

It is advisable to burn as promptly as possible after the rain, as soon as the small materials and log surfaces have dried enough to ignite easily and while the lower duff layer in the slash and all fuels in adjacent timber are still damp. In selecting the best day, the dampness of the duff should be determined at several points in adjacent timber and in the area to be burned by digging into the duff with the hands. The inflammability of fine fuels can be estimated by the brittleness of twigs. A better method is to burn a small sample of fine slash. If the fire will not spread, burning should be discontinued until conditions improve. Best results are obtained when the fire spreads slowly and many sets are required to ignite the entire area.

Even though the relative humidity is low, the fire can be easily managed if the air is calm and the duff is moist. Successful, controlled, nondestructive slash fires have been observed burning under these conditions shortly after a rain when the relative humidity was only 25 percent.

Weather Bureau forecasts should be studied before burning and also after burning is under way. The Weather Bureau wishes to assist with slash-burning projects and is glad to provide fire weather forecasts.

Setting the Fires

In setting the fires, the most dangerous edges should be lit first, and a safety strip should be burned around areas to be left unburned. Topography and condition of the slash should be considered in the firing progression. In all cases, the uphill and leeward sides of the area should be fired first. It is best to proceed slowly at first, and edges should be well burned out before setting additional fires. Hot, destructive burning can result from setting off too much area at one time.

Once started, burning should be continued until all fuels within the slash area have been ignited, but burning should be discontinued whenever set fires will no longer spread. Smoldering fires scattered through a large area of unburned fuel are apt to produce an undesirably hot fire when burning conditions become more severe during the afternoon of the next day. To avoid this circumstance, it is also advisable to delay setting more fires until about noon the next day or until such a time as they will spread. Frequently, excellent results can be obtained by burning south slopes and dry exposures during the early part of the night, and north slopes, creek bottoms, and other damp areas during the heat of the next day.

Mop-Up

The importance of mop-up to continuing success of slash burning after a rain cannot be overemphasized. In burning immediately after a rain, dryer weather can be expected. After the slash fire has cooled, any live edges should be trailed and mopped up.

The proper time to do this mop-up is while weather and fuel conditions are still favorable for moderate burning. The objective should be to have the edges of the burned slash dead before dangerous weather conditions occur. If the slash has been properly burned under the right conditions, a clean burn will be obtained, and not much live edge will remain 24 to 36 hours after the slash has been fired. A clean burn properly mopped up will not spread fire even though the weather becomes dangerous.

Those who have tried this method for a number of years claim that the results are achieving the objectives of good slash burning with less trouble, loss, and expense than burning before an expected rain. ■

PRESCRIBED BURNING IN THE NORTHERN ROCKY MOUNTAINS*

Charles T. Coston

Prescribed burning got its start in the longleaf pine region of the South, where silviculturists discovered that controlled burning of the forest floor litter not only increased timber productivity, but also improved grazing and wildlife habitat, served as a fungus control measure, and reduced dangerous fuels.

Burning Objectives

Such fuel reduction is of major importance here in the Northern Rocky Mountains, where the dense stands of reproduction and fire-killed trees, steep slopes, and extremely dry fire seasons create optimum burning conditions. Fuel reduction is designed to rid the forest of areas containing dense, highly flammable fuels, and to increase the economic value of the land. Both suppression and presuppression costs are reduced by the resulting lower fire hazard.

Areas of dense fire-killed timber can produce only a scattering of green timber for the many years that nature is disposing of the dead trees, at most no more than 10,000 board feet (24 m^3) per 100 years. The same type of area, however, when prescribe-burned, can produce at least 20,000 board feet (48 m^3), and the best sites can increase volume production to as much as 40,000 or 50,000 board feet (94–118 m^3) per 100 years (Lyman 1945).

> Fuel reduction rids the forest of dense, highly flammable fuels and increases the economic value of the land.

Since the outbreak of the spruce bark beetle epidemic in Idaho and Montana in 1951, prescribed burning has been used very successfully as a means of destroying these insects (fig. 1). Areas of infested Engelmann spruce are usually clearcut, because the percentage of infestation runs very high, often to as much as 100 percent. The logging leaves a great deal of slash and tops as well as unmerchantable trees, all of which contain a large number of beetles. These areas are then broadcast burned, the result being the death of the beetles.

Planning a Burn

Generally speaking, the best time of year to prescribe-burn is in the fall. In the Northern Rockies, a moderate rain usually comes during early September, followed by a period of warm, dry weather. This is the time when most burning is done. No attempt to burn should be made when conditions are not good enough to assure a clean burn. A general guide for weather and fuel

Figure 1— *Broadcast burning of slash on a logged-over area infested by spruce bark beetles on the Lolo National Forest in Montana. Standing trees are western larch, a fire-resistant species, which will serve as a seed source to regenerate the area. Photo: USDA Forest Service.*

When this article was originally published in 1954, Charles Coston was a forestry aid for the USDA Forest Service, Lolo National Forest, and a student in the School of Forestry at Montana State University.

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The project chief must know the air currents created by fires, how to draw fires together, how to lead fires into different areas of the burn.

conditions needed to accomplish the desired type of burn is as follows:

1. Relative humidity 25 to 50 percent;
2. Wind 8 miles per hour (13 km/h) or less;
3. Fuel moisture 8 to 12 percent; and
4. Burning index 30 to 40.

Proper planning of a prescribed burning project is of vital importance. The area to be burned should be prepared well in advance of the planned date of burning. Then there should be a certain amount of leeway to allow the project manager to take advantage of weather conditions.

Preparing the Area

The preparation of an area usually consists of constructing firelines around the proposed burn, felling dangerous snags, and in some cases felling standing timber to assure fuel continuity. Arrangements for an adequate control force should be made. This will depend upon the characteristics of the area to be burned.

On moderate slopes, lines may be built most economically by bulldozer. On slopes up to 60 percent and in light fuels, the hand trencher may be used; but on steep slopes, lines must be built by hand.

All snags that are likely to throw spots should be felled within 200 to 300 feet (60–90 m) inside the line. All rotten and shaggy-barked snags near the outside of the line should also be felled. All dangerous snags should be felled in small areas and in long narrow areas.

Dozer piling along critical sectors and the burning of these piled areas well in advance of broadcast burning reduces risks.

Desirable Conditions

Lyman (1945) states that, "Experienced judgment is necessary to size up fuel conditions and to determine the most desirable flammability conditions to wait for. The most desirable condition for heavy fuel types is a calm, quiet afternoon with overcast skies and relative humidity between 20 and 34 percent. Fuel moistures of 6 to 9 percent are best, depending upon fuel type."

The Weather Bureau* can predict suitable weather for burning. Ideal conditions would be a period of calm weather followed by rain a day or two later. This would lessen the mop-up job, which is necessary on most burns.

Since wind is the most variable adverse condition that threatens the success of a prescribed burning project, it is the condition that should be watched most closely. In the Northern Rockies, morning winds are generally from the east, since the sun warms the east slopes first. Then the winds shift to the south and increase in velocity. During midmorning, upslope winds start with the rising of heated air from lower elevations. The upslope winds continue until late afternoon, when downslope winds start as a result of cold, heavy air draining back into the lower elevations. Highest wind velocities usually occur in midafternoon (Barrows 1951).

A knowledge of fire behavior is necessary in prescribed burning. The project chief must know the air currents created by fires, how to draw fires together, how to lead fires into different areas of the burn. He must know when to set fires in certain areas of the burn so that all of the fires will draw together and assure a good burn.

The element of timing cannot be overstressed. Proper timing of sets prevents spot fires, and it determines the effectiveness of the burn. This is the main reason that propane torches are preferred in firing. They are fast and dependable.

Methods of Burning

While the afternoon is generally the best time to burn, under certain conditions night burning is more advisable, especially when daytime burning hazards are very high and there is considerable danger of spotting. Night burning also enables one to take advantage of the downslope winds. The fire can be set along the upper edge of the burn, and the wind moves it downhill until the fire builds up its own updraft and reverses. Then another row of sets is made below the line of fire and the lower fire draws the upper fire down to it. Under certain conditions, fires may thus be led down a slope. This method is not considered to be the best, because there is considerable danger of losing on the uphill side as a result of lack of heat inside. Fires have a natural tendency to spread uphill.

A better method of firing on the slopes is to set a triangle of fire well inside the proposed burn and to allow heat to develop well downhill

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* Now the National Weather Service.

and inside. Then the fire can be worked in a point uphill to the line and led out to the line on all sides by progressive firing. Buffer strips can be used to ease fire up to the line. Care should be taken to fire right up alongside the line in progressive firing, and to set hot fires well inside to draw the fire away from the line.

On level ground, the circular method of burning can be used with a high degree of success. Hot fires are started in the center of the area to be burned, and they pull air in from all sides. Then fires are set around the outside of the circle and are drawn in to the center.

Control Force

The key to success in controlled burning lies in a competent control force. This enables the use of hot fires without the constant danger of their getting out of control. All the equipment deemed necessary should be on hand: tankers (fig. 2), dozers, and trenchers, anything that makes the burn safer. Of course, there is a financial limit. Therefore, it becomes necessary to use fires in such a manner as to never get more fire than the control force can handle.

In prescribed burning there can be no set guides to be used on any particular area during any season. Each region has its own topography, fuels, and weather, and each area within a region has fire-affecting peculiarities all its own. Before burning, therefore, each area must be studied carefully. Slope, wind, fuels, and any other factor that might possibly affect fire behavior must be carefully noted, and a detailed plan of action must be made to suit each specific proposed burn.

Fire has taken its place along with the other tools of the silviculturist, and it promises more uses and benefits as we become more familiar with its effects.


Figure 2—*A jeep tanker being tested prior to the broadcast burning of an area of lodgepole pine slash on the Deerlodge National Forest in Montana. Photo: USDA Forest Service.*

The key to success in controlled burning lies in a competent control force.

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THE CHRISTMAS EVE PRESCRIBED BURN*

Albert A. Thomas

It was the morning before Christmas. Santa Claus was loading up and the holly and mistletoe were being hung. Gifts were being wrapped, and the weather was just right for prescribed burning on the Escambia Experimental Forest. The south Alabama woods were damp, the north wind was swaying the tree tops, and the air temperature was near freezing.

This was the weather the Escambia foresters had wanted for nearly 2 months. Brown-spot needle disease had invaded several large areas of longleaf reproduction on the forest. The only practical way to save the infected seedlings was to prescribe-burn, and this was the day for the job. Seven years of study and experience went into the planning and application of the Christmas Eve burn (fig.1).

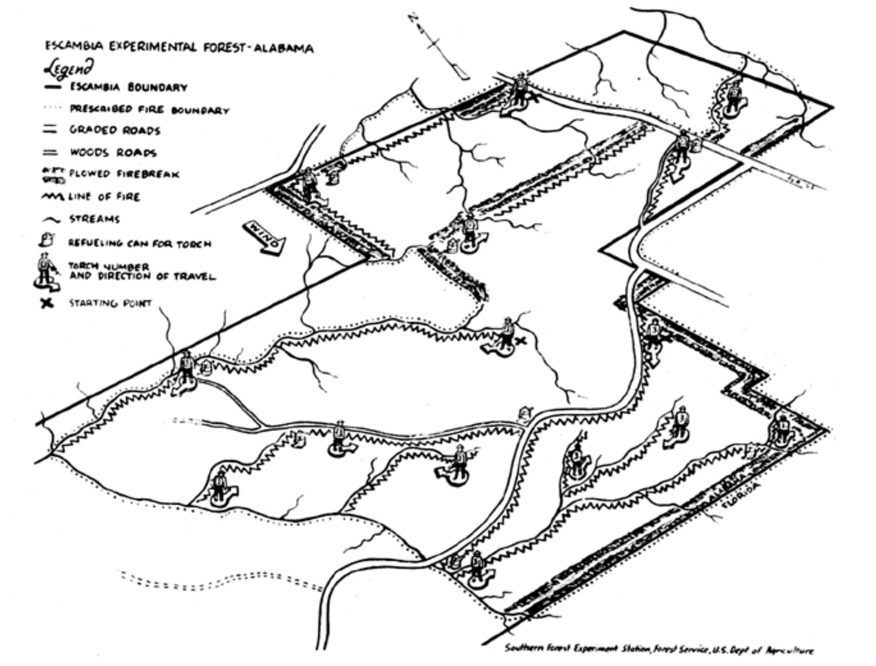

Figure 1— *In the Christmas Eve prescribed burn, nearly 1,400 acres (560 ha) of longleaf pine seedlings were rid of brown-spot disease at a cost of 6 cents an acre by 4 men working 4 hours.*

Prescribed burning is a calculated risk. The risk should be taken only after careful planning and preparation based on a thorough understanding of fire and fire behavior. The guiding principle for prescribed burning on the Escambia is the burning yardstick.

The yardstick is simple. Benefits from the fire must exceed all burning cost plus fire damages. Application is more complex. A five step procedure is used: diagnosis, prescription, preparation, treatment, and appraisal. When properly followed, this procedure removes most of the gamble, and fire becomes a useful tool in the longleaf forest.

> Benefits from a prescribed fire must exceed all burning cost plus fire damages.

Diagnosis

First, exactly what areas on the forest contained heavy brown-spot infection? What damages could be expected from the use of prescribed fire? To find out, a survey was made. After the first killing frost in early November, the percent of brown-spot infection was estimated on a minimum of 100 longleaf seedlings on each 10- to 40-acre (4–16-ha) reproduction area.

The survey showed several hundred acres of grass-stage long-leaf reproduction infected with brown-spot, with the degree of infection ranging from a low of 15 percent to a high of over 35 percent. Past experiments and experience have shown that areas with 25 percent or more infec-tion in November should be prescribe-burned during the coming winter. To prevent reinfection, the area surrounding the seedlings should also be burned where possible.

When this article was originally published in 1956, Albert Thomas was with the East Gulfcoast Research Center, Southern Forest Experiment Station.

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Longleaf seedlings can generally be burned safely if:

1. They are at least one-half inch (1.3 cm) in diameter at the root collar;
2. Very little root is exposed; and
3. The seedlings are not in active height growth.

The survey showed that if fire was applied properly, damage should be confined to a few scattered seedlings 1 to 5 feet (0.3–1.5 m) high that were already nearly dead from brown-spot.

The areas that needed burning were mapped. Then, to plan for control of the fire, information was obtained on the condition of rough, natural firebreaks, roads, and trails.

The diagnosis was that several large areas were dangerously infected. Fire was needed and could be applied without excessive damage.

Prescription

Next was to prescribe the fire treatment for each area—the kind of fire and the weather needed.

If the areas had had a heavy rough and lots of draped fuel, a backfire would have been prescribed. Heavy roughs with draped fuel burn very hot, and unnecessary overhead scorch to standing timber would occur if a headfire were used. The survey showed, however, that the areas contained a light rough—a small accumulation of pine straw and not much grass. A fast-running headfire would be safe and do a better job than a backfire.

Weather is the most important factor in prescribed burning.

Weather is the most important factor in prescribed burning. Cold weather and plenty of ground moisture are essential. This means burning in winter as soon as possible after 1 inch (2.5 cm) or more of rainfall. To get a fast-moving headfire, a moderate, cold north wind is needed—north wind because it is usually dependable and steady in south Alabama. To insure that all areas will be covered while ideal weather lasts, fires should be started by 10:00 a.m. and be completely underway by noon.

The prescription was a headfire on a day when ground moisture was plentiful and a moderate, steady, cold north wind was blowing. The fire was to be underway before noon and to cover the areas in a few hours.

Preparation

Successful burning can only be done after thorough preparations for applying and controlling the fire.

In delineating each area to burn, natural firebreaks such as roads and streams were used, wherever possible, to save firebreak construction. Nearby landowners were contacted. Letting neighbors know what's going on is always good public relations, and on the Christmas Eve Burn permission was needed to burn two areas into natural firebreaks outside the forest boundary. This saved more than a half mile (0.8 km) of firebreak construction and eliminated two heavily infected areas adjoining the forest.

Since the prescription called for headfire and a north wind, two lines about 100 feet (30 m) apart were plowed and burned on the south, east, and west boundaries to control the fire where natural firebreaks were not available. On the north side of the area, only a single plowed line was necessary.

Next was to be sure a head fire would be underway in all areas by noon of D-day, and that burning would be completed a few hours later. The map showed that one line of fire along the north boundary would have to travel more than a mile (1.6 km). This is too far. Experience has shown that one-half mile (0.8 km) is about the maximum for the time allowed in the prescription. Otherwise, the burn may not be completed before weather conditions change. Another east/west firing line was therefore put in. Natural firebreaks could be used to fire the rest of the area.

The benefits of several thousand dollars in brown-spot control far exceeded the burning cost plus the minor damages of the fire.

A total of 9 miles (14 km) of line had to be fired. One torch man would be able to fire about 3 miles (5 km) in the allotted 2 hours between 10:00 a.m. and noon. The line was roughly divided into 3-mile (5-km) sections and assigned to men designated as Torches 1, 2, and 3. Since 1-gallon (3.8-L) fire torches hold only enough fuel for about three-fourths of a mile (1.2 km) of line, refueling cans would be needed at intervals along the line. A small letter-size map was prepared to show each torch man:

1. The line to fire,
2. The direction of travel,
3. Locations of refueling cans, and
4. How to fire his part of the line.

A crew of three torch men and one man supervising and patrolling the burning area was required.

By early November, everything was ready except the most important item, the weather.

Treatment

It was the day before Christmas. Santa Claus was busy with his myriad preparations for his trip that night, but the weather was just what the doctor ordered for prescribed burning. There had been almost 3 inches (8 cm) of rainfall in the past 3 days. Air temperature was down to 29 °F (–1.6 °C). A cold front was overhead and a moderate, steady north wind was blowing. The Weather Bureau predicted that this condition would last for 10 to 12 hours.

Early morning telephone calls were made ordering the crew to get into their "burning" clothes. The Alabama and Florida forestry departments were notified to expect a big smoke starting at 10 o'clock. Torch fuel was distributed to the planned points along the burning lines.

At 9:30 a.m., the crew met on the forest. A small test fire was set, and then each torch man was briefed and given his map. At exactly 10 o'clock all three torches started firing. A few minutes after 12 noon, all torches were through and well over half of the area was burned. At 2 o'clock over 90 percent of the area was burned. By 3 o'clock, the crew, tired but satisfied, was back home helping Santa Claus.

Successful burning can only be done after thorough preparations for applying and controlling the fire.

Appraisal

What were the benefits? Longleaf experts agree that a heavy infection of brown-spot can ruin a stand of seedlings. The established seedlings treated by the Christmas Eve Burn were worth at least $4,000. It is doubtful that half of these would have survived and grown without the pre-scribed fire. At least $2,000 worth of seedlings were saved.

What was the cost? The whole job, including diagnosis, prescription, preparation, treatment, and appraisal, came to less than $100.

What were the damages? A seedling survey after the fire showed less than 1-percent loss in stocking—a value of not more than $50. Most of the lost seedlings were stunted and heavily infected with brown spot and probably would have died anyway. Their value was more than offset by many fringe benefits, such as hardwood brush control, seedbed preparation, hazard reduction, and a large area burned to prevent reinfection of the reproduction areas.

The burning yardstick showed that the benefits of several thousand dollars in brown-spot control far exceeded the burning cost plus the minor damages of the fire. ■

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PRESCRIBED BURNING TECHNIQUES IN LOBLOLLY AND LONGLEAF PINE ON THE FRANCIS MARION NATIONAL FOREST*

John T. Hills

The results obtained by the use of prescribed fire are determined largely by the recognition of existing conditions and by the skillful application of fire. Much has been learned through the extensive use of fire under a combination of various conditions and methods of application. If consideration is given to all factors influencing a fire, the results of a prescribed burn always come closer to what is wanted than would otherwise be the case. Some of these factors are season of year, amount of fuel, fuel moisture (upper and lower layer), temperature, wind direction and velocity, and days since one-half inch (1.3 cm) or more of rain.

Several cardinal points should be considered just before and during the use of fire:

1. Get the latest weather report,
2. Remember that a constant wind strong enough to direct the fire is necessary for control,
3. Begin burning on the downwind part of the area to be burned, and
4. Remember that fire is best kept under control by fire itself—offensive actions often eliminates defensive ones.

Through trial and error, several techniques in applying fire under a given set of conditions have proved successful on the Francis Marion National Forest in South Carolina.

Checkerboard or Spot Firing

The checkerboard technique is best suited for use in stands 20 years and older, medium rough (2 to 3 years), wind 3 to 5 miles per hour (5–8 km/h), and temperature around 60 °F (16 °C). After establishing a safe line of fire on the downwind side of the area to be burned, the method consists of setting a series of spot fires in checkerboard design parallel to the baseline. The distance between the spots and their size can be varied according to the factors at hand.

The advantages to be gained by using this method follow:

1. It is safe (as far as the use of fire goes). The fires compete for space and fuel, and before any damage can be done both have been consumed.
2. A clean and complete burn is assured.
3. A minimum amount of fireline construction is necessary.
4. The number of men to be used is not limited.
5. Large areas can be burned quickly—before weather conditions change.

Strip Burning

The method of burning in strips is very adaptable and can be used in all age classes large enough to be burned. It consists of setting a series of solid lines of fire parallel to the baseline. This technique can be used effectively to kill undesirable hardwood (summer or winter fire); reduce heavy rough (as soon after rain as rough will burn); and control brown-spot, where flames should reach needles 3 feet (1 m) or more from the ground.

The advantages are that the intensity of the fire can be controlled by varying the distance between lines of fire in proportion to the amount of fuel and the size and density of undesirable hardwoods to be killed. The advantages mentioned under the checkerboard technique are also obtained.

Flanking Fire

When the head of a wildfire is stopped, two flanking fires remain for a time. Fire fighters having experience in fire suppression in the Coastal Plain region probably have observed that such fires are very effective in killing undesirable hardwoods and removing heavy rough with little or no damage to the pine.

This flanking type can also be used in an area to be prescribe-burned by building the fire in the shape of a right triangle, the base of which is downwind. It is similar to a backing fire but burns much faster and cleaner.

Before selecting one of these plans of action, the land manager should consider the advantages of each method in relation to the results expected. ■

When this article was originally published in 1957, John Hill was a forester for the USDA Forest Service, Francis Marion National Forest.

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PRESCRIBED BURNING IN SHORTLEAF–LOBLOLLY PINE ON ROLLING UPLANDS IN EAST TEXAS*

E.R. Ferguson

Large test burns on rolling uplands in east Texas have proved quite variable and only moderately effective in controlling undesirable hardwood understory. This is in contrast to encouraging results achieved with prescribed fires on small plots in the same general type (Ferguson 1957). Runoff and surface soil movement on two diverse soils were little affected by these single fires.

The Study

Twelve fairly uniform units were established on the Neches District of the Davy Crockett National Forest. The units, averaging about 190 acres (80 ha) each, were in a shortleaf–loblolly pine sawlog stand with a medium to heavy brush–hardwood understory.

The units were paired according to similarity of topography, overstory, and understory. This provided six pairs of units, two of which were randomly assigned to each of three seasons of burn. One unit of each pair was randomly selected for burning and the other was left unburned as a check.

Ten sampling points were systematically located within each unit, and at each point one 1/10-acre (0.04-ha) plot and one 1/250-acre (0.0016-ha) plot were established. Stems on these plots were inventoried before and after the prescribed fires.

Burns were made in November 1952, March 1953, and April 1953. Burning on all units followed the same pattern. Lines were plowed and fire was set along the leeward boundaries, following which the flanks and finally the windward boundaries were fired. As time permitted, supplemental lines of fire were started through the interior of the units.

On selected units, burned and unburned, hydrological test areas were located on the prevailing soils, Boswell fine sandy loam and Lakeland fine sand. These were 4- by 20-foot (1-m × 6-m) runoff plots with metal borders, located on gentle (5 to 8 percent) and moderate (11 to 16 percent) slopes. They provided weekly records of surface runoff and a cumulative record of soil loss.

Results

The prescribed burns were only moderately successful in controlling the undesirable hardwoods (fig. 1). The number of stems 1/2 to 2 inches (1.3–5.1 cm) in diameter was reduced 1/3 to 1/2, but these reductions were largely offset by an increase in sprouts and

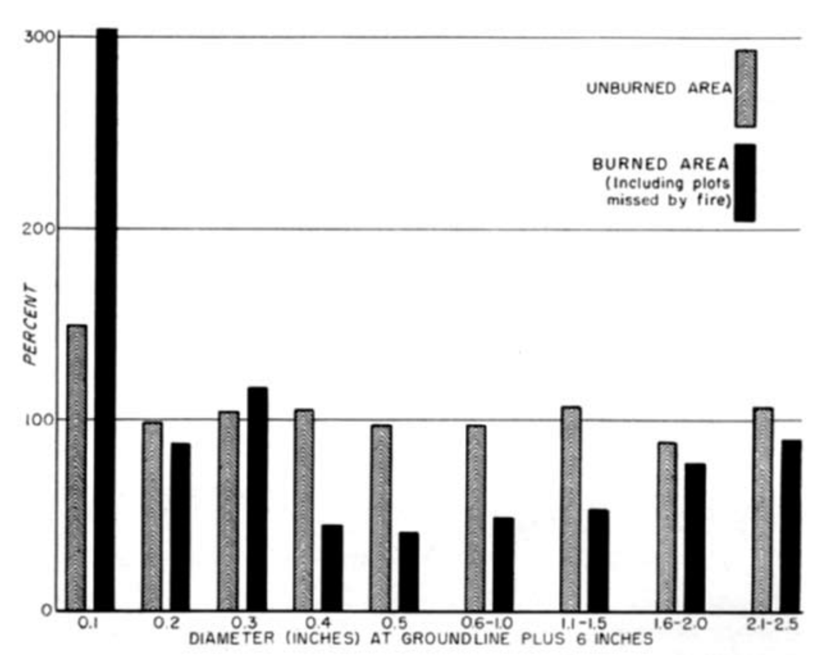

Figure 1—*Hardwood stems after treatment, shown as percent of number on plot before treatment.*

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root suckers. The result has been a moderate, but probably temporary, reduction in understory volume.

There were no differences in effectiveness between burns made in the three seasons tested. Failure to achieve greater reduction in small hardwoods was in part due to the light and variable nature of the prescribed burns. Only about 80 percent of the area within the burning units was actually burned, and less than half of that was covered by a medium or severe fire. On limited areas with severe burns, there was some loss of sawtimber pines. Such divergent results reflect the widely varied burning conditions that occur on extensive areas of rough terrain. To approach the effectiveness demonstrated on small plots, prescribed burning will require much closer control with resultant higher labor costs and equipment expense.

> The prescribed burns were only moderately successful in controlling the undesirable hardwoods.

> Runoff and surface soil movement on two diverse soils were little affected by these single fires.

The single fires of the study had little effect on surface water runoff and soil movement from the hydrologic test plots. On the Lakeland fine sand, the prescribed burns had too little effect on infiltration rate to be reflected in runoff. On the Boswell fine sandy loam, burning appeared to increase runoff slightly. There was little difference in runoff on slopes ranging from 5 to 13 percent.

Soil loss was light on all plots (table 1) and safely below the maximum erosion rate permissible on watershed lands.

The possibility that more severe or repeated fires could have more serious effects should not be overlooked. The test plots still had 1/8 to 1/4 inch (0.3–0.6 cm) of litter after the fires. With complete exposure of the mineral soil, both runoff and erosion undoubtedly would have been much greater.

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Table 1—*Soil loss per acre (0.4 ha) in 18 months.*

	Lakeland fine sand			Boswell very fine sandy loam		
	Slope	Soil loss		Slope	Soil loss	
Treatment	(percent)	tons	tonnes	(percent)	tons	tonnes
Burned	8	0.14	0.13	5	0.73	0.66
Burned	12	0.11	0.10	11	0.28	0.25
Unburned	8	0.15	0.14	6	0.17	0.15
Unburned	15	0.16	0.15	13	0.13	0.12

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USE OF FIRE IN FOREST MANAGEMENT*

Robert D. McCulley

Fire is used in timber management mainly to help establish new stands. Prescribed fire can improve the seedbed, clean up green and dead fuels from a planting site, or control undergrowth during the life of a stand so that competition with seedlings can be held to a minimum when reproduction cuts finally are made. Its use for these purposes has been limited to certain geographic locations and to timber types where conditions of weather, fuel, and topography offered special reason to expect success. This has been mainly in the South and West.

Natural Fires Influence Forest Composition

That fire has had a relationship to the kind of timber in the forest is long established. This seems obvious for jack pine, lodgepole pine, and other species that may require high temperatures to release their seed. It is equally true of those species that lose out in competition with their more tolerant neighbors if some disturbance such as fire does not upset the trend of succession. Douglas-fir is such a tree. So are white pine, loblolly pine, quaking aspen, and many others. The list is long, and it tends to grow longer as we glean more ecological information from the forest.

Fires favor certain tree species in several ways, thus perpetuating cover types that tend to lose out in competition with those higher on the successional scale. They kill back the competitors and, if intense enough, reduce their numbers. They remove litter accumulations and expose mineral soil, the favored seedbed for many forest trees. Also, in general, they provide the conditions of light, temperature, and moisture relations that, temporarily at least, favor the establishment and growth of the so-called fire types. Fire species tend to be light seeded and aggressive in filling in denuded areas. They are intolerant of shade.

The main use of prescribed fire in this country has been for fire protection.

Prescribed and Uncontrolled Fires May Not Produce Same Effects

A forester's first acquaintance with fire was generally in trying to control it. As a byproduct of its destructiveness, he saw some of the things it accomplished in selected areas—the freshening of forage for domestic livestock in the South, the fortuitous thinning of dense young stands of ponderosa pine, the sanitation removal of brown-spot needle blight of long leaf pine, the release of seed held in serotinous cones of jack pine, the improved seedbed and generous establishment of numerous species in all sections of the country. However the link between the action of wildfire and the prescription and use of fire for specific purposes is not necessarily very strong. The users must assure control within prescribed boundaries. And damage to residual trees must be held within tolerable limits. These limitations tend to reduce the intensity of prescribed fires and thus to curtail their effectiveness for some purposes. Fire intensity especially is a problem where selective action is desired where unwanted vegetation must be killed and valuable vegetation saved.

Properly Prescribed Fire Does Not Seriously Threaten Soil Productivity

Many foresters are apprehensive about the long-term effects of fire use on the soil. Generalizations on this point pervade the literature. Yet there are few things less subject to generalization. The possible variation in any fire situation is tremendous. It is not enough to assume that because organic litter is a valuable soil conditioner, and because fire destroys litter, that fire necessarily is destructive of soil values. There is much more to the story than that.

In some situations, fire certainly lowers soil productivity. I can outline a case where there can be little argument. South of Plymouth, NC, is a stretch of country that can only be described as desolate. To a forester it may resemble early photographs of the stumpland wastes left after removal of virgin white pine and the subsequent fires in the Lake States. As far as the eye can see stretches a swamp populated by

When this article was originally published in 1960, Robert D. McCulley was chief of the division of forest management research, USDA Forest Service, Lake States Forest Experiment Station.

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cotton bullrushes and other aquatic vegetation. Stumps and snags poke up through it. This is the result of fire following logging on organic soil. The soil itself has been burned away, making natural establishment of trees impossible.

Another case is where fire removes the protective mantle of organic matter from the soil and destructive erosion results. The extreme example is the southern California mountains, where flood has followed fire on many an occasion. Less spectacular but no less serious destruction of the soil has occurred in many other places.

If we rule out places where peat will burn and where erosion is a serious complicating factor, we come to an area where there still is much room for difference of opinion. However, the evidence from research on the effects of fire on the soil can narrow that area of possible disagreement.

First of all, fire temperature seems to have very limited influence on the mineral soil itself. Soil samples from burned and unburned areas were analyzed following the severe fires of 1918 that destroyed Cloquet, MN. They showed no loss of nitrogen from the surface layers of the mineral soil. Except where heavy fuels burn for long periods of time, as may occur in slash disposal, the temperature effect downward into the soil is limited to a very thin layer.

Soils from which the organic mantle has been burned away, time and again, have shown higher levels of some nutrients other than nitrogen than similar unburned soils. Even though nitrogen is driven off from the litter as one of the products of combustion, the loss is of questionable importance at least in some cases. Prescribed fires seldom burn away all of the undecomposed organic material, and may remove a negligible amount.

> We have some assurance that periodic use of fire poses no serious threat to soil productivity from the nutrient standpoint.

Many cases of a nutrient situation after burning have been shown by chemical analysis, by comparative growth of annual plants, and by comparative growth of pine seedlings on burned and unburned areas. There is no long-term history of soil nutrient relationships under controlled conditions. However, even though the story is incomplete, it gives us some assurance that periodic use of fire poses no serious threat to soil productivity from the nutrient standpoint.

On the other hand, the physical condition of the soil is impaired by repeated clean burns. Where this occurs it will accentuate runoff problems. A single, severe slash disposal fire in Douglas-fir, under current slash-burning practices, has only a minor influence on physical characteristics of the soil.

Advantages to Using Fire

The main use of prescribed fire in this country has been for protection. However, in a few instances it has become a standard tool in timber management. Notable is its use for hardwood brush control in the South and Southeast.

Some of the variability in fire effects can be reduced by modifying the fuels. In the California foothills, brush has been made more flammable through being mashed down with a bulldozer and allowed to cure before burning. Areas treated in this manner can be burned when the general fire hazard is relatively low. Area ignition, the simultaneous firing of numerous places in the burning unit, has achieved somewhat the same results through providing a quick buildup in temperature with resulting intense and clean burns. These methods of increasing the intensity and uniformity of fires have been used in range improvement work. They have possible application in replanting site preparation.

Effects of seedbed improvement with fire have been worked out for several of the soil conditions within the loblolly pine type. In general, the improvement is substantial but not as great as with mechanical scarification. However, fire has been less expensive to apply. Results are good where bird and rodent populations are low and where climatic extremes do not lead to heavy losses of germinated seedlings. Burning favors successful establishment of longleaf pine. Variable results from field trials have been reported for many other species, including jack pine.

To sum up the present status of fire use, we can point to relatively few places where it is included in the routine of timber management. Hardwood control in the South is the major one. There are many examples of application on a small scale. There are even more test runs of an investigative character. Solution of problem situations through fuel modification or by other means can be expected to broaden general application where some of the limited trials now are being made. ■

REDUCTION OF FUEL ACCUMULATIONS WITH FIRE*

Robert M. Romancier

Prescribed burning has often been used to reduce fuel accumulations, but only rarely has specific information been gathered to determine the effectiveness of a burning program. A 4-year study on the Camp Experimental Forest in Sussex County, VA (maintained in cooperation with Union Bag-Camp Paper Corporation in Franklin, VA) provides a measure of the effects of repeated prescribed burns on the depth and character of the forest floor. The objectives of the burning program were seedbed preparation, fuel reduction, and the control of understory vegetation.

Stand Conditions

The stand used in this study consisted mainly of 60-year-old loblolly pine (*Pinus taeda* L.) in mixture with blackgum (*Nyssa sylvatica* Marsh), red maple (*Acer rubrum* L.), and a scattering of various oaks. The average basal area per acre was 120 square feet (28 m^2/ha) for the pine and 35 square feet (8 m^2/ha) for the hardwoods.

The study measured the effects of repeated prescribed burns on the depth and character of the forest floor.

Initially, the very abundant shrub layer, composed mostly of *Clethra* and *Vaccinium*, had an average height of about 2.5 feet (0.8 m). It probably would have prevented adequate pine regeneration after harvest unless reduced by some special treatment.

Below the dense shrub layer was a heavy accumulation of litter. Measurements of the litter depth and shrub height were taken before each fire (table 1). The average fuel accumulation was 4.8 inches (12.2 cm) deep and consisted of normal forest leaf and twig fall, along with larger pieces of wood, stumps, down trees, and other woody material. According to Metz, the average annual litter fall from such a stand is slightly more than 2 tons per acre (4.5 t/ha) (Metz 1952).

The stand was located on two soil types: Fallsington very fine sandy loam and Othello very fine sandy loam, about equally represented. These soils have very poor drainage; water stands on the Othello most of the year. Under such conditions, normal decomposition is greatly retarded, resulting in an excessive buildup of litter and in the development of an A_0 horizon. This horizon consists of partially decomposed organic matter and contains many small leaf pieces and roots.

The A_0 horizon or mat is usually very moist and is not ignited by the ordinary prescribed burn, except when a stump or log catches fire, thus drying out the mat around it. Then a slow, smoldering ground fire is started that is very difficult to extinguish short of flooding or trenching to mineral soil. When exposed by fire or other disturbances, the residual mat forms a very good seedbed.

Treatments

The study area was composed of four 40-acre (16-ha) compartments. One compartment was not burned and served as a control. The others

Table 1—*Average litter depth and shrub height before each fire.*

Time of measurement	Litter depth		Shrub height	
	inches	cm	inches	cm
Before the winter fire	4.8 ± 0.6	12.2 ± 1.6	29.3 ± 4.6	74.4 ± 11.7
Before first summer fire	3.0 ± 0.4	7.6 ± 1.0	14.8 ± 1.7	37.6 ± 4.3
Before second summer fire	2.5 ± 0.3	6.4 ± .8	8.3 ± 1.3	21.0 ± 3.3
Before third summer fire	1.8 ± 0.4	4.6 ± 1.0	6.0 ± 1.4	15.2 ± 3.6

When this article was originally published in 1960, Robert Romancier was a forester for the USDA Forest Service, Southeastern Forest Experiment Station.

* The article is reprinted from *Fire Control Notes* 21(4) [October 1960]: 121–123

received a winter burn, and then one, two, and three summer burns respectively.

The winter fires served to create more uniform conditions within each compartment, and were considered as a preparation for the summer burns to follow. These winter fires reduced the height and density of the low hardwoods and facilitated wind movement through the stands.

The summer fires, in June or July, did the heavy work of fuel reduction, control of understory vegetation, and seedbed preparation. Most of the study area was burned by headfires, although backfires were frequently used to prevent breakovers into unburned areas.

The weather characteristics were very similar for all of the summer fires. The burning index (recorded using a type 8-0 Fire Meter) was 4 or 5, the relative humidity was close to 50 percent each time, and the air temperature was between 84 °F and 92 °F (29–33 °C). The fuel moisture ranged between 5.6 and 7.6 percent. Winds were westerly, with velocities usually close to 2 to 4 miles per hour (3 to 6 km/h) measured at 8 feet (2.4 m) above the ground.

At the end of the burning program, samples of organic matter were collected, weighed, and separated into their woody and litter components. Subsamples of woody and litter fuel were oven dried and a conversion factor obtained so that the dry weights could be expressed as tons per acre of dry fuel.

Results

The results revealed that each fire caused a considerable reduction in the depth of the litter and in the average height of the shrub layer. A fuel reduction of 9.1 tons per acre (20.4 t/ha) resulted following a winter and one summer burn (table 2). Two additional summer fires removed another 5 tons of fuel per acre (11.2 t/ha). The most surprising fact revealed by this study was the very high initial fuel weight of 36.1 tons per acre (80.9 t/ha). This concentration can best be explained by the wet, poorly drained site and heavy stand of trees and lesser vegetation.

Supplementary samples were taken to determine the relative amounts of the readily flammable upper layer of litter and of the less flammable lower layers. The first series of fires (one winter, one summer) caused considerable change in the composition of the fuel; subsequent fires seem to have had little effect upon the relative amounts of the two fuel types (table 3).

This study points out that on Fallsington and Othello very fine sandy loam soils, fuel accretion comes not just from leaf and twig fall, but also from below. The dark mat of partially decomposed organic matter that develops under such conditions dries out and fluffs up following a fire in the litter above, and is capable of sustaining a fire within a short time.

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Table 3—*Proportion of fuel by litter layers following treatment.*

Treatment	Upper layer of litter	Lower layer of litter
Unburned control	23.5%	76.5%
One winter, one summer fire	13.1%	86.9%
One winter, two summer fires	16.5%	83.5%
One winter, three summer fires	14.6%	85.4%

Table 2—*Fuel remaining following treatments.*

	Litter		Woody fuel		Total fuel	
Treatment	tons/acre	t/ha	tons/acre	t/ha	tons/acre	t/ha
Unburned control	32.8	73.5	3.3	7.4	36.1	80.9
One winter, one summer fire	24.4	54.7	2.6	5.8	27.0	60.5
One winter, two summer fires	21.8	48.9	1.7	3.8	23.5	52.7
One winter, three summer fires	20.5	45.9	1.6	3.6	22.1	49.5
Total reduction	12.3	27.6	1.7	3.8	14.0	31.4

TIME–TEMPERATURE RELATIONSHIPS OF TEST HEADFIRES AND BACKFIRES*

Lawrence S. Davis and Robert E. Martin

Time–temperature relations were measured during the course of a preliminary investigation of the thermal characteristics of forest fires. Observations on five headfires and five backfires in 8-year-old gallberry–palmetto roughs on the Alapaha Experimental Range near Tifton, GA, are the basis for this report.

The Test

All burning was done on July 22, 1959, between 10 a.m. and 2 p.m., with air temperatures about 90 °F (32 °C). The moisture content of the upper layer of fuels, as measured by fuel-moisture sticks, decreased from 12 to 8 percent during the burning period. Winds varied from 1 to 4 miles per hour (2–6 km/h) and the burning index was 1. Fuels, including litter and lower vegetation, averaged 5 to 10 tons per acre (11–22 t/ha).

Backfires advanced at the rate of about 1 chain per hour (20 m/h) and headfires at the rate of 10 to 20 chains per hour (200–400 m/h). Temperature measurements were made at 3-second intervals as the fires—with about a 20-foot (6-m) run—passed thermocouples located at eight 1- and 4-foot (0.3–1-m) heights above ground.

> A plot of temperature against time represents one of a fire's most significant thermal characteristics.

Chromel–alumel thermocouples, when used with leads insulated with fiberglass and stainless steel mesh, were very satisfactory in these tests. Milliameters were used as measuring devices because they are relatively cheap and are readily wired and transported. Recording potentiometers would serve the purpose better but are expensive and more cumbersome to use in the field.

The Results

Composite time–temperature lines for these head and backfires are plotted on the accompanying chart (fig. 1). At the 1-foot (0.3-m) level, the headfire temperatures rose abruptly to a maximum of about 1,600 °F (870 °C). They then fell off, at first sharply, and then at a decreasing rate. The slower moving backfires produced temperatures from 250 °F to 600 °F (120–315 °C) at the 1-foot (0.3-m) level and maintained this temperature range for several minutes. The second temperature peak associated with backfires occurred when the line of fire had passed the thermocouple, but the flames were still directed at it as a result of wind movement.

At the 4-foot (1-m) level, headfire temperature peaks barely exceeded 500 °F (260 °C); backfire tempera-

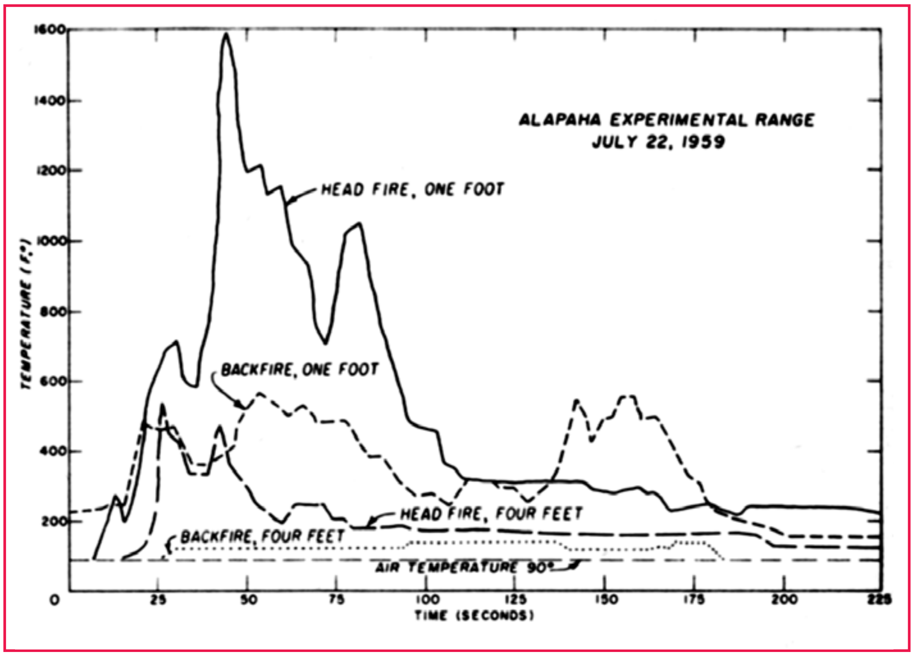

Figure 1—*Temperatures developed by five headfires and five backfires in 8-year-old gallberry–palmetto roughs.*

When this article was originally published in 1961, Lawrence Davis and Robert Martin were with the USDA Forest Service, Southern Forest Fire Laboratory, Southeastern Forest Experiment Station.

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ture peaks at the same level barely exceeded 125 °F (52 °C).

Lindenmuth and Byram (1948) made a comparison of heat factors associated with backfires and headfires in the longleaf pine type. In this type, which was primarily grass mixed and overlain with longleaf needles, their measurements indicated that headfires are cooler near the ground—up to 18 inches (46 cm)—than backfires. Our measurements do not indicate such a relationship for the gallberry–palmetto roughs, at least at the 1- and 4-foot (0.3–1-m) levels. If there is a zone in this type where headfires are cooler than backfires, it is probably within a few inches of the ground.

A plot of temperature against time represents one of a fire's most significant thermal characteristics.

Three-Dimensional Analysis

A plot of temperature against time represents one of a fire's most significant thermal characteristics. By measuring these relationships at different heights above ground, a three-dimensional, quantitative analysis of a fire can be made, which in turn can be used to rate fuels according to heat yields. Vegetation damage should be closely related to a fire's time–temperature behavior if initial vegetation temperature is taken into account.

Many more fires in different fuels under different weather conditions must be measured before the energy release that takes place in wildfires can be estimated. Detailed and carefully documented studies are now in progress at the Southern Forest Fire Laboratory.

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Prescribed Burning for Hazard Reduction on the Chippewa National Forest*

Thomas A. Fulk and Robert Tyrrel

An unusual combination of fuel types on the Chippewa National Forest in northern Minnesota has resulted in annual prescribed burning in marsh meadows as a fire prevention technique. Vast areas of marsh meadows constitute a high-hazard fuel when in the cured stage. These meadows contain primarily grasses, rushes, and sedges. Woody shrubs are not uncommon, particularly along meadow perimeters and on natural levees adjacent to watercourses. During the spring months, meadows are frequently flooded during years of normal or above-normal precipitation. This frequent flooding is a factor that contributes to the continuance of the meadow cover type.

Fire Danger

Because of the elongated patterns formed by this vegetative type, a wildfire can quickly increase in perimeter and enter adjoining timber at several widespread locations. Figure 1 shows a meadow which is recognized as having an exceptionally high fire hazard. A fire on this meadow could quickly expand to 25 miles (40 km) of perimeter. A rate of spread of 400 chains of perimeter per hour (8 km/h) can occasionally be expected on meadow fires. Thus, in the case illustrated, a fire could reach 25 miles (40 km) of perimeter in 5 hours. Inaccessibility and difficulty of rapid travel are also part of the fire control problem. Incendiary fires are common and, during the past 5 years (1958–62), accounted for 23 percent of all wildfires on the Chippewa National Forest.

Vast areas of marsh meadows constitute a high-hazard fuel when in the cured stage.

In addition to the physical features of the land, the sociological aspects are also significant in fire prevention. Public education in fire prevention is an important part of fire control activity. The problem of public education in fire prevention is similar to that in the Southern States. In northern Minnesota, a long tradition of meadow burning exists, perhaps beginning in the early use of meadows for hay production because annual burning was thought to produce better hay. Meadow hay is known to have commonly been cut as late as 1950.

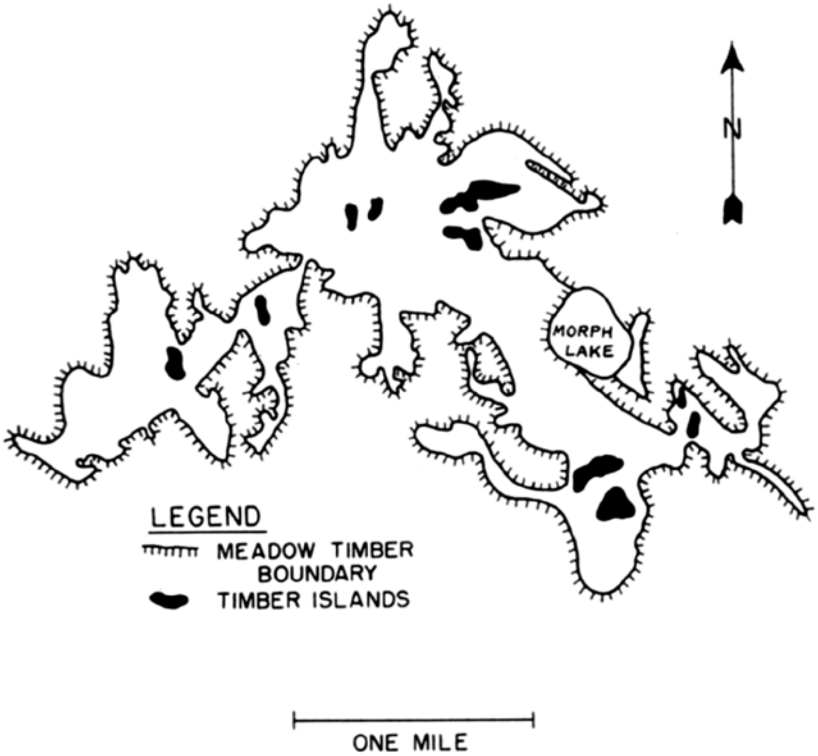

Figure 1—*Morph Meadow, Blackduck Ranger District, Chippewa National Forest, Minnesota.*

When this article was originally published in 1963, Thomas Fulk was a forester for the USDA Forest Service, Hiawatha National Forest; and Robert Tyrrel was a district ranger for the USDA Forest Service, Superior National Forest.

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* The article is reprinted from *Fire Control Notes* 24(3) [July 1963]: 66–68.

Table 1—*Meadow type available and area prescribed burned by ranger districts.*

Ranger district	Available area[a]		Prescribed burned annually[a]	
	acres	ha	acres	ha
Bena	20,000	8,000	12,500	5,100
Blackduck	5,500	2,200	3,545	1,434
Cass Lake	3,300	1,300	1,600	650
Cut-Foot Sioux	11,285	4,566	3,050	1,234
Dora Lake	5,540	2,240	1,650	667
Marcell	313	126	45	18
Remer	10,240	4,140	5,760	2,330
Walker	22,000	8,900	4,837	1,957
Totals	78,178	31,637	32,987	13,349

a. Varies with annual water level.

Meadow Burning

Prescribed burning of meadows has been a management tool for approximately 35 years on the Chippewa National Forest. The objective has been to reduce the hazard by burning under safe conditions.

Prescribed burning of meadows has been a management tool for about 35 years on the Chippewa National Forest.

Safe conditions for prescribed meadow burning exist throughout an approximate 3- to 4-day period in the spring. At this time, snowmelt exposes marsh vegetation and dries rapidly in the open. Under the cover of adjoining timber snowmelt lags, residual snow provides an efficient firebreak. The date of burning may vary by several days from meadow to meadow, depending upon latitude, orientation, and snow catch.

Meadow burning is frequently done individually or by two-person teams. During the 3- or 4-day period when conditions are optimum, several thousand acres must be burned by the four- or five-person staff of each ranger district. Table 1 shows the area burned by each ranger district and total acres of meadow available by district.

A meadow-burning team will commonly burn a river meadow 5 to 10 miles (8–16 km) long in a day. Burning is usually done in the same manner as backfiring; wooden matches or drip torches are most commonly used for ignition. The fire is usually set so that the wind will carry flame across the meadow to be burned.

No attempt is made to control the fire, since residual snow under adjoining timber provides an adequate control line. Because of river oxbows and snowdrifts, burning is never uniform; nevertheless, breaking the continuity of fuel conditions suffices to prevent wildfire from spreading unchecked.

No attempt is made to control the fire, since residual snow under adjoining timber provides an adequate control line.

Burning Needed

The need for prescribed meadow burning has often been evaluated and discussed by forest personnel. Generally, the conclusion has been that burning is necessary for effective fire prevention, particularly in light of the incendiary fire problem. It is better to burn when conditions in the woods are safe than to take a chance on the area burning during periods of high fire danger. ■

PRESCRIBED BURNING TECHNIQUES ON THE NATIONAL FORESTS IN SOUTH CAROLINA*

Zeb Palmer and D.D. Devet

Many prescribed burning effects on national forest lands are well known. However, little study has been done on burning techniques to achieve specific results under specific conditions of weather, fuel, and topography.

This note will primarily consider the prescribed burning techniques used on the national forests in South Carolina. Prescribed burning has been used as a management tool for more than 20 years (fig. 1). Fortunately, the even-aged timber management plans for the forests permitted extensive use of fire. More than 43,000 acres (17,400 ha) are now prescribe-burned annually.

Figure 1—*District ranger on the Santee Ranger District, Francis Marion National Forest, briefs his crew prior to the start of burning operations.*

Purpose of Prescribed Burning

The initial purpose was to reduce fuels to lessen the fire hazard. Later prescribed burning was used in undesirable species control, brown-spot disease control, planting-site preparation, seedbed preparation, range betterment, and wildlife habitat improvement.

Burning to improve wildlife habitat is used to obtain specific results such as:

- Removing leaf and needle litter, which has a smothering effect on desirable forbs and legumes,
- Stimulating quail indicator species such as tick trefoil (*Desmodium* spp.) and partridge pea (*Chamaecrista* spp.),
- Increasing deer browse,
- Encouraging fruiting of ground oak (*Quercus pumila*) and huckleberries (*Vaccinium* spp.),
- Maintaining openings for deer and turkey, and
- Reducing basal area of noncommercial understory species.

Importance of Weather

Burn only if the weather is right. A list of weather conditions acceptable for prescribed burning are listed in table 1. These conditions apply to most of the Southeastern United States.

A special fire danger weather station is not necessary. Local weather bureau offices can supply

Table 1—*South Carolina weather conditions under which prescribed burning can be conducted.*

Factor	Winter	Summer
Relative humidity	20–45%	20–55%
Wind velocity	3–10 mph (5–16 km/h)	3–10 mph (5–16 km/h)
Wind direction	*	*
Temperature range	34–75 °F (1–24 °C)	85–100 °F (29–38°C)
Buildup index	3–30	6–40

* Any reasonably constant direction is acceptable. The most unreliable wind directions are in the easterly quadrants.

When this article was originally published in 1966, Zeb Palmer was the district ranger for the USDA Forest Service, Ouachita National Forest, AR; and D.D. Devet worked on the fire control staff for the USDA Forest Service, national forests in South Carolina, Columbia, SC.

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* The article is reprinted from *Fire Control Notes* 27(3) [July 1966]: 3–4, 14.

all conditions necessary except the buildup index. Soil moisture conditions must be field checked. There must be a damp humus layer in the A_0 horizon.

Firing Techniques

Five firing techniques are now used on the National Forests in South Carolina:

1. Backfire,
2. Headstrip,
3. Spot or checkerboard,
4. Flank, and
5. Headfire.

These techniques are employed on specific occasions to accomplish specific purposes (fig. 2). Two or more techniques are used for most burns.

Backfire. A baseline is established, and perimeter and interior lines are placed approximately 10 chains (200 m) apart. There may be plowed lines or natural barriers such as creeks, roads, or swamps. On slopes, the baseline should be the top of the ridge, and the perimeter lines should be on flanks. Interior lines should be as close to the contour as possible. The fire is started on the baseline (fig. 3). After the base is safeguarded, the interior lines are fired.

This method is employed in slope burning and burning in relatively young timber stands, and results in a minimum of scorch. It is recommended for prescribed burning beginners.

Prescribed burning has been used as a management tool in South Carolina for more than 20 years.

Backfiring is employed in slope burning and burning in relatively young timber stands, and results in a minimum of scorch.

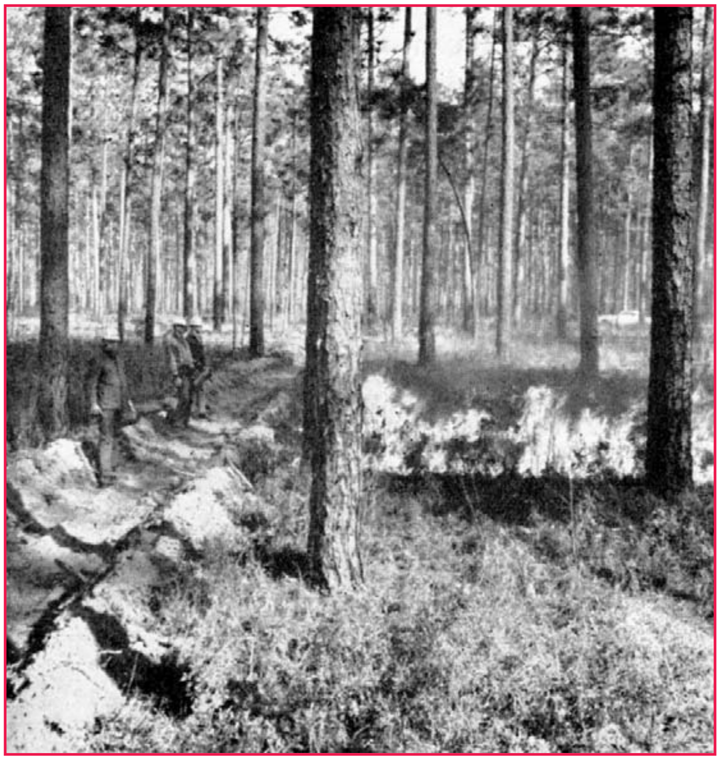

Figure 2—*Prescribed burning crew watches small test fire to see if it is burning according to the weather forecast.*

Figure 3—*Backing fire is started along the plowed line used as a base of operations.*

The method works well with heavy fuel, gives a minimum of scorch, provides heat at ground line for the longest periods, and is recommended for summer burning when there are high temperatures, heavy fuels, low relative humidities, strong winds, and high fire dangers. This method is the most popular, easiest to apply, and fastest.

However, this method needs steady wind from a constant direction, plenty of time, interior lines prepared in advance, and continuous and uniform fuels (at least 1 ton per acre [2.2 t/ha] of fuel).

Headstrip. Short headfires are run with the wind into a prepared baseline or burned area. The strips will vary in width, depending upon density and distribution of fuel. This technique is combined with a backing fire to initially secure the baseline. After the base is secured, strip burning is begun.

This technique can be conducted when relative humidity is 50 to 55 percent, has flexibility for wind direction changes, can be conducted in scattered light fuels, needs minimum preparation, is relatively inexpensive, is cheaper because few plowed lines are required, and is rapid.

Spot or Checkerboard. This technique is also called “area ignition.” A series of small spot fires are uniformly distributed so all spots converge before any one spot can gain momentum. Possible damage to residual stands is least for closest spots.

A skilled crew familiar with fire behavior and burning objectives is required.

Flankfiring is frequently used to secure the edges of the prescribed burn when a backfire, strip headfire, or checkerboard fire progresses.

This technique should be used primarily for winter burning at low air temperatures. It can also be used when conditions are too hot for headstrip burning.

Flankfire. A fire that spreads perpendicularly to the prevailing wind is started. The line of fire is started directly into the wind (fig. 4). The fire then spreads laterally at right angles to the established line. This technique is frequently used to secure the edges of the prescribed burn when a backfire, strip headfire, or checkerboard fire progresses.

Flanking is the cheapest and fastest burning procedure.

This method requires a steady wind, uniform and preferably light fuels, and a trained crew.

Figure 4—*Flankfire is started with a backfiring torch by a crewman walking directly into the wind.*

Headfire. The head fire is employed on special occasions. The fire is permitted to run with the wind into a prepared firebreak that will stop the spread. This is a dangerous and specialized method employed primarily to kill all aerial vegetation. This technique is used to maintain a wildlife opening under certain conditions, and in brown-spot disease control. It is also used when a hot, fast fire is needed.

If not carefully used, this technique could result in a wildfire with spotting, crowning, and other undesirable characteristics.

Summary

Five basic firing techniques are employed for prescribed burning on the national forests in South Carolina. One technique or a combination of techniques is best under certain conditions of fuel, weather, and topography.

Prescribed burning requires experience and knowledge of fire behavior. All personnel using prescribed burning should recognize the constructive and destructive power of fire. ■

A FIELD TRIAL FOR REGULATING PRESCRIBED FIRE INTENSITIES*

Stephen S. Sackett

Certain firing techniques can be used to control the intensities of prescription burns. When lines of fire are set to permit spread with the wind, fire intensities are generally greater than those produced by lines of fire moving against the wind. Flankfires generally create intensities somewhere between those generated by headfires and backfires. Spotfires often generate the entire range of intensities—the leading edge behaving as a headfire, the sides as flankfires, and the rear as a backfire.

Multiple lines or spots of fire are often necessary when a large area has to be burned in a specified time. The lines or spots of fire have a "drawing" effect on each other where they converge, and their individual intensities become magnified in the junction zones. Since most fire damage occurs within these junction zones, the interval between fire sets is vital in regulating overall intensities.

Procedure

A workshop on prescribed burning was held recently on the Francis Marion National Forest, South Carolina. All burns took place in an open, mature stand of loblolly and longleaf pine averaging about 80 feet (24 m) in height. Litter fuel consisted mainly of a 2- to 3-year accumulation of needles, and the vegetative undergrowth was composed of wiregrass (*Aristida stricta* Michx.), gallberry (*Ilex glabra* (L.) Gray), titi (*Cyrila racemiflora* L.), and other minor shrub species.

When this article was originally published in 1968, Stephen Sackett was a research forester for the USDA Forest Service, Southern Forest Fire Laboratory, Southeastern Forest Experiment Station, Macon, GA.

Not all crown scorching results in damage to those species studied, but excessive amounts may be harmful.

Mild February weather prevailed: the air temperature was 68 °F (20 °C) and the average relative humidity 34 percent; wind was light and from the southeast in the stand, with gusts up to 19 miles per hour (31 km/h) in the open. The spread index was calculated at 33, and the buildup index totaled 16. Three days had elapsed since the last rain—0.34 inch (0.86 cm). Although the surface fuel was moderately dry, the soil was still damp.

Four 4-acre (1.6-ha) blocks were allotted for spotfires, and five for strip headfires. In order to evaluate the effect of distance between fire sets on behavior and intensities of the resulting fires, particularly in junction zones, the number of sets per block in the four spotfire blocks was varied as follows: 2, 4, 30, and 60 spots.

In the five strip headfire blocks, the strips were placed about a chain (20 m) apart. All plots were burned the same day. Estimates of the resulting crown scorch (table 1) served as gages of fire intensities.

Observations

From observations of rate of spread, flame height, and vegetative fuel consumption, fire intensities appeared to increase directly with the number of ignition points and were inversely related to the spacing between fire sets.

When examined for scorch 2 months after burning, the condition of the crowns supported preliminary observations. The strip headfire blocks had a greater percentage of class C and D tree crowns than did any of the other treatment blocks. Scorch was negligible in those blocks that had been burned with two or four spots. In those with 30 and 60 spots, the percentage of scorch approached that in blocks burned with strip headfires (fig. 1). As the number of

Table 1—*Scorch classifications used for field trial.*

Class	Percent crown scorch
A	None
B	1–33
C	34–66
D	67–100

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* The article is reprinted from *Fire Control Notes* 29(3) [July 1968]: 5–6.

Flankfires generally create intensities somewhere between those generated by headfires and backfires.

spots increased (spacing between decreased), the chances for convergence and greater intensities also increased.

Not all crown scorching results in damage to those species studied, but excessive amounts may be harmful. Scorching does, however, indicate the level of fire intensity. Because of the relatively large bole sizes and tree heights involved, observations made during this demonstration probably resulted in conservative interpretations. A younger stand would likely have suffered greater crown scorch and thus more potential damage.

Conclusions

The interval between fire sets appears to strongly influence the fire intensities created by prescription burning. Data from this demonstration indicate that, with many sets placed close together, it should be possible to produce a high-intensity burn. Conversely, a low-intensity fire should result from fewer sets and wider spacing.

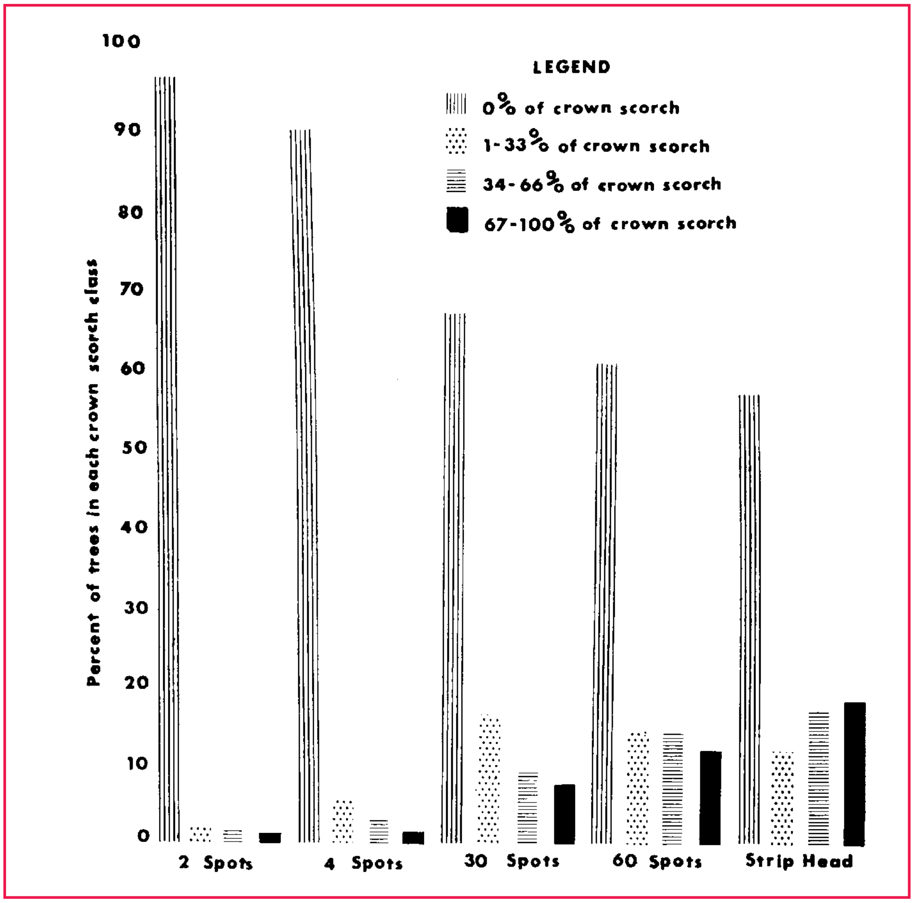

Figure 1—*Crown scorch associated with a variety of firing techniques.*

The interval between fire sets appears to strongly influence the fire intensities created by prescription burning.

In the South, most fire prescriptions in pine stands call for low-intensity fires that do not damage the crowns of crop trees. Sometimes, however, higher intensities are necessary; for instance, in clearcut areas where fire is used for slash disposal, or in mixed stands where hardwoods are undesirable and need to be controlled.

If further study shows that interpretations made in this demonstration are applicable for a normal range of fuel and weather conditions, another useful means will be available to regulate prescribed fire intensities. ■

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PRESCRIBED NIGHTTIME BURNS BRING BENEFITS*

Stephen S. Sackett and Dale D. Wade

A nighttime prescribed fire successfully reduced the wildfire hazard created by slash left in a recently thinned plantation of 20-year-old slash pines. Weather, fuels, and fire behavior are briefly described.

Prescribed burning, if properly applied, is the most economical means of eliminating the wildfire hazard created by slash left in pine plantations after a commercial thinning. One such burn designed to reduce slash, although originally scheduled for the daytime, was successfully carried out at night on the Southlands Experiment Forest, International Paper Company, near Bainbridge, GA. If these prescribed burns can be conducted at night, the number of hours available for burning is increased. The project was part of a cooperative study by the Southern and Southeastern Forest Experiment Stations.

Stand Conditions

The area was a 20-year-old plantation of slash pine (*Pinus elliottii* Engelm.) to which prescribed fire had previously been applied in the fall of 1966 and in the spring of 1967. These fires had reduced the litter on the area from 16 tons per acre (36 t/ha) to 4 tons per acre (9 t/ha). In December 1967, the plantation was thinned to one-half its original density; approximately 200 8-inch (20-cm) trees were removed per acre. Total ground fuel was increased to 10 tons per acre (22 t/ha) by the resulting slash (fig. 1).

The time scheduled for this prescribed burn was the daylight hours of March 19, 1968, based on predicted weather conditions. By that afternoon, however, the air temperature had risen to 82 °F (28 °C) and the windspeed was 4 miles per hour

Figure 1—*Total fuel after thinning was approximately 10 tons per acre (22 t/ha).*

When this article was originally published in 1970, Stephen Sackett and Dale Wade were associate fire behavior scientists, USDA Forest Service, Southern Forest Fire Laboratory, Macon, GA.

Prescribed burning, if properly applied, is the most economical means of eliminating the wildfire hazard created by slash after a commercial thinning.

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* The article is reprinted from *Fire Control Notes* 31(4) [Winter 1970]: 9-10.

(6 km/h). The relative humidity had dropped to 21 percent, creating a relatively low fine-fuel moisture of about 8 percent. According to the nearest Fire Danger Rating Station 7 miles (11 km) away, the buildup index (a measure of cumulative moisture deficiency in fuels beneath the surface layer) was 28 and the spread index (a measure of the relative rate of forward movement of surface fires) was 20. These indexes indicated a high fire-danger condition. Burning under this combination of fuel moisture and weather would probably damage crop trees.

Favorable Burning Conditions

By 9:00 that evening, conditions were more favorable for burning: The air temperature had dropped to 63 °F (17 °C) and the relative humidity had risen to 66 percent. As a result of this increase in relative humidity, fuel moisture had risen to 14 percent. The windspeed recorded 4 feet (1.2 m) above ground level in the plantation was 1 to 2 miles per hour (1.6–3.2 km/h)—enough to give direction to the fire and dissipate some of its convective heat. Because of this improvement in conditions, a decision was made to go ahead with the burn.

The relatively light winds dictated the use of a headfire (fire set to spread with the wind) for slash reduction. A backfire was used to widen the downwind control line by reducing the fuel along its inner edge.

Figure 2—*Fine fuels were virtually eliminated by the prescribed fire.*

If these prescribed burns can be conducted at night, the number of hours available for burning is increased.

The headfire progressed at a rate of 265 to 345 feet (81–105 m) per hour. Flames varied in height from 2 feet (0.6 m) in the litter to 5 to 8 feet (1.5–2.4 m) in heavy concentrations of slash, and higher flames were occasionally observed. Some glowing embers landed outside the control lines; but, because of the high humidity and increased fuel moisture, no spot fires developed.

Results

All slash less than 0.5 inch (1.27 cm) in diameter was consumed. Litter was reduced by 74 percent, leaving 1 ton per acre (2.2 t/ha) and virtually eliminating any threat from wildfire (fig. 2). Crowns were scorched on 12 percent of the trees, but less than 2 percent of the trees died. Most of those killed were suppressed trees too small to cut during the thinning operation. Greater windspeeds would probably have prevented crown scorch and shortened burnout time without aggravating the problems of control.

These results demonstrate the suitability of prescribed burning at night as a management tool for the prevention of wildfire hazards. Not only did the decision to burn at night increase the time available for burning, but it also provided an additional means of regulating the prescribed fire's intensity. ■

RX FOR BURNING ON THE APACHE NATIONAL FOREST*

Bill Buck

The Apache National Forest, like many southwestern forests situated on the Colorado Plateau, has significant fuel hazard problems. The extensive fuel accumulations in these coniferous forests are the product of several factors: the climate of the Southwest; the history of forest use by stock men and loggers, creating an environment favorable to the establishment of extensive "doghair" (Black Jack) thickets; and the steadily increasing logging operations, for which the needed slash cleanup has not been adequately financed.

How Much in a Year?!

The Apache acquires 40,000 acres (3,300 ha) of new slash fuels each year, with an average of 45 tons of dead fuels per acre (100 t/ha). Vast acreages on the Apache actually have two or more deposits of slash—resulting from successive cuttings since the early 1950s. If we are to correct this excess, we must make successful use of prescribed fire.

The Apache initiated its prescribed burning administrative studies in 1967. Under the direction of Harry Nickless, district fire control officer, 400 acres (130 ha) of the Iris Springs project were burned on the Springerville Ranger District in November.

When this article was originally published in 1971, Bill Buck was the fire control officer for the USDA Forest Service, Apache National Forest.

The Apache National Forest, like many southwestern forests situated on the Colorado Plateau, has significant fuel hazard problems.

Prescriptions for Fires

In 1968, we modified the Iris Springs prescription and burned additional acres. The results of these prescribed burns were successful enough to be helpful to other foresters with similar problems. We burned 800 acres (268 ha) at a cost of $2.50 per acre and stayed within justifiable mortality limits.

Table 1 compares the statistics of three block burns in the Iris Springs Burn. Comments on the burn are included, and indicated optimum prescriptions are given.

The following prescription works in our situation:

- Temperature: maximum, 50 °F (10 °C); minimum, 40 °F (4 °C);
- Relative humidity: 30 to 40 percent;
- Fuel moisture sticks: 20 percent; and
- Wind: 10 to 15 miles per hour (16–24 km/h) (steady).

To some degree, tradeoffs can be made between prescription elements; lower temperatures and higher relative humidity than those prescribed could be satisfactorily

Logging and pulp slash. This hottest burn had a convection column well developed to 10,000 feet (3,000 m) above ground surface.

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* The article is reprinted from *Fire Control Notes* 32(1) [Winter 1971]: 10–12.

Table 1—*Statistics of the 1968 Iris Springs Burn.*

Conditions	**Block Number**		
	6	**10**	**4**
	I. Record of actual burn		
Area	30 acres (12 ha)	60 acres (24 ha)	30 acres (12 ha)
Fuel type	Ponderosa pine with 3- and 4-year-old logging slash	Ponderosa pine with 3-year-old logging slash	Ponderosa pine with 3-year-old logging slash
Fuel loading	Heavy (over 30 tons/acre [67 t/ha])	Heavy (over 30 tons/acre [67 t/ha])	Average (30 tons/acre [67 t/ha])
Aspect	Southeast	East	Southeast
Slope	20 percent	30 percent	15 percent
Observed weather:			
–Temperature	40–43 °F (4–6 °C)	38–46 °F (3-8 °C)	32–41 °F (0-5 °C)
–Relative humidity	38–44 percent	20–40 percent	28–32 percent
–Wind	15–25 mph (24–40 km/h)	5–10 mph (8–16 km/h)	0–5 mph (0–8 km/h)
–Fuel moisture stick[a]	30 percent	20 percent	15 percent
Firing method	We utilize strip head firing primarily, working downslope on the contour. This technique gives us optimum control and flexibility.		
Fire behavior observed	Hot, parallel to wind cool, against wind	Ideal burn, little too hot at 1400	Too hot in places, scorch and crowning
Fuel consumption:			
–Light	70 percent	90 percent	80 percent
–Medium	40 percent	60 percent	60 percent
–Heavy	30 percent	30 percent	20 percent
Duff	Average depth in all three blocks—3 inches (7.6 cm). Consumption averaged 1 inch (2.5 cm) depth, with complete consumption beneath and adjacent to fuel concentrations.		
Comments	The gusts rather than the high winds seemed to do the only damage. The high winds would fan the fires in the pulp tops to high temperatures; then the wind would quit, allowing vertical dissemination of heat into the tops of the pole stand.	Ideal burning conditions. Very little scorch or kill.	Fuel moisture may have gotten a little too low. Also, lack of wind contributes to "baking" the crowns. The aspect seemed to have considerable affect.
	II. Indicated optimum prescription		
Temperature	43 °F (6 °C)	40 °F (4 °C)	35 °F (2 °C)
Relative humidity	38 percent	30 percent	30 percent
Wind	15 mph (24 km/h)	10 mph (16 km/h)	10–15 mph (16–24 km/h)
Fuel moisture stick[a]	20 percent	20 percent	20 percent

a. 1/2 inch (1.3 cm).

offset by strong, steady winds or by using slope and firing techniques in your favor.

Mortality Strips

In the most severe scorch area, mortality strips one year after the Iris Springs Burn revealed these losses:

- 11-1/2 percent of the stems over 6 inches (15 cm) diameter at breast height (d.b.h.),
- 16-1/2 percent of the stems 3 to 6 inches (8–15 cm) d.b.h.,
- 18 percent of the stems under 3 inches (8 cm) d.b.h., and
- 36 percent was the total loss (30 percent of this 36 percent was in the suppressed or intermediate trees).

The loss represented 15-1/2 percent of the basal area, 10 percent of the 15-1/2 percent being in the suppressed, intermediate class.

Another sample taken on an unthinned site (Loop Burn) revealed 45 percent of the total stems were lost—41 percent of which were under 3 inches (8 cm) d.b.h. and which had been suppressed to a basal area of 99 square feet per acre (23 m^2/ha). On a high class II site index, 74 percent of the total trees were left.

Our Objective

Our objective is to compile a catalog of proven prescriptions to burn any given site in the pine type. Each prescription will vary, dependent upon the basic ingredients of slope, aspect, weather, fuel arrangements, fuel densities, character of residual stand, and the desired density and composition of the residual stand when completed. And, in order to reach our objective, several factors have to be considered.

Canyon bottom thinning slash: left, before burn; thinning stem, 3 inches (8 cm); fuel moisture, 7-1/2 percent; temperature, 40 °F (4 °C); relative humidity, 50 percent. Right, after burn, same location; note end of log in both pictures.

Our objective is to compile a catalog of proven prescriptions to burn any given site in the pine type.

Men Are Important, Too. The prescription alone doesn't get the job done. Of first importance are men. The men selected as your torch men must develop a "feel" for the job. They must know when to slow or accelerate the ignition rate; how much heat they've got going and if it is for or against them; and, when they need more fire momentum, how to get it and how to break it (firing techniques).

What Does It Look Like? Another important factor is the negative aspect of a scorched stand. We must realize we can't burn on a production basis without some degree of mortality. We are not going to get 100 percent consumption of ground fuels with a cool burn.

Money Matters

Financing has to be programmed. To plan a burn relying on contributed labor is wishful thinking. You must be guaranteed ahead of time that the right manpower will be on hand when you need it—and on short notice. This requires approved financing.

When to Burn

It is important to recognize when you can safely burn. For the Apache, the time is late October and November. This puts us just past the fall drying trend and into the cooler temperatures and shorter days before our first winter storms. This is the time of year when the perennial grasses are cured, offering the flash fuels necessary to carry the fire. We begin our burns 1 to 4 days following light precipitation, which allows the light fuels to pick up then lose the necessary fuel moisture for a medium spread factor.

Logging tops: above, intermingled with reproduction; below, torching out, reducing residual stand. This is the most difficult situation to cope with because such fuel arrangements invariably mean loss of patches of trees.

It is important to recognize when you can safely burn.

Logical Layout

The physical layout of your project must be logical. Individual blocks must be laid out so that they can be totally ignited and held, within 4-hour periods. Generally, this means about an 80- to 150-acre (27- to 50-ha) block for a four- to six-man crew. Fuel arrangement, density, and moisture content; topography; cultural features; and aspect of slopes will all affect block layout.

Conclusion

Prescription burning can be a successful and practical solution to much of the fuel hazard on the Apache. Our work so far indicates that we are nearing the desired prescriptions, while within justifiable losses of the residual stand and within economic limits. ■

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FIRE IS A TERROR ... BUT ALSO A TOOL*

Richard E. Baldwin

Instead of promoting only the idea that all fires are *bad*, fire prevention efforts need to emphasize fire as a forest management tool and as a natural environmental happening.

Smokey Is a Good Teacher

The Cooperative Forest Fire Prevention (CFFP) program with Smokey Bear as the symbolic image of fire prevention is an impressive success story. The millions of dollars of advertising services contributed to the program have paid off in resources saved, even though the saving can't be accurately measured.

Many dedicated fire protection people have been swept into the mainstream of the mass media approach to fire prevention, and today fire prevention is almost synonymous with public relations, Smokey Bear, and the idea that all fire is bad. For example, if you are considering hiring a fire prevention specialist, what is one of the first prerequisites for the person? You probably will say, "They must be good in public relations."

Prevention Has Many Facets

But there are other aspects and approaches to fire prevention that probably need increased emphasis, such as prevention engineering and fuel management.

The public needs to learn that fire is a dynamic factor of the forest environment, not necessarily good or bad but natural.

Consider fuel management. Why isn't more effort put into it? Fuel management requires scientific understanding of fire behavior and fuels. Unlike the mass media approach, the results of fuel manipulation designed to prevent fires can be realistically tested, measured, and evaluated to determine cost/benefit answers.

The results of the mass media approach, on the other hand, cannot be precisely determined. Furthermore, these results are in terms of the number of people contacted and not in terms of actual resource damage averted.

Are We Our Own Victims of Oversell?

Early-day lumber companies harvested vast areas in a devastating and reckless manner, with little concern for the soil, fire hazard, or perpetuation of a healthy forest cover. Because the silvicultural methods of clearcutting were carelessly applied, the public was aroused and educated to believe that clearcutting was all bad. Did forest managers oversell the public to the point that scientific management is seriously hampered today?

Can this same question be put to the "all fire is bad" type of prevention program mentioned earlier? Will the public be able to accept forest fires as a fact of life, that fire's impact on forest ecosystems is as elementary as soil, air, and water?

Educational Reemphasis Needed

Fire prevention efforts must cease trying to manipulate public attitudes with single objectives, as if it were selling a brand name soap powder. Educational programs should complement overall land management objectives. Since wildfire has been generally misrepresented as being bad, this concept needs to be tempered, and the natural role of fire in our forests emphasized. The public needs to learn that fire is a dynamic factor of the forest environment, not necessarily good or bad but natural.

A.B. Mount, silvicultural research officer from Australia, made the following observation after visiting fire research organizations in our country:

> "I was told that anti-pollution authorities are about to ban forest burning in Oregon; this in spite of general recognition by most foresters that fire is an integral part of the local forest environment. However, this recognition has apparently not been strong enough to allow a vigor-

When this article was originally published in 1972, Richard Baldwin was chief of the Fire Programs Branch, Division of Fire Control, USDA Forest Service, Missoula, MT.

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> "... the very efficiency of the fire brigades guarantees fuel accumulations that will one day produce a holocaust."
> – A.B. Mount, silvicultural researcher from Australia

> ous campaign of public education on the need for forest fires. Perhaps if the complete role of fire in the environment had been understood by the public, foresters would be more outspoken about their use of fire."

Mount also makes the following observation:

> "One remarkable difference between Australia and North America occurs after a fire disaster. In Australia there is public recognition of fuel accumulations and public pressure for the use of controlled fire to reduce these accumulations. In California, there appears to be public condemnation of the firefighting organizations for not controlling the fire. It is apparently overlooked that the very efficiency of the fire brigades guarantees fuel accumulations that will one day produce a holocaust."

Fire's Natural Role Must Be Understood

Along with public reeducation, comprehensive burning prescriptions, realistic pre-attack planning, and fire prevention engineering through fuel and vegetative manipulation must constitute the backbone of the approach to fire management in the 1970s. When fire's natural role in the environment and its ecological significance are understood, land management programs will be able to complement natural processes instead of trying to overpower them with man's advanced technical skills and machines. ■

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STEREO PHOTOGRAPHS AID RESIDUE MANAGEMENT*

Kevin C. Ryan and R.E. Johnson

Photographs of activity fuels increase the usefulness of fuel inventory records for fuel management planning and the evaluation of fuel treatment. This article documents the development and fire management applications of a color stereo photo series on the Shelton Ranger District, Olympic National Forest, WA. The local photo series combines stereo photography with fuel inventory in an extensive catalog of treated and untreated residue fuelbeds. The visual reinforcement provided by the photographs is effective for communication and as a memory aid.

Past Uses

For years, fire managers have used photographs of fuel complexes as decision making and training aids. The photographs were often accompanied by qualitative ratings of fuel hazard; for example, the low, medium, high, and extreme ratings given to rate of spread and resistance to control (Hornby 1936, USDA Forest Service 1968). Fireline notebooks (USDA Forest Service 1969) also use photographs to key fuel models for fire behavior prediction.

When this article was originally published in 1979, Kevin Ryan was a research forester for the USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Forest Residues Program, Seattle, WA; and R.E. Johnson was a fuels management assistant for the USDA Forest Service, Shelton Ranger District, Olympic National Forest, WA.

Evaluating Fuels

The development of the planar intercept fuel sampling theory (Brown 1971) and field inventory procedures (Brown 1974) now make it possible to measure actual fuel loadings. The National Fuel Classification and Inventory System (USDA Forest Service 1974) outlines a method to classify fuels using photographs and these fuel inventories. The procedure gives managers both quantitative and visual records of various fuel complexes. The system was used to develop a photographic series of the various levels of treated and untreated activity-created residues in Region 6 (Maxwell and Ward 1976 a and b). The photographs are a visual record of forest residues that can be used as a training tool in fire management and for facilitating interdisciplinary discussion of residue levels and treatment objectives. The photos also can be used with supporting inventory and harvest data and fire modeling to establish treatment standards. The costs and benefits of treatment alternatives can then be evaluated to determine the best treatment method.

> For years, fire managers have used photographs of fuel complexes as decision making and training aids.

Applicable Use

The coastal Douglas-fir–hemlock photo series (Maxwell and Ward 1976 a) includes examples of residue loadings applicable to the Olympic National Forest. Personnel on the Shelton Ranger District, however, felt additional resolution of residue loadings was desirable because of the complex mixture of mature, over-mature and second-growth timber stands on the district. The need was highest in areas of highly defective old-growth Douglas-fir because of the heavy residue loadings created by harvesting this timber from steep slopes. It was also felt that local inventories would increase the fire management staff's ability to understand and apply photographs to fuel inventory and increase the manager's confidence in the inventories.

Procedure

Cutover units on the District are being systematically inventoried by the planar intercept sampling technique (Brown 1974). Fuels are inventoried in the 1-, 10-, 100-, and 1,000+ -hour time-lag fuel size classes. Fuel and duff measurements are also taken. Permanent photo points are established so that the photographs depict a panoramic view of representative residue loadings. Color stereo paired photographs are taken from these points (fig. 1).

Inventory data are processed and average fuel loading and depths are calculated. The variance and standard errors in fuel measurements are recorded as an index of

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* The article is reprinted from *Fire Management Notes* 40(3) [Summer 1979]: 7–9.

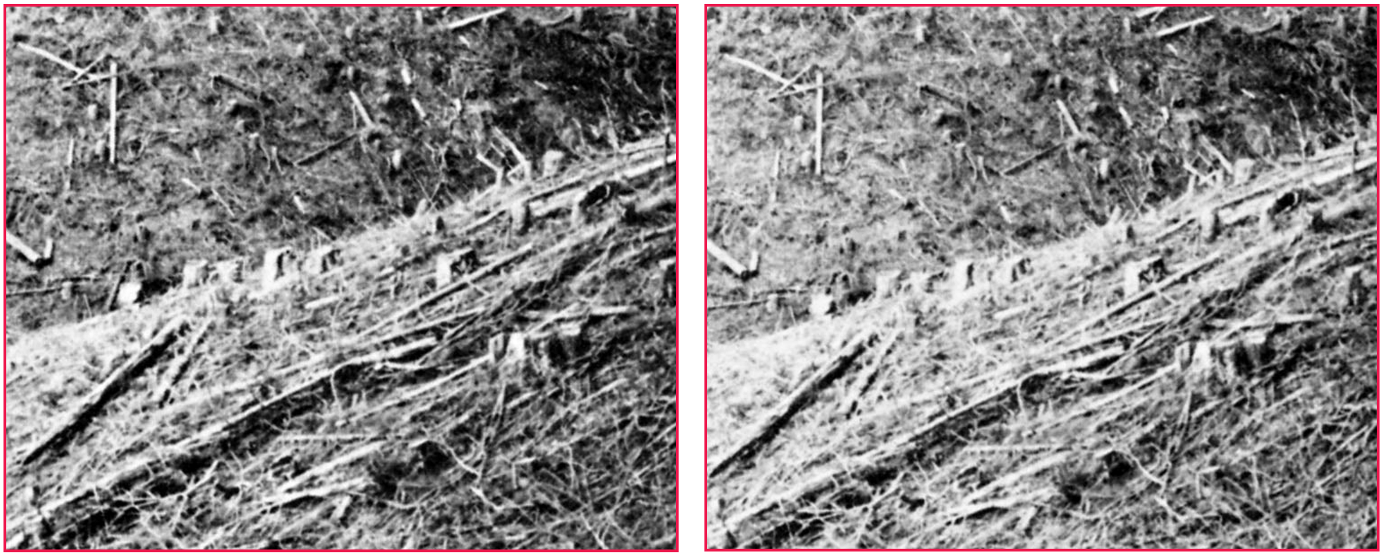

Figure 1—*Stereo pair prior to residue disposal.*

Viewing photographs of similarly treated units helps quantify objectives.

fuelbed variability and a measure of inventory precision. This inventory information is then used to develop residue treatment prescriptions.

Set Objectives

The inventory data help to establish objectives for treatment of units. The management needs of several disciplines are entered into the information used in prescription development and aid in developing prescriptions and setting priorities. Viewing photographs of similar units that have been treated helps in the quantification of objectives. Typical objectives are to:

- Lessen duff disturbance,
- Reduce fine fuels as much as possible,
- Increase the number and quality of planting spots, and
- Reduce the negative impact on air quality.

On this district, prescriptions generally call for broadcast burning because other treatments are restricted by the steep topography and heavy loadings.

Establish Prescription

Complex management needs require burning prescriptions to be more finely tuned than ever before. At present, the National Fire Danger Rating System (NFDRS) (Deeming et al. 1977) is being used to develop burning prescriptions. Past experience is used to select combinations of temperature, humidity, and wind.

The desired spread component, burning index, and energy release component are identified and a burning prescription is established. As computer capability becomes more accessible to the fire management staff, local fuel models and fire modeling may be used.

Treatment

When burning conditions are within prescribed limits, the area is treated. The actual fuel moisture, temperature, humidity, wind direction and speeds, and NRDRS indices are recorded for subsequent use in the burn evaluation.

Re-inventory

The units are re-inventoried following treatment. Post-treatment stereo photographs are taken from the photo points (fig. 2). The success of the burn can then be evaluated by comparing the actual and the desired conditions following treatment. This is an interdisciplinary process, as was the prescription development phase, which becomes more refined and accurate with additional experience.

Valuable Database

This development of a stereo photo series tailored to the local situation and needs is an important element of fuels management on the Shelton Ranger District. The photos are arranged from lightest to heaviest fuel loading and then placed in an album. Together with the supporting information from burning plans and treatment evaluations, they constitute an extensive database for planning residue treatments. Such documentation makes past experience usable and, in turn, increases future success.
The photo album allows one to

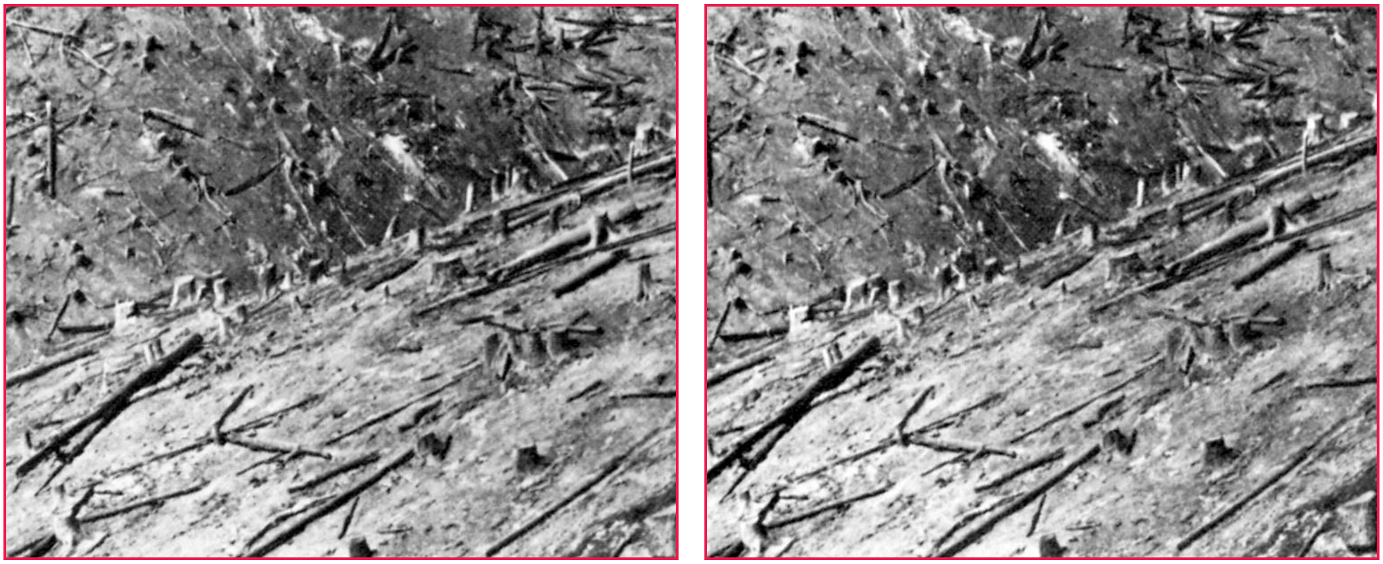

Figure 2—*Stereo pair after residue disposal.*

compare, for example, what 50, 75, or 100 tons of fuel per acre look like. This makes discussion with personnel in other disciplines easier. As more units are inventoried and photographed, it may be possible to estimate residue loadings to sufficient accuracy by simply comparing the fuels on a unit to stereo photos from units with similar loadings. The photos also provide a visual record that will be useful in documenting the long-term breakdown and decay of untreated fuels and residual large logs that may interfere with second growth management.

The inventory and evaluation system establishes baseline data for developing prescriptions and measuring achievement. It gives a reliable estimate of fuel consumption, which can be used to evaluate hazard reduction and site preparation. It also gives an estimate of available fuel for reporting smoke conditions to State air pollution agencies.

The stereo photos and supporting documentation are useful in planning. The actual costs of treating a unit can be used in appraising disposal costs in units projected to have similar loadings. The system also ensures that a new fuels manager will have the benefit of the previous manager's experience.

Advantages of Stereo

Stereo photos have an advantage over single-frame photos because the depth of field increases the resolution of fuel elements, making it easier to relate photographs to actual conditions. It is also easier to use the stereo photos when estimating fuel loadings on un-inventoried units. Because individual fuel elements are easier to see, the user can envision the proportion of size classes in the fuel complex. This makes interpreting photographs easier, thus allowing a better estimate of fuel loading.

> Complex management needs require burning prescriptions to be more finely tuned than ever before.

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POSITIVE EFFECTS OF PRESCRIBED BURNING ON WILDFIRE INTENSITIES*

James A. Helms

Prescribed burning has existed in the South since early habitation. Indians and settlers were burning the woods to make use of the positive aspects of fire. Today the modern forest manager still uses fire to enhance resource management. Controlled fire is used to meet management prescriptions relating to hazard reduction, site preparation, control of undesirable plant species, wildlife habitat improvement, Brown-spot Needle Blight control, and range improvement.

This article documents and analyzes two case examples where the fuel reduction resulting from prescribed burning had positive results in aiding wildfire suppression.

Benefits

Documentation of the actual modification of wildfire intensity in prescribed burn areas has been neglected. Two case histories are outlined here to show how two wildfires were affected. No attempt has been made to completely analyze or justify the cost of the hazard reduction job in light of the positive effect on suppression efforts or resource damage. However, emphasis is given to the identification, location, and recognition of recent prescribed burn areas as an integral part of initial attack dispatch plans.

> These benefits now need to be documented and compared with actual effects on wildfire.

The Blountsville Fire

During the early morning hours of April 4, 1978, the Blountsville Fire was one of a series on the Chattahoochee–Oconee National Forest in Georgia (fig. 1). It started some distance from the main groups of fires and went undetected until 11:45 am. Even though initial attack was prompt, the fire had already gained momentum and required extended initial attack by all the state tractor plow units in the county plus tractor plow units from private industry, the USDA Forest Service, and two state units from adjacent counties. The conditions of the fire are listed in table 1.

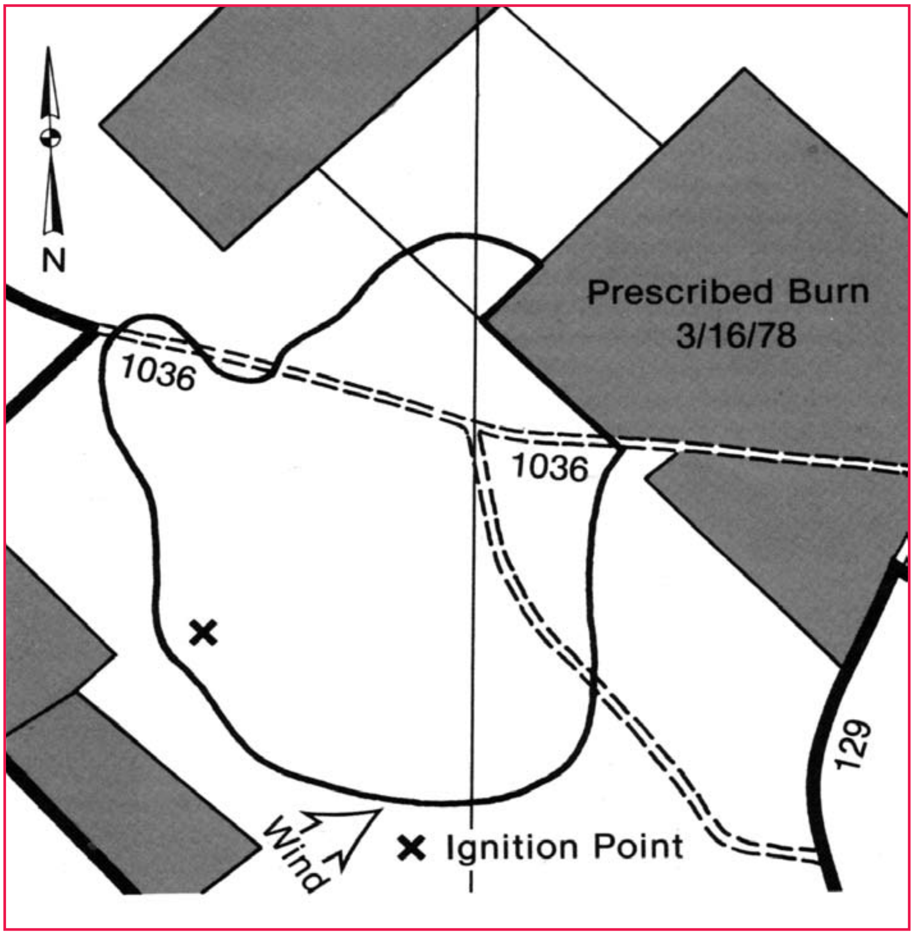

Figure 1—*The Blountsville Fire.*

When this article was originally published in 1979, James Helms was a regional fire coordinator and fire management specialist for the USDA Forest Service, Southern Region, Atlanta, GA.

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* The article is reprinted from *Fire Management Notes* 40(3) [Summer 1979]: 10–13.

The fire was burning in an 8-year-old loblolly pine plantation (fig. 2). Fuels were 2 to 6 tons per acre (5–14 t/ha) of perennial grass and pine needles. It was spotting well ahead of the main fire. The fire burned into a 40-plus-year-old loblolly pine stand, where fuels were 6 to 8 tons per acre (14–18 t/ha), and jumped a 20-foot (6-m) dirt road. To this point, control efforts were futile. After the fire crossed the road, it burned into an area that had been prescribe burned 19 days earlier (fig. 3).

The change in fuel loading to less than 1 ton per acre (2 t/ha) caused an immediate reduction in intensity and rate of spread. The fire was quickly contained and attention turned to control lines around the flanks and rear.

Suppression action started at 12:20 p.m. and the fire was controlled at 5 p.m. the same day. Conjecture is that had the prescribed burn area not been there, the fire would have advanced another 60 to 80 chains (1.2–1.6 km) and increased another 300 acres (120 ha) in size before burning conditions moderated enough to slow it down.

The fuel reduction was enough to break up the head of the fire, reduce the intensity, and allow containment success.

The Woodpecker Fire

The Woodpecker Fire occurred on April 2, 1978, on the Biloxi Ranger

> The fuel reduction was enough to break up the head of the fire, reduce the intensity, and allow containment success.

Table 1—*Conditions on the Blountsville Fire.*

Factor	Measure
Dry bulb temperature	81°F (27.2 °C)
Relative humidity	36 percent
Fine fuel moisture	6 percent
Wind	West at 9 miles per hour (14 km/h)
Forward rate of spread	46 chains per hour (0.9 km/h)
Perimeter increase	143 chains per hour (2.9 km/h)
Byram's Fireline Intensity	260 Btu/sec/ft (900 kW/m)
Flame length	5 to 6 feet (1.5–1.8 m)
Keetch-Byram Drought Index	196

Figure 2—*Blountsville Fire fuel type.*

Figure 3—*Fuels 19 days after prescribed burn.*

District, DeSoto National Forest in Mississippi (fig. 4). This was a 346 acre (140 ha) fire that burned in the area that was prescribe burned in January 1976. The fire burned hot and moved fast, but damage was light, even on 95 acres (38 ha) of pine plantation.

This fire was started by an incendiarist on National Forest land. It was set in at least seven different places. District forces were committed on other fires and the reassignment of attack forces caused a 25-minute delay in initial attack. This allowed the fire to gain momentum that carried it to Class E—300,999 acres (121,810 ha)—size. Initial attack was with two tractor plow units. Follow-up was with another tractor plow unit and 22 people.

The fire had a forward rate-of-spread of 30 chains per hour. Flame length averaged 5 feet (1.5 m). Wind gusts up to 12 miles per hour (19 km/h) caused short periods of spread and intensity above this. Average intensity was computed at 210 Btu/sec/ft (725 kW/m) (Byram's fireline intensity). Because of the 1976 prescribed fire treatment, fuels consisted almost exclusively of pine needles and grass litter (fig. 5). The intensity level of 210 Btu's was of very short duration, which reduced the damage potential considerably.

Spotting did occur, but the flaming brands were light and didn't persist long enough to cause long-distance spotting. Had heavier fire brands been available, conditions were favorable for long-distance spotting. Again, these favorable factors were the result of the fuel reduction effected by prescribed burning.

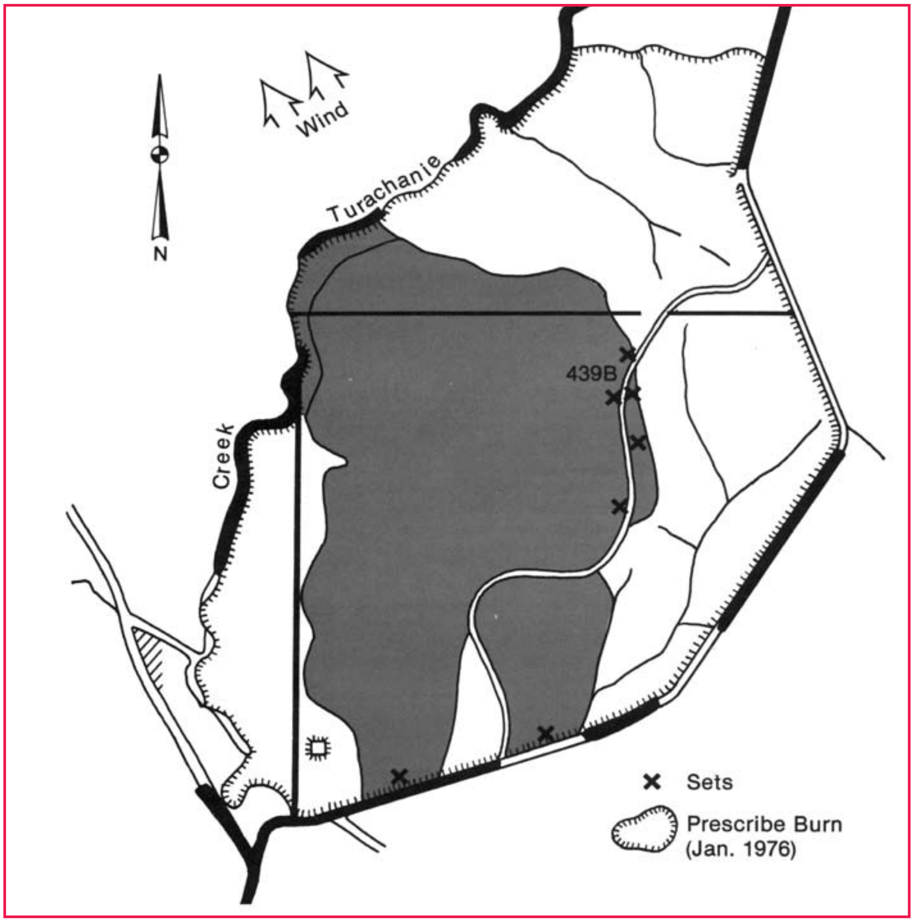

Figure 4—*The Woodpecker fire*

Figure 5—*Woodpecker fire fuel type.*

These factors made it possible for suppression forces to use both constructed and natural barriers for control lines. Strategy was developed with the knowledge that the area had been burned by prescription 2 years earlier. Had the fuel not been reduced or altered by prescribed fire, the creek shown on the north end (fig. 6) of the fire would not have been sufficient for a control line. Spotting would have carried the fire over the creek. Control from that point on would have been very difficult.

Knowing the fuel condition and the fire behavior probabilities allowed the fire boss to determine early in the effort that his current forces would be sufficient. This was very important since the district and its neighbors were still experiencing new fire starts. This decision freed other district and co-op forces to attack and control the new fires in a timely manner.

Figure 6—*Unburned 8- to 10- year loblolly fuels*

Positive Effects

These two cases document some positive effects of the hazard reduction of prescribed fire. These factors can:

- Reduce fire intensity,
- Reduce resistance to control,
- Reduce heat persistence and corresponding damage potential,
- Reduce suppression forces needed for containment/enhance use of natural barriers,
- Reduce mopup and patrol time,
- Give fire bosses an easily identifiable, positive factor in formulating strategy and deploying forces, and
- Increase production rates of line building equipment.

These positive effects are significant factors in cost-benefit analysis when planning and budgeting a prescribed burning program. The results should be carefully documented and made available for dispatcher use in initial fire attack planning.

Summary

In summary, the positive effects of hazard reduction by prescribed fire have been expressed frequently. These benefits now need to be documented and compared with actual effects on wildfire. ■

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THE COLE BROADCAST BURN*

James B. Webb

In recent years, the positive aspects of underburning using prescribed fire have been extolled by fire managers. Many of the claims have been perceived as less than credible. Our horizons are perpetually expanding with each proven application of fire as a management tool (Martin and Dell 1978). Credibility is also improving as proof points to success. This article is presented as further evidence of the useful role fire can serve in forest management.

Prescribed fire is indeed a viable tool to treat thinning slash in pole-size Douglas-fir and western larch.

Tonasket Example

The use of fire to modify the fire hazard in precommercial thinning slash on the Tonasket Ranger District, Okanogan National Forest, started 5 years ago. Thinned stands composed primarily of ponderosa pine were the first areas to be treate[illegible] the sugge[illegible]nland Dougl[illegible]ch led fire m[illegible]te using fire to[illegible]n stands heavil[illegible]pecies.

positiveeffectsofprescribedburningonwildfireintensities

A test plot in the Cole Creek Drainage, Tonasket Ranger District, containing 150 acres (60 ha) was prepared for burning. The plan was to burn a 20 acre (8 ha) plot under a specific prescription. If that prescription looked acceptable, the remaining 130 acres (50 ha) were to be burned within the same general parameters.

Downed fuel inventories on the area indicated discontinuous fuel accumulation (table 1).

Most of the fuel resulted from thinning 5 to 6 inch (13–15 cm) d.b.h. Douglas-fir 12 years before. The residual stand consisted of 7 to 8 inch (18–20 cm) d.b.h., 60-percent Douglas-fir and 40-percent western larch, on a 12- by 12-foot (4-m × 4-m) spacing. Slope averaged 20 percent with a northeast aspect.

The objectives of the burn were to:

- Determine feasibility of treating heavy thinning slash in Douglas-fir and western larch type;
- Remove 90 percent dead woody material, 0 to 3 inches (0–7.6 cm) category;
- Remove 40 percent dead woody material, less than 3 inches (> 7.6 cm) category;
- Improve site preparation for ponderosa pine seed in unstocked openings; and
- Retain the residual stand in vigorous condition.

To accomplish the objectives, a prescription range was developed (table 2).

Table 1—*Fuel accumulation—Cole Broadcast Burn.*

Size class	Plot 1		Plot 2		Plot 3	
	tons/acre	t/ha	tons/acre	t/ha	tons/acre	t/ha
0–0.25 inches (0–0.64 cm)	1.16	2.60	0.08	0.18	9.32	20.89
0.25–1 inches (0.64–2.5 cm)	2.28	5.11	2.28	5.11	9.89	22.17
1–3 inches (2.5–7.6 cm)	4.00	9.67	2.00	4.48	22.02	49.36
3 inches (7.6 cm) sound	23.82	53.40	0.00	0.00	9.23	20.69
3 inches (7.6 cm) rotten	38.77	86.91	0.00	0.00	0.00	0.00
Total	70.03	156.99	4.36	9.77	50.46	113.12

When this article was originally published in 1980, James Webb was a district ranger for the USDA Forest Service, Tonasket Ranger District, Okanogan National Forest, Okanogan, WA.

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* The article is reprinted from *Fire Management Notes* 41(3) [Summer 1980]: 3–4.

The Prescribed Fire

The desired weather conditions prevailed for several days in mid-October. We burned the 20 acre (8 ha) test plot with slow backing fires set along numerous interior lines that ran parallel to the contours. The lines were 3 to 5 chains (60–100 m) apart. Flame heights seldom exceeded 3 feet (1 m) and averaged 18 inches (46 cm). Gusty winds to 10 miles per hour (16 km/h) dispersed the smoke and heat well. Temperatures ranged from 45 °F to 50 °F (7–10 °C), with relative humidity varying from 35 to 45 percent. Fuel moisture sticks held at 11 to 12 percent.

The original 20-acre (8-ha) test plot looked good (fig. 1). On that basis, we continued the burn to cover the full 150 acres (61 ha). All initial impressions seemed to verify our premise that prescribed fire was indeed a viable tool to treat thinning slash in pole-size Douglas-fir and western larch.

Figure 1—*A pocket of fuel remaining after the burn was completed provides a good indication of preburn conditions.*

Postburn Analysis

Several post-burn analyses have been completed. They included visits to the site by a soil scientist, silviculturist, wildlife biologist, ecologist, entomologist, and numerous miscellaneous interested folks. All objectives were met. Seventy-five percent of the dead fuel greater than 3 inches (7.6 cm) in size was consumed. Only 2 percent of the residual stand died after the burn. Insect numbers did increase slightly immediately after the burn. Soil disturbance was lighter than originally predicted. Only 15 percent of the humus layer burned to expose mineral soil.

Because the fall burn consumed considerable amounts of large fuel, we conducted a spring burn under the same prescription on an additional 65 acres (26 ha). Results were much the same in all but the large logs and stumps. They showed less consumption due obviously to higher spring moisture content.

The most encouraging thing about using fire in this way is the low per-acre cost and environmental compatibility. For $9.56 per acre we were able to accomplish what normally cost $60 per acre to machine pile and $200 per acre to hand pile. Burning actually resulted in less soil disturbance than by either piling process.

Numerous resource management specialists from various disciplines have looked at the Cole prescribed underburn. With few exceptions, they are enthusiastic about the opportunity we have to add fire to our management tools. Additional applications will surface as fire managers' knowledge increases.

Table 2—*Prescription range developed to accomplish prescription burning goals on the Cole Creek Drainage, Tonasket Ranger District.*

Measure	From	To
Fuel stick moisture	10%	22%
Relative humidity	25%	45%
Windspeed	4 mph (6 km/h)	10 mph (16 km/h)
Wind direction	Northerly	
Temperature	45 °F (7°C)	65 °F (18°C)

Reference

Martin, R.E; Dell, J.D. 1978. Planning for prescribed burning in the Inland Northwest. Gen. Tech. Rep. PNW–76. Portland, OR: USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. ■

STAGE UNDERBURNING IN PONDEROSA PINE*

John Maupin

Underburns are conducted for range and wildlife habitat improvement, silvicultural objectives, visual resource management, and fuel reduction. Fuel reduction underburns are used for disposing of thinning, timber slash, and natural fuels.

Underburning is cost competitive with other methods of fuel treatment and provides other benefits, such as nutrient recycling, browse regeneration, and pruning of the residual stand. Also, burning avoids the adverse effects, such as soil compaction, of machine treatment methods.

The Ochoco National Forest, located in central Oregon, has embarked on a major underburning operation. In 1980, the forest conducted first entry underburns on about 4,000 acres (1,600 ha) of ponderosa pine. Plans call for increasing the program to about 8,000 acres (3,200 ha) in the next few years.

Historically, pine stands on the Ochoco were visited by low intensity fires at intervals of 2 to 15 years. These fires kept natural fuel levels low. However, effective fire suppression has resulted in a buildup of natural fuels such as litter, heavy logs, brush, reproduction, and snags.

Under present conditions, first entry underburns in ponderosa pine present a challenge to the fire manager since, in many cases, natural fuels may total 30 tons per acre (67 t/ha) (fig. 1). Also, the lower canopy level of the overstory is close to the ground and therefore very susceptible to scorch. Consequently, the prescribed fire manager must use techniques that limit damage to the residual stand.

After heavy fuels are reduced, the second stage burn can be conducted with a prescription that will produce desired fuel reduction throughout the unit (fig. 2).

The prescription for stage burning usually centers on control of flame length. Maximum permissible flame length in any given stand depends on ambient air temperature, canopy windspeed, and slope. Flame length can be largely controlled by firing technique. For instance, narrow strip head fires will produce shorter flame lengths than wide strip head fires.

First entry underburns require strong commitment from the resource manager. Burning costs and damage potential will be high on first entry burns. After the first entry, however, costs of maintenance burns fall off dramatically and damage potential is negligible. ■

Figure 1—*Fuels of 30 tons per acre (67 t/ha), prior to first stage burn.*

Figure 2—*Fuels remaining after second stage burn.*

When this article was originally published in 1981, John Maupin was a fire staff officer for the USDA Forest Service, Ochoco National Forest, Prineville, OR.

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* The article is reprinted from *Fire Management Notes* 42(3) [Summer1981]: 16–17.

PRELIMINARY GUIDELINES FOR BROADCAST BURNING LODGEPOLE PINE SLASH IN COLORADO*

G. Thomas Zimmerman

Lodgepole pine (*Pinus contorta*) is a highly important species in forest management in Colorado. Combinations of a very widespread range, considerable acreage supporting large volumes, and wide ecologic amplitude contribute to the high value of this species (Wellner 1975). Because of its importance, lodgepole pine stands are intensively managed for wood fiber production in northern Colorado.

But on many sites, insufficient natural regeneration is occurring following timber harvesting. Artificial regeneration following machine piling and burning also fails to produce desired stocking levels.

The depth of forest floor duff layers in these stands appears to be the principal cause of regeneration failure. The germination of lodgepole pine seed is favored by full sunlight; seedlings develop best in mineral soil or disturbed duff free of competing vegetation (Pfister and Daubenmire 1975). Duff layers common to lodgepole pine stands in the Intermountain Region are usually shallow and seldom average more than 2 in (5 cm) (Brown 1975).

In northern Colorado, Alexander (1979) found duff layers as deep as 3.6 inches (9 cm). Depths exceeding 4 inches (10 cm) were found in some of the clearcuts burned in this study. Seeds from surrounding trees apparently germinate in duff rather than mineral soil and perish during droughty summer months. Machine piling followed by burning fails to scarify enough area for natural restocking. Planting in thick duff layers becomes labor intensive and costly.

> Prescribed broadcast burning of clearcut logging slash successfully and safely reduces slash buildups and forest floor duff layers.

The importance of fire in establishing proper site conditions for lodgepole pine regeneration is well known (Brown 1975). Broadcast burning can destroy unopened cones present in slash. Alexander (1966) observed less natural regeneration on burned plots than on either undisturbed or disturbed mineral soil plots. However, Lotan and Perry (1976) state that broadcast burned areas may be the most suitable for germination and survival of artificially applied seeds, although true ash surface effects on germination were not reported.

In Colorado, little research has been conducted, or experience gained, regarding burning prescriptions, firing techniques, and duff reduction in lodgepole pine stands. Adams (1972) compared natural regeneration following broadcast burning with other slash disposal methods but presented no information pertaining to the actual burning.

Data collected during experimental fires in lodgepole pine slash have been used to develop preliminary guidelines for prescribed burning in southwestern Alberta (Quintilio 1970, 1972). These guidelines relate rate of head fire spread and depth-of-burn to the appropriate components of the Canadian Forest Fire Weather Index System.

In an attempt to improve regeneration success following logging, personnel from the USDI Bureau of Land Management (BLM) conducted broadcast burning in lodgepole pine clearcut areas. This report summarizes the results obtained from the initial prescribed burning trials.

Site Description and Methods

Lodgepole pine forests represent the principal vegetative type present. Prior to logging, stands were comprised of an average of 218 merchantable and 138 cull stems per acre (respectively, 539 and 341 per hectare). Harvest operations removed a gross volume

When this article was originally published in 1981, Thomas Zimmerman was a graduate student in the Department of Forest and Wood Sciences at Colorado State University, Ft. Collins, CO, and a former fire management officer for the USDI Bureau of Land Management, Craig District Office.

* The article is reprinted from *Fire Management Notes* 43(1) [Winter 1981–82]: 17–22.

of nearly 11,000 board feet per acre (64 m^3/ha) and were completed during the summer of 1979. Following timber removal, all remaining standing stems were felled into the burn units. Prescribed burning was carried out on numerous clearcut blocks ranging in size from 3 to 10 acres (1.2–4 ha) with results presented from three representative units.

Downed woody fuel accumulations were measured by the planar intersect method (Brown 1974). Permanent fuel inventory transects were established along lines running upslope through each burn unit. Duff measurements taken along these transects refer to the sum of the fermentation layer (F), material starting to discolor and break down because of weather and microbial action, and the humified layer (H), where decomposition has advanced.

Weather conditions were measured on the site prior to and during burning with the components of a standard belt weather kit. Variables measured include: dry bulb temperature, relative humidity, wind speed, and wind direction.

Fuel moisture contents (10-hour timelag) were measured by weighing a standard array of 0.5-inch (1.3-cm) ponderosa pine fuel sticks (Deeming, et al. 1977).

Prescribed burning was carried out during late September and early October. On all units, ignition was started at 1 p.m. each day with drip torches used as ignition devices. Firing techniques used inclued: strip head, backing, and ring center fires.

Preburn Fuel Description

As is characteristic in lodgepole pine forests following timber harvesting, logging residues accounted for the majority of downed woody fuels (fig. 1). In all units burned, fuel particles in the greater than 3-inch (7.6-cm) sound size class comprised the majority of slash fuels (fig. 2). Fuels in the greater than 3-inch (7.6-cm) rotten size class were noticeably absent in all burn units (fig. 2).

Figure 1—*Preburn fuel conditions.*

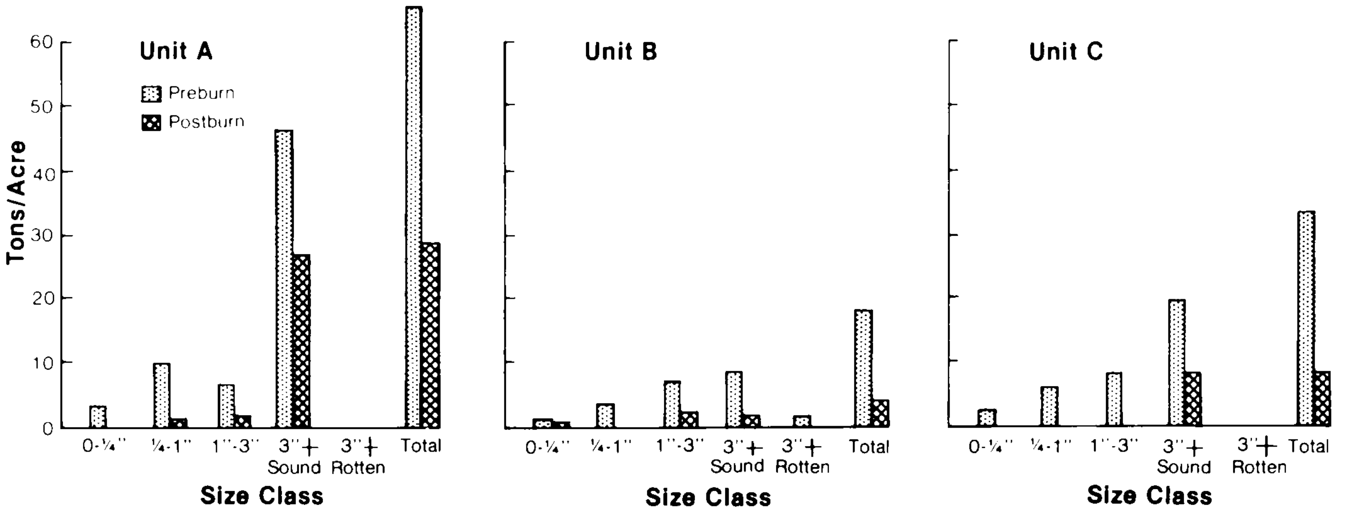

Figure 2—*Concentration of fuels in burned units.*

Preburn measurements showed that Unit A contained the greatest fuel concentration, totaling 65.64 tons per acre (147.15 t/ha) of downed woody materials. The sparsest concentration of fuels, 17.60 tons per acre (39.46 t/ha) was found in Unit B before burning. Unit C contained 40.68 tons per acre (91.20 t/ha) of woody fuels.

Weather Conditions

Weather measurements indicated that conditions during burning of Unit A involved the highest relative humidity and lowest wind speed and fuel moisture encountered during all burning (table 1). Conditions changed slightly during the burning of Unit B with decreases in temperature and relative humidity while wind speed increased. Fuel moisture in this unit was the highest measured during all burning. Weather conditions experienced while burning Unit C included the warmest temperature, lowest humidity, and highest consistent wind speeds (table 1).

Fire Description

No precipitation fell on the areas for nearly 3 weeks before burning. In units where strip head fires were used, uphill control lines were burned out initially, then strips of 15 to 100 feet (4.6–30 m) in width were ignited downslope. Strip head fire intensities varied with the strip width. Lowest intensity was observed where the fires backed downhill. Maximum intensity, highest flames, and greatest vertical convection occurred where head fires from one strip and backfires from a previous strip burned together (fig. 3).

Broadcast burning destroys the potential seed source near the ground but can generate sufficient heat to open serotinous cones of standing trees.

The ring center firing technique created a situation where indrafts drew heat away from surrounding tree crowns and fuels. Firebrands generated by this high intensity fire were drawn upward with the smoke column and traveled considerable distances before coming into contact with unburned fuels.

Maximum distances traveled by these firebrands were not estimated and no spot fires occurred during use of this firing method. Because of the lack of firebrand spotting, this method was extremely successful on flat areas completely surrounded by live trees. However, the extreme heat generated resulted in crown scorch and mortality of trees around the perimeter.

No problems occurred with mop-up of any units. Spot fires caused by burning embers transported across the firelines occurred most often when temperatures were above 70 °F (21 °C) and relative humidities below 25 percent. Burning during these conditions required more holding forces. Maintaining control of the burn became quite labor intensive.

Figure 3—*Strip head fire on a clearcut lodgepole pine area managed by the USDI Bureau of land Management.*

Table 1—*Weather measurements.*

Unit	Temperature °F	Temperature °C	Relative humidity	Windspeed mph	Windspeed km/h	Wind direction	Fuel moisture (10-hr. timelag)
A	55	13	40%	2	3.2	SE	9.5%
B	54–56	12–13	31–37%	0–6	0–9.6	NW	12.5%
C	70	21	25%	3–5	4.8–8	SE	11.5%

Fuel Reduction

Fuel consumption by prescribed burning varied with the firing techniques used, weather conditions, preburn fuel loading, and duff depth (fig. 4). In Units A and C greatest reductions were observed in all size classes less than 3 inches (7.6 cm) (fig. 2). Unit B, which had the lowest amount of fuel greater than 3 inches (7.6 cm) (chiefly sound), had the highest percent reduction of any unit in this size class.

Total fuel reduction in Unit A was 57 percent and left postburn levels of downed woody fuel at 28.5 tons per acre (63.9 t/ha) (fig. 2). Unit B post burn fuels totaled 8.81 tons per acre (19.75 t/ha), a reduction of 83 percent. Burning in Unit C resulted in a reduction of 75 percent, leaving the postburn level at 9.36 tons per acre (20.98 t/ha). Reductions of 100 percent were observed in all size classes less than 3 in (7.6 cm) in this unit.

Depth of burn varied from 0.44 to 3.68 inches (1.12–9.35 cm) (table 2). Following burning, duff depths were 0.6, 0.4, and 0.06 inches (1.5, 1.0, and 0.15 cm) for Units A, B, and C, respectively. Duff reduction exceeded 40 percent in all three clearcuts and was greatest in Unit B, which also had the greatest depth prior to burning.

Figure 4—*Postburn conditions of lodgepole pine clearcuts.*

Table 2—*Preburn duff loading/depth and duff removal by prescribed burning.*

Unit	Weight*		Depth		Reduction	Depth of burn	
	tons/acre	t/ha	in	cm		in	cm
A	15.52	34.79	1.07	2.72	44%	0.47	1.19
B	59.16	132.62	4.08	10.36	90%	3.68	9.35
C	7.25	16.25	0.50	1.27	88%	0.44	1.12

* Computed by the formula: mean depth x 14.5 = tons per acre (on file at Northern Forest Fire Lab, Missoula, MT).

Summary

Prescribed broadcast burning of clearcut logging slash successfully and safely reduces slash buildups and forest floor duff layers and prepares sites for natural and artificial regeneration in Colorado lodgepole pine communities. Because lodgepole pine regeneration is prolific following wildfires, prescribed burning is a method of site preparation that can approximate natural conditions.

When adequate surface fuels are present to support fire spread, strip head fires and backfires can be used. Strip head is the most versatile method of prescribed burning and allows the firing boss to control the level of fire intensity (Martin and Dell 1978). Backfires are the gentlest and slowest moving fires (Martin and Dell 1978). Successful backfires require lower fuel moisture content and better fuel continuity than head or strip head fires.

Ring center fires can be used where heavy fuel buildups are present on relatively flat slopes. This firing technique develops high intensity fires, rapid burnout, and vertically dispersed smoke. Martin and Dell (1978) state that this technique can be used where available fuels can produce sufficient intensities to overcome winds and where there is no concern for live trees inside the burn unit.

Prescribed broadcast burning of clearcut logging slash in Colorado lodgepole pine forests will produce satisfactory results when carried out under the following conditions:

- Temperature (dry bulb): 54 °F to 70 °F (12–21 °C)
- Relative humidity: 25 to 40 percent
- Windspeed: 0 to 6 miles per hour (0–9.6 km/h)
- 10-hour timelag fuel moisture: 9.5 to 12.5 percent

Weather conditions pose one of the principal limitations when attempting to use fire as a tool in forest management.

Although desired results were achieved with this prescription, adequate advance preparation and control planning can permit completion of prescribed burning on specific sites under different weather conditions. For example, while the prescription lists wind speed as 0 to 6 miles per hour (0–9.6 km/h), subsequent fires were safely carried out with wind speeds as high as 18 miles per hour (29 km/h).

Weather conditions pose one of the principal limitations encountered when attempting to use fire as a tool in forest management. In northern Colorado during the peak burning period, low humidities and variable, gusty winds are prevalent. Frequent high temperatures must also be considered because they can be responsible for increases in fire intensity and the likelihood of erratic fire behavior due to the preheating of fuels, decrease in humidity, and increase in unstable air from ground heating (USDA Forest Service 1973). These conditions drastically limit the number of suitable burning days.

Questions also arise concerning the effects of fire on growing conditions for artificial regeneration, particularly surface soil temperature changes. Endean and Johnstone (1974) have attributed better survival and growth of planted stock to slash removal and seedling placement. Fuel and duff consumption by fire can also facilitate easier, more efficient planting and lower susceptibility to mortality from droughty summers.

Leaving residual trees rather than felling them may provide a natural seed source. Broadcast burning destroys the potential seed source near the ground but can generate sufficient heat to open serotinous cones of standing trees.

However, because the seed trees are not sufficiently wind firm or fire resistant and require heat above the safe hazard level to open the cones, Endean and Johnstone (1974) have suggested that lodgepole pine seed trees show no promise as a seed source in combination with prescribed burning. But, where long-term survival of residual trees is not a prerequisite to burning, the use of broadcast fire may stimulate the opening of serotinous cones.

While the results and suggestions presented in this report are preliminary, it appears that prescribed fire can be used for reduction of slash fuels and site preparation in clearcut lodgepole pine forests. Perhaps these preliminary guidelines will be a starting point in the development of sound programs of fire use to achieve desired forest management objectives.

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UNDERBURNING TO REDUCE FIRE HAZARD AND CONTROL IPS BEETLES IN GREEN THINNING SLASH*

Dick Smith, Robert Mrowka, and John Maupin

Slash from precommercial thinning in ponderosa pine creates a fire hazard and potential reservoir for insect infestation. Historically, thinning slash has been treated by mechanical means or by handpiling and burning. Mechanical treatment often causes adverse impacts such as soil compaction and damage to the residual stand. Handpiling, the alternate method, is very expensive.

In an attempt to find an economical and environmentally acceptable method of hazard reduction, the Snow Mountain Ranger District of the Ochoco National Forest began underburning green thinning slash.

Site Description

The first burn area consisted of a 14-acre (6-ha) ponderosa pine site at an elevation of 5,000 feet (1,500 m). Slope was less than 10 percent on a western exposure. The stand contained 960 trees per acre (2,370 trees/ha) before thinning. In January 1981, the stand was thinned to a spacing of 18 feet by 18 feet (5.5 x 5.5 m). Trees over 7 inches (18 cm) in diameter at breast height (d.b.h.) were not thinned unless they were deemed undesirable. Seedlings were not thinned since they would be killed by the underburn. Slash was lopped to less than 2 feet (0.6 m) to keep average flame length around 3 feet (0.9 m).

> The burn produced temperatures high enough to significantly reduce Ips emergence from slash in July and August.

A post-thinning exam of permanent plots revealed 284 trees per acre (702 trees/ha), ranging from seedlings to trees 40 inches (102 cm) in diameter. Average d.b.h. measurements were 8.4 inches (21 cm).

Fuel loading ranged from 8 to 12 tons per acre (18–27 t/ha), with the majority of fuel in the 0.3-inch (0.8 cm) class. Ips entrance holes were very numerous in slash on the site. No formal survey was conducted, but brood levels appeared to be moderate.

Burn Objectives

The objectives of the burn were to:

- Remove up to 90 percent of fine fuels (primarily needles),
- Remove no more than 40 percent of duff cover,
- Maintain 100 to 225 trees per acre (250–550 trees/ha),
- Limit scorch to 50 percent of green crown on leave trees, and
- Destroy most of the second hatch of Ips pine engraver beetles in the slash prior to midsummer emergence (Mitchell and Martin 1980).

The Prescription

Table 1 is a prescription developed in hopes of producing a maximum flame length of 4.5 feet (1.4 m), with a desired average of 3 feet (0.9 m).

Since the critical item of the prescription was green fuel moisture, the rate of needle cure was monitored closely. Had green needles cured completely, it would have been difficult to obtain the desired 3-foot (0.9-m) flame length.

Table 1—*A prescription to produce a maximum flame length of 4.5 feet (1.4 m) and an average of 3 feet (0.9 m).*

Factor	Maximum	Minimum
Fine fuel moisture	12%	8%
Relative humidity	45%	30%
Windspeed	10 mph (16 km/h)	4 mph (6 km/h)
Temperature	75 °F (24 °C)	40 °F (4 °C)
Green fuel moisture	50%	40%

When this article was originally published in 1983, Dick Smith was a fuels management technician, Robert Mrowka was a silviculturist, and John Maupin was a fire management officer for the USDA Forest Service, Snow Mountain Ranger District, Ochoco National Forest, Prineville, OR.

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* The article is reprinted from *Fire Management Notes* 44(2) [1983]: 5–6.

Ignition was planned for the cure phase when needles were still green and contained enough moisture to have a dampening effect on the fire, yet dry enough to be consumed.

Firing

Firing started at 5:30 p.m. on June 4 and was completed in 3 hours. Strip head fires with a firing width of 10 to 15 feet (3-5 m) were used. This strip width produced the desired flame length of 3 feet (0.9 m). Conditions at ignition time were:

- Relative humidity: 38 percent,
- Windspeed: 5 to 8 miles per hour (8–13 km/h),
- Green fuel moisture: 50 percent, and
- Temperature: 70 °F (21 °C).

Results

Approximately 75 percent of fine fuels were removed. A decrease in windspeed midway through the burn probably reduced fine fuel consumption.

Less than 40 percent of the duff cover was removed, and average crown scorch on trees left standing was 12 percent.

> Timber and fire management personnel are enthusiastic about the operation and have planned several additional burns.

An examination of the postburn stand revealed that 196 trees per acre (484 trees/ha) remained. These trees ranged from 1 to 40 inches (3–102 cm) in d.b.h., with an average size of 10 inches (25 cm) in d.b.h. Two-thirds of all trees less than 4 inches (10 cm) in d.b.h. were removed; larger, more desirable trees were retained.

The burn produced temperatures high enough to significantly reduce Ips emergence from slash in July and August. No Ips infestation of living trees had occurred as of December 1981. Low numbers of Ips emergence holes were noted in mortality trees with high scorch levels. Ips may have contributed to the demise of these trees.

Approximately 3 percent of residual trees were infected by turpentine beetles. No mortality has occurred in these trees. No attacks by western pine beetles or mountain pine beetles have been observed.

Costs for the burn were approximately $40 per acre. Since it was necessary to conduct the burn after normal working hours to meet the prescription, much of this cost was due to overtime salaries.

Summary

The overall objectives of the burn were met. Timber and fire management personnel on the ranger district are enthusiastic about the operation and have planned several additional burns. It is felt that leave-trees should be a minimum of 3 to 4 inches (8–10 cm) in d.b.h. and 20 feet (6 m) tall before this treatment should be attempted.

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A MATRIX APPROACH TO FIRE PRESCRIPTION WRITING*

Steven Raybould and Tom Roberts

Writing fire prescriptions is a formal procedure by which most prescribed fire managers set fire behavior determinants within certain limits. The limits are usually a combination of fire behavior modeling (Albini 1976) and the fire manager's personal experience. They include both "fixed" and "variable" elements (Green 1981), often expressed as ranges:

A. Fixed Indicators

- Dead fuel: 50+ percent
- Live fuel moisture: 80+ percent
- Average slope: 35 percent
- Aspect: Northwest
- Continuity of fuel: 80 to 90 percent
- Season: February 15 to June 30

B. Variable Indicators

- Fuel stick moisture (10 hours): 9 to 12 percent
- Relative humidity: 20 to 35 percent
- Windspeed: 0 to 10 miles per hour (0–16 km/h)
- Air temperature: 60 °F to 80 °F (16–27 °C)
- Time of day: 8:30 a.m. to 4 p.m.

Prescriptions thus derived are intended to produce fires intense enough to achieve the objectives of the fire and manageable enough to control with a cost-effective effort.

When this article was originally published in 1983, Steven Raybould was a fire prevention officer and Tom Roberts was a wildlife biologist for the USDA Forest Service, San Bernardino National Forest, San Jacinto Ranger District, Idyllwild, CA.

> Our solution was to devise a system that would more closely reflect the subtle ways different prescription elements interact.

The Problem

A fire prescription is usually a simple list of estimated or premeasured values for the fixed elements and a list of acceptable ranges for the variable elements on the day of the burn, as tabulated above.

During the development of a prescribed fire program on the San Bernardino National Forest in California, we found this approach to be unnecessarily restrictive. The separate elements in a prescription are not closely interrelated. Windspeed, for example, has little to do with relative humidity; 10-hour fuel sticks can read quite low on a dry day, but green fuel moisture might be high.

Thus, while general and long-term trends will push all indicators in the same direction (toward "hotter" or "cooler" conditions) during any given burning period, indicators can act in ways that offset each other.

We commonly encountered situations where one element was out of prescription on the "hot" side and one was out on the "cool" side. Rather than seeing these as two reasons not to do the burn, experience and theory told us that the two elements would compensate for each other and that the burn could proceed safely. For legal reasons, however, this was not possible.

Approved burn plans represent formal authorization to take certain acceptable risks on behalf of the USDA Forest Service. The project or prescribed fire manager is usually not free to make changes in the prescription without going through the time-consuming process of reapproval.

The Prescription Matrix

Our solution to the problem was to devise a system that would more closely reflect the subtle ways in which different prescription elements interact. At the core of this approach is the severity level, expressed as a numerical range of "severity points." The concept of a severity level or range is far more useful than ranges of prescription elements, since humidity levels or fuel-stick readings are not important by themselves, but rather as determinants of how vigorously a fire will burn.

The severity levels are defined in conventional fire behavior terms in table 1. The point score, which determines if conditions are "in prescription," is determined by adding together individual scores read from a matrix (table 2). In the matrix, each prescription element,

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* The article is reprinted from *Fire Management Notes* 44(4) [1983]: 7-10.

Table 1—*Description of fire severity levels and corresponding fire behavior.*

Severity Level		Fire behavior description
Light burn	13 points 26 points	Up to 20 percent of the area will be burned. Most prescribed burns in 1-hour fuels occur in this range. There is very little ignition. Some spotting may occur, but is associated with winds above 9 miles per hour (14 km/h). Flame lengths will usually be a minimum of 2–3 feet (0.6–0.9 m); 0–55 Btu/sec/ft (0–190 kW/m).
		Charred leaf litter is produced when poorly aerated litter is not totally incinerated. Some grayish ash is present. Maximum temperature during this "black ash" condition is 350 °F (177 °C); soil surface temperature is 25 °F (4 °C) to 3 inches (7.6 cm) down. A light burn has less than 2 percent of area severely burned. The remaining area is lightly burned or not burned at all. Less than 40 percent of the brush canopy is consumed.
	29 points 39 points	Twenty to 40 percent of the area may be burned. This generally represents the limit of control for handcrews at the flaming front. Glowing brands could cause spotting below 50 percent humidity. Handlines should be able to hold the fire. Flame lengths will usually be a minimum of 3 to 4 feet (0.9–1.2 m); 56–110 Btu/sec/ft (194–380 kW/m).
Moderate burn	41 points 52 points	Forty to 50 percent of the area may be burned. The flaming front will be too intense for handcrews to work directly. Machines, engines, tractors, or indirect methods can be used successfully. Fuel burns easily. Flame lengths will usually be a minimum of 4 to 6 feet (1.2–1.8 m); 111–280 Btu/sec/ft (384–969 kW/m).
	65 points	The leaf litter and fine woody material is consumed, leaving a "bare-soil" condition. Maximum temperatures produced are 750 °F (399 °C); soil surface temperature is 550 °F (288 °C) to 3 inches (7.6 cm) down. A moderately burned area has less than 10 percent of the area severely burned and over 15 percent moderately burned. Between 40 and 80 percent of the area is consumed with the remaining charred twigs larger than 1/4 to 1/2 inch (0.6–1.3 cm) in diameter.
	70 points 78	Fifty to 60 percent of the area could be burned. Fuel has high ignitability, with occasional crowning and spotting caused by gusty winds; otherwise, moderate burning conditions. A standard handline might not hold the fire if there is considerable litter, rat nests, or grass across the line. Flame lengths should be the same height or greater than the fuel for a successful burn at this severity level. Flame lengths could be a minimum of 7 to 9 feet (2.1–2.7 m); 231–520 Btu/sec/ft (799–1,799 kW/m).
Severe burn	80	Sixty to 70 percent of the area will be burned. The fuel has quick ignition with rapid buildup. The heat load for anyone within 30 feet (9 m) is dangerous. However, the flaming front should only last a few minutes near the line. Flame lengths will usually be a minimum of 10 to 13 feet (3–4 m); 521–670 Btu/sec/ft (1,802–2,318 kW/m).
	91 98	Severe burns are typically characterized by a "white ash" condition. Maximum temperatures exceed 950 °F (510 °C); soil surface temperature exceeds 750 °F (399 °C) to 3 inches (7.6 cm) down. A severely burned area has more than 10 percent severely burned with more than 80 percent moderately or severely burned. Eighty percent of the brush canopy is completely consumed, leaving plant stems greater than 1/2 inch (1.3 cm) in diameter.
	104 110 117	Up to 80 percent of the area will be burned. Extended spotting and firewhirls could occur with fire behavior being on the extreme side. Any spot fires will spread rapidly. Suppression efforts at the head of the fire, without existing control lines, will be ineffective. Flame lengths will generally exceed 14 feet (4.3 m); 671–1,050 Btu/sec/ft (2,321–3,632 kW/m).

Table 2—*A fire prescription matrix. To find severity level, follow indicator column down to appropriate figure and then left to severity points. Total points for level of severity—use one half points as needed.*

Severity points	Indicators												
	Fixed								Variable				
	Average fuel depth: feet (m)	Continuity of fuel: % of cover	Dead fuel: % of total	Live fuel moisture: %	Slope: %	Aspect	Season	Model (SCAL)	Dead fuel moisture 10 hour stick: %	Relative humidity: %	Wind speed—mid-flame mi/h (km/h)	Temperature: ° F (°C)	Time of day
1	1 (0.3) 2 (0.6)	20	15	90	0	N	Spring April 15-30, May	G	15	60	0 (0)	20 (6.6)	7 p.m.
2		30	20	80	10				12	45	2 (3)	45 (7.2)	
3	3 (.9)	40	30	76	15 25	NE	Late spring Early summer June, July		10	35	4 (6)	59 (15)	9 a.m. 6 p.m.
4	4 (1.2)	41	31	75	30	E	Winter Jan., Feb.		9	34	5 (8)	60 (15.5)	10 a.m.
5	5 (1.5)	55	40	65	35	SE/ NW		B	7	29	6 (10)	70 (21.1)	5 p.m.
6		70	45	60	40 50	W	Early spring March, April 1-14		6	25	8 (13)	80 (26.7)	4 p.m.
7	6 (1.8)	71	46	59	55	SW	Early winter Dec.		5	24	9 (14)	81 (27.2)	3 p.m. 11 a.m.
8		80	55	50	60		Summer Aug., Sept.	C	4	19	10 (16)	89 (31.7)	2 p.m.
9	7 (2.1) 8 (2.4) 9 (2.7) 10 (3)	90	65	45	65 70	S	Fall Oct., Nov.		3	15	11 (18) 15 (24)	95 (35)	1 p.m. 12 p.m.

fixed or variable, can be assigned a value. In this way, a windspeed of 15 miles per hour (24 km/h)—point score 9—can be used to compensate for a high relative humidity of 50 percent—point score 1.

Either of these values would be "out of prescription" according to the old system of fixed and variable indicators. But windspeed compensates for high humidity (we have burned under these conditions). And, the score given by these values (10) is the same as that given by the "in prescription" values of windspeed of 6 miles per hour (10 km/h)—point score 5—and relative humidity 29 percent—point score 5.

The implication here is not that the fire will behave identically no matter how the score of 10 is derived, but that control will be possible with the same forces and that approximately the same percentage of the area will burn.

Limitations

The matrix uses eight fixed and five variable indicators. The point score assigned to an indicator is, of course, the aspect of the matrix that will prove or disprove the validity of this approach. Fire behavior determinants produce effects that are notoriously nonlinear. For example, according to the Fireline Handbook (USDA Forest Service 1980), rate of spread doubles when dead fuel moisture drops from 15 to 10 percent, but it triples between 10 and 5 percent.

> This matrix is an attempt to increase the prescribed fire manager's flexibility without sacrificing safety.

Fuel depths appear to have an essentially arithmetic relation to intensities up to a certain point, after which effect is much less (Cohen pers. comm.). It is worth noting also that even the most sophisticated fire behavior models do not always agree with observed fire behavior (USDA Forest Service 1980).

The point values given in table 2 represent a working compromise between fire behavior models available and experience of both researchers and fire managers. We anticipate many changes as the matrix approach is refined. Currently, we are doing chaparral burning with matrix prescriptions in the 41 to 78 range. Generally, prescribed fires have behaved in the manner predicted by the severity level score. However, the matrix underpredicts somewhat for windspeed and when chamise (*Adenostoma fasciculatum*) predominates on a site.

Summary

This matrix has been adopted by the San Bernardino National Forest. It is an attempt to increase the flexibility of prescribed fire managers without sacrificing safety.

Modifications of the point scoring system will occur as more information becomes available.

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UNDERBURNING ON WHITE FIR SITES TO INDUCE NATURAL REGENERATION AND SANITATION*

Gary J. Petersen and Francis R. Mohr

The Blue Mountains of eastern Oregon and southern Washington contain a wide range of vegetation types—from non-forested meadows and grassland plateaus to heavily forested steep mountain slopes.

Approximately 24 percent of the 278,000 acres (112,500 ha) on the La Grande Ranger District of the Wallowa–Whitman National Forest, La Grande, OR., is conifer stands of white fir (*Abies concolor*), grand fir (*Abies grandis*), or white fir–grand fir hybrids (*Abies grandis x concolor*), generally referred to as "white fir sites" or "white fir stands."

Past timber harvest activity on these sites frequently involved a silvicultural system of selectively cutting trees that had a high risk of mortality before the next scheduled harvest.

This high-risk management practice and the resulting postharvest site conditions caused increasing concern on the district. Following harvest, stands contained many trees heavily damaged with basal wounds, root or heart rot—laminated root rot (*Phellinus weirii*) or Indian paint fungus (*Echinodontium tinctorium*)—and high levels of suppressed growing stock. Advanced regeneration in some cases was so suppressed that 12 to 15 years later growth release had not yet released. Problems due to soil compaction and fuel buildup were also identified.

When this article was originally published in 1984, Gary Petersen was a silviculturist for the USDA Forest Service, La Grande Ranger District; and Francis Mohr was a fuels management specialist for the USDA Forest Service, Wallowa–Whitman National Forest, Baker, OR.

Prescribed underburning in shelterwoods was eventually chosen to manage white fir stands. Twenty-four units totaling 903 acres (365 ha) were underburned during the spring, summer, and fall months in 1980–83. The units, on slopes from 0 to 45 percent, varied in size from 13 to 185 acres (5–75 ha) and contained fuel loading estimates of up to 23 tons per acre (51 t/ha) in the 0 to 3 inches (0–7.6 cm) in diameter size class. Total fuel loading ran as high as 45 tons per acre (101 t/ha).

> This high-risk management practice and the resulting postharvest site conditions caused increasing concern on the district.

Site Description

A typical white fir underburn unit contained 14 large overstory shelterwood trees per acre, primarily Douglas-fir (*Pseudotsuga menziesii*), western larch (*Larix occidentalis*), and white fir at least 15 inches (38 cm) diameter at breast height (dbh). The trees were evenly spaced, full crowned, and free from defect. Often the understory trees numbered 3,000 to 4,000 stems per acre (7,400–9,900 stems/ha).

Preburn Preparation

Before burning, all understory trees less than 7 inches (18 cm) dbh (many of which were disease damaged or suppressed) were felled. This preburn activity contributed to the success of the underburn because it eliminated fuel ladder continuity and created a more uniform, horizontal fuel bed close to the ground. The resulting homogeneous fuel bed permitted more control of the fire behavior—a more evenly sustained fire versus erratic fire output. This fuel bed, in turn, widened the "burning window" (number of burning days available) in which it was possible to conduct the burn.

Burn Objectives

The objectives for this burning program were to expose mineral soil on at least 30 percent of the unit and to consume at least:

- 70 percent of the fuels 0 to 1/4 inch (0–0.6 cm) in diameter,
- 60 percent of the fuels 1/4 to l inch (0.6–2.5 cm) in diameter,
- 50 percent of the fuels 1 to 3 inches (2.5–7.6 cm) in diameter, and
- 10 percent of the fuels 3 inch and greater (≥ 7.6 cm) in diameter.

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* The article is reprinted from *Fire Management Notes* 45(2) [1984]: 17–20.

The constraints for this burn were to:

- Retain 50 percent of existing duff layer, and
- Kill no more than 50 percent of the trees over 20 inches (51 cm) dbh.

Burning Prescription and Implementation

The burning prescription established that a flame length not exceeding 5 feet (1.5 m) during 80 percent of the time of the burn was desirable. Because a wide range of temperatures and relative humidities could exist, careful monitoring of the ignition pattern and sequence would be necessary to manage the heat intensity. There were times when additional ignitions had to cease while heat from larger fuel material and concentrations dissipated.

Duff moisture and fine fuel moisture content were the critical environmental prescription elements for this prescribed burn. The prescription called for a duff moisture content range of 60 to 75 percent and a fine fuel moisture content of less than 10 percent. Duff in contact with larger size fuels or concentrations would be consumed, exposing the mineral soil necessary for seedling establishment.

Duff on areas with lighter fuel loadings would not be totally consumed and thus would meet the desired soil covering constraint. The low fine fuel moisture content was necessary to achieve fuel consumption objectives and ensure sustained fire spread in the lighter fuel volume areas. In essence, the prescribed burn was intended to achieve the goal of matching a natural surface fire.

Critical duff and fine fuel moisture content for the project area were often not met until mid-August. However, daytime temperature, relative humidity, and wind conditions were at limits that exceeded heat intensities of 4- to 5-foot (1.2–1.5-m) flame lengths. Therefore, units were frequently burned during the night.

Results

Preburn and postburn fuel data for a recently burned unit (Minefield #28) are shown in table 1.

Underburning can be successful under white fir. By comparing the objectives with the results, the prescribed burn met or came close to meeting all the objectives set forth in the burn plan.

Postburn examination of the unit (table 1) revealed 27 percent consumption of total fuel loading. However, the consumption of smaller sized fuels is most important in reducing fire hazard and providing adequate seedling establishment sites for natural regeneration. The postburn fuel bed arrangement of partially consumed larger size fuels is a significant contribution as shade for the seedlings and meeting other resource objectives for the site.

Mortality to the shelterwood leave trees was within the 5 percent constraint without rearranging fuels near these trees prior to burning. The moderately thick bark of mature white fir and high branching habitat that develops when grown in a fully-stocked stand lessens the trees' susceptibility to fire damage.

Natural regeneration has been achieved on these prescribed burn units with a high degree of success. After one growing season, portions of units contain as many as 80,000 seedlings per acre (200,000 seedlings/ha). Height growth of western larch has been as much as 5 inches (13 cm) in the first growing season (fig. 1).

Underburning may be the most practical way to achieve consistent success with natural regeneration of western larch and at considerable savings. The species composition varies depending on the overstory, but it includes

Table 1—*Ground fuel characteristics before and after burn.*

Fuel item	**Preburn**	**Postburn**	**Consumed/ reduced**
	tons/acre (t/ha)		**%**
Loading			
–Total fuel loading	23.3 (52.2)	17.1 (38.3)	27
–By size class:			
0–1/4 inch (0–0.6 cm)	0.6 (1.3)	0.2 (0.4)	67
1/4–1 inch (0.6–2.5 cm)	2.3 (5.2)	0.9 (2.0)	61
1–3 inch (2.5–7.6 cm)	2.9 (6.5)	1.8 (4.0)	38
≥ 3 inch (≥ 7.6 cm), sound	17.5 (39.2)	14.2 (31.8)	19
≥ 3 inch (≥ 7.6 cm), rotten	0	0	0
	in (cm)		
Fuel depth	12.9 (32.8)	2.9 (7.4)	77
Duff depth	0.2 (0.5)	0.08 (0.2)	60

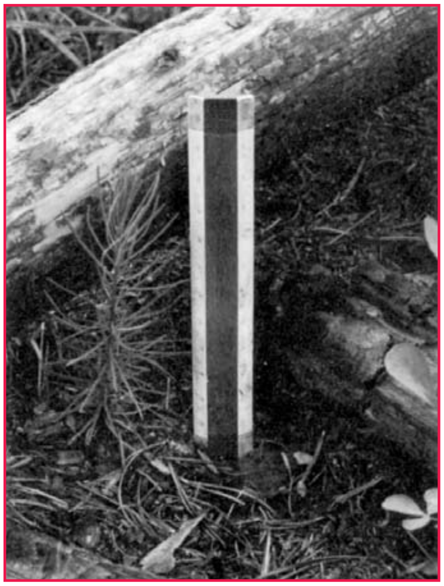

Figure 1—*A vigorous, naturally seeded seedling in the Ladd Canyon prescribed burn area shows 5 inches (13 cm) of growth after one growing season.*

all major species common to the area. This varied regeneration composition gives the land manager many options for future management of a stand.

Based on 903 acres (365 ha) completed on the La Grande Ranger District in the last 3 years, the average cost to prescribe underburn a white fir stand was $56 per acre. Night burning required fewer people to do the job, thus lessening cost. Preburn weeding and cleaning activity was contracted at $43 per acre. Currently, artificial regeneration is being contracted at $289 per acre. Therefore, each naturally regenerated acre resulted in $190-per-acre savings over prevailing contract planting costs.

Wildlife managers have also been quick to point out benefits for their resource. Most burned areas were soon reoccupied with more succulent vegetation and wider diversity of browse plants (fig. 2). Sufficient snags were still standing. Larger size fuel coverings still existed for small mammal habitat. Finally, underburning eliminates a need for machine site preparation or fuel disposal activities, thus lessening soil compaction and site disturbance.

Summary

Prescribed underburning met most of the resource objectives for managing white fir sites on the La Grande Ranger District. This technique can reduce fuel loading and arrangement—lessening fuel problems for future managers, while preparing a seed bed for natural regeneration.

The site is sanitized of diseased and defective trees and regenerated with desirable seedlings. Natural regeneration in place of hand planting has netted considerable financial savings to the reforestation program. Land managers have ample flexibility to manipulate stand composition to meet future objectives.

Wildlife benefits were enhanced in terms of food and habitat as a result of plant production and species diversity. Soil compaction and adverse soil effects were minimized.

Treatment cost for weeding, cleaning, and burning each acre averages $99. Artificial regeneration is currently $289 per acre. Each acre burned and naturally regenerated results in a $190 savings in the reforestation program.

Outlook

The Wallowa-Whitman National Forest anticipates the prescribed burning of 1,400 to 1,600 acres (570–650 ha) of white fir stands annually during the next 3 years, primarily to favor natural regeneration and sanitize the sites. If accomplished, this will result in a projected annual reforestation savings of $260,000 to $285,000.

Fire and fuel managers on the forest are reevaluating how these prescribed burns might be done within the desired constraints and at reduced cost. Such considerations as night burning with fewer igniters, shape and size of harvesting units, staggered work schedules, and use of specialized fire suppression crews are some alternatives that will be evaluated during the coming season. ■

Figure 2—*White fir shelterwood underburn one growing season after burning in the Ladd Canyon project area. Note reoccupation of site by herbaceous vegetation. Portions of this unit also contain up to 80,000 seedlings per acre (200,000 seedlings/ha).*

PRESCRIBED BURNING OF A CHAINED REDBERRY JUNIPER COMMUNITY WITH A HELITORCH*

Guy R. McPherson, Robert A. Masters, and G. Allen Rasmussen

Prescribed burning is an effective means of reducing downed woody debris in redberry juniper (*Juniperus pinchotii*)– mixed grass communities. Conventional ground ignition techniques are effective and relatively inexpensive, but they are limited to accessible areas. Large areas of rough terrain cannot be burned in a single day using ground ignition methods. This paper describes a prescribed fire conducted on a large area with a helitorch.

The 9,914-acre (4,015-ha) unit is dominated by redberry juniper– mixed grass habitat characteristic of the Texas rolling plains. It is located on the 7L division of the Triangle Ranch, 24 miles (40 km) northeast of Paducah, TX (latitude 34°10' N, longitude 100°00' W).

The unit was chained 2 years prior to burning. Red needles were present on the chained juniper at the time of burning. Fine fuel bed was composed primarily of tobosagrass (*Hilaria mutica*), little bluestem (*Schizachyrium scoparium*), sideoats gramma (*Bouteloua curtipendula*), vine mesquite (*Panicum obtusum*), buffalograss (*Buchloe dactyloides*), and threeawns (*Aristida* spp.).

Aerial ignition was selected for safety and time considerations. Steep, dissected terrain made hand ignition unsafe.

As a result of light grazing pressure—40 acres (16 ha) animal unit per year—most grass plants were not grazed, leaving an abundance of rank material that reduced the palatability of forage. Chained woody debris impaired livestock handling and decreased forage availability and accessibility. Furthermore, seedlings and basal sprouts of redberry juniper and honey mesquite (*Prosopis glandulosa*) were present on the unit.

Objectives

The specific burn objectives were to:

- Remove 80 percent of downed woody debris,
- Reduce juniper canopy cover by 70 percent,
- Remove decadent material from 70 percent of grass plants, and
- Check encroachment of juniper and mesquite by killing 70 percent of young plants.

The last two objectives would be met if fire carried over 70 percent of the unit. Rank growth of herbaceous plants is removed by burning. Juniper and mesquite trees are killed if burned at a young age. Juniper trees can be killed if less than 15 years old (Steuter and Britton 1983). Honey mesquite can be killed if less than 2.5 years old (Wright and others 1976).

Methods

The effectiveness of the burn in removing downed woody debris and reducing canopy cover was measured along five 98-foot (30-m) permanent transects randomly located in the unit. In addition, 20 temporary sampling planes were established. Permanent transects were marked with 3-foot (1-m) lengths of concrete reinforcement bar numbered with metal livestock ear tags. Downed woody debris along transects was inventoried using a planar-intercept technique (Brown 1974). Canopy cover of all shrubs was estimated using line intercept (Canfield 1941).

After burning, inventory of woody debris and canopy cover was repeated on permanent transects and on an additional 20 temporary transects. For each transect, percent consumption of woody debris was calculated according to Brown (1974). Reduction of canopy cover was determined by:

When this article was originally published in 1985, Guy McPherson, Robert Masters, and Allen Rasmussen were research assistants at Texas Tech University, College of Agricultural Sciences, Department of Range and Wildlife Management, Lubbock, TX.

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Percent reduction =
[1 – (postburn cover ÷ preburn cover)] x 100 percent

To test the efficiency of permanent sampling, t-tests were conducted on all attributes measured.

Burning Strategy

The unit was prepared and burned according to Wright and Bailey (1982). Two firelines were dozed 400 feet (120 m) apart on the north and east sides of each unit. Eleven miles (18 km) of fireline were burned out with strip head fires in January and February of 1985 under cool conditions (relative humidity 40 to 60 percent, temperature 40 °F to 60 °F (4–16 °C), and windspeed 0 to 10 miles per hour (0–16 km/h).

Main unit head fires were lit with a helitorch on 2 days, February 25 and March 6, 1985. Weather conditions were measured every 30 minutes with a belt weather kit (USDA Forest Service 1959).

Aerial ignition was selected for safety and time considerations. Steep, dissected terrain made hand ignition unsafe. Sheer drops of 65 to 100 feet (20–30 m) were common. Fine fuel load in drainages was about 9,000 pounds per acre (10,000 kg/ha). The unit was dissected by numerous fuel discontinuities in the form of roads, streams, and rocky ridges.

Large units can be burned safely and quickly with a helitorch at far less expense than hand ignition.

A strip head fire ignition pattern starting in the northeast corner and moving southwest into the wind was used to ignite the unit. Strip spacing was 300 to 450 feet (100–150 m). Consequently, an estimated 300 miles (480 km) of strip head fires were needed to burn the unit. Hand ignition would have required at least 600 work hours, not including time for holding crews. By contrast, 70 work hours were required for aerial ignition.

Ignition fuel was a mixture of Alumagel and unleaded gasoline. The amount of Alumagel used varied according to air temperature and relative humidity. Cool and moist conditions required more Alumagel.

With an air temperature of 69 °F (21 °C) and relative humidity of 34 percent, 12.3 pounds (5.6 kg) of Alumagel were mixed with 50 gallons (190 L) of gasoline. With an air temperature of 59 °F (15 °C) and relative humidity of 45 percent, 13.2 pounds (6 kg) of Alumagel were required to obtain the desired consistency.

The fuel mixture was applied at an average speed of 40 miles per hour (65 km/h) from a height of 150 to 200 feet (45–60 m). The mixture was dropped in a 15-foot-wide (5-m-wide) strip, each drop the size of a golf ball (fig. 1).

Personnel and equipment were the same both days. A burn boss, aerial ignition boss, 5-person helipad crew, and two 6-person holding crews were used. The unit could not be seen in its entirety from a single observation point. Therefore, the aerial ignition boss directed ignition from the helicopter. The burn boss, located on the best possible ground observation point, directed the activities of ground personnel and coordinated ground-to-air communication. Two radio frequencies were used—one for the burn boss, helicopter, and helipad boss, and the other for the burn boss and holding crews.

Results

Ignition of the unit was completed in about 10 hours. The first day, air temperature ranged from 63 °F to 69 °F (17–21 °C), relative humidity ranged from 30 to 40

Figure 1—*Aerial ignition of chained redberry juniper using a helitorch.*

percent, and windspeed was 10 miles per hour (16 km/h). After a week of undesirable weather, burning was completed on a cooler day; temperature 54 °F to 59 °F (12–15 °C), relative humidity 40 to 50 percent, and windspeed 8 miles per hour (13 km/h).

Containment of the fire was not a problem. No suppression actions were required. Conditions for burning on March 6 were cooler than normally prescribed for this fuel type. Early spring green-up, leading to a rapidly increasing green component in the fuel bed, forced ignition on a relatively cool day. As a result, the specific burn objectives were not met on the area burned March 6.

From transects flown after completion of ignition, it was determined that 61 percent of the unit burned. Concentration of livestock on ridges and low-lying flat areas reduced continuous fine fuel below 1,000 pounds per acre (1,100 kg/ha) and created fuel breaks. By comparison, drainages and hillsides were not heavily grazed. As a result, only 20 to 30 percent of the areas of greatest livestock concentration were burned. However, dissected terrain was characterized by 80 to 90 percent fire coverage.

Table 1—*Downed woody fuel and canopy cover reduction resulting from a spring prescribed fire in the Texas rolling plains.*

Attribute	**Transects**					
	Permanent[1]		**Temporary**[2]		**Total**[3]	
	Mean	**Standard error**[4]	**Mean**	**Standard error**	**Mean**	**Standard error**
Preburn woody fuel						
cubic feet/acre	240.0	71.4	287.2	58.6	277.2	48.6
m^3/ha	16.8	5.0	20.1	4.1	19.4	3.4
Postburn woody fuel						
cubic feet/acre	155.8	82.9	134.3	34.3	138.6	31.4
m^3/ha	10.9	5.8	9.4	2.4	9.7	2.2
Woody fuel reduction (%)	35.1		53.2		50.0	
Preburn canopy cover (%)						
Downed woody debris	12.6	4.0	12.8	1.8	12.8	1.6
Redberry juniper	15.1	3.0	13.0	1.3	13.4	1.2
Other shrub species	2.7	1.7	3.1	0.8	3.0	.7
Total	30.4	6.0	28.9	2.6	29.2	2.3
Postburn canopy cover (%)						
Downed woody debris	7.5	2.1	8.2	1.2	8.1	1.0
Redberry juniper	6.0	2.5	6.2	1.6	6.2	1.3
Other shrub species	2.3	1.5	2.2	.7	2.3	.6
Total	15.8	3.9	16.7	2.2	16.5	1.9
Canopy cover reduction (%)						
Downed woody debris	40.4		35.9		36.7	
Redberry juniper	60.2		52.3		53.7	
Other shrub species	14.8		29.0		23.3	
Total	48.0		42.2		43.5	

[1] n = 5
[2] n = 20
[3] n = 25 (combined results from all transects)
[4] Standard error of the mean calculated according to Steele and Torrie (1980)

Additional research is needed before permanent transects can be universally recommended.

Table 1 summarizes reduction in woody fuel volume and canopy cover. Results from permanent and temporary transects were similar for all attributes measured. Downed woody fuel and total canopy cover were reduced only 50 and 44 percent respectively, primarily due to the discontinuous nature of the fire.

Where fine fuel was continuous enough to ensure fire spread, woody fuel volume was reduced 90 percent, and total canopy cover was reduced 85 percent. Moreover, consumption of 54 percent of live tree canopy reduced juniper stature. In addition to improving visibility across the pasture, this reduction in plant stature will reduce the competitive ability of juniper—thereby increasing production of herbaceous species. On the second day of ignition, cooler than normal conditions, coupled with light fuel loads in some areas, produced less than desired results.

Total cost of burning the unit was $22,439.97, or $2.26 per acre ($5.59/ha). The helitorch was contracted for $1.00 per acre ($2.47/ha). Remaining costs were primarily attributed to personnel ($6,150) and transportation ($3,996).

Management Implications

Near optimal weather conditions on February 25 compensated for fine fuel inadequacies, and burn objectives were achieved. Because of cooler weather conditions and increased percentage of green fine fuel on March 6, overall objectives were not met.

In light of this burn, we believe large units can be burned safely and quickly with a helitorch at far less expense than hand ignition.

Because of the speed of the operation, communication is of fundamental importance when using aerial ignition. Our experience indicates that two radio frequencies are desirable to minimize confusion.

Permanent and temporary transect means were not significantly different ($P < 0.01$) for any of the attributes measured. Therefore, these data indicate that fewer transects can be used for sampling downed woody debris and shrub canopy cover in this fuel type if transects are permanently established.

Permanent sampling planes can be established almost as quickly as temporary transects in the field.

The increased sampling efficiency offered by permanent transects indicates that they are a viable alternative to temporary transects in this fuel type. Additional research, however, is needed before permanent transects can be universally recommended.

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PRESCRIBED FIRE IN THE SOUTHEAST— FIVE STEPS TO A SUCCESSFUL BURN*

James Lunsford

While the use of prescribed fire in the Southeastern United States predates any type of formal records, it can nonetheless be traced to use by Native Americans and members of the cattle industry established by the first settlers from Europe (Komarek 1981).

The Southeast was settled primarily by people of a pastoral background from Scotland, Wales, Ireland, England, and Spain. These cattle herders made up 75 percent of the white population of the time (Owsley 1949). The use of fire to maintain grazing land for cattle was brought from the home countries, where its use continues today.

Open range in the Southeast was prevalent, lasting officially until 1949 when Florida enacted closure of the last open range. However, lack of enforcement extended open range into the 1950's.

Cattle Grazing

Cattle grazing, carried out in the Appalachian Mountains in a manner similar to the coastal plains, was particularly favored on high ridges and mountain tops that could not be farmed. This use accounts for most of the "mountain balds" of the southern Appalachians today. Fire was used to maintain these mountain pastures and is currently used today to maintain these balds for their esthetic values.

When this article was originally published in 1978, James Lunsford was a prescribed fire and smoke management specialist for the USDA Forest Service, Southern Region, Atlanta, GA.

Figure 1—*The handheld drip torch is the most frequently used source of ignition for prescribed burning in the South.*

The three physiographic regions of the Southeast—the coastal plains, the mountains, and the piedmont—have their own unique requirements for the use of prescribed fire. The pine forests of the coastal plains allow almost unlimited use of fire because of the natural resistance of the southern pine tree to damage by heat. However, the hardwoods of the mountains are damaged severely by fire. Its use, therefore, is limited to openings, bald maintenance, and site preparation for planting commercial trees.

The piedmont is made up of rolling hills and a mixture of hardwood and pines. The use of prescribed fire must be compatible with the vegetation occupying the site. Grasses and herbaceous plants are nurtured and respond favorably to fire, whereas small hardwoods will be top-killed and some will eventually be eliminated. Live tissue has a tolerance of heat to about 145 °F (63 °C), but lesser temperatures will kill live tissue if exposed for a long period of time

Southern yellow pine trees have thick, insulating bark that provides protection, and a damaging level of heat is seldom reached, especially on large trees. For all species, the larger the tree, the more heat it can resist. The tolerance of heat is much less for hardwoods and for other pine and fir species.

Let me borrow a paragraph from Pyne (1982) to help set the stage for the use of fire:

> *A fire environment consists of the fuels, topography, and weather within which a fire burns. When a fire environment combines with a consistent pattern of ignition, then a fire regime results, characterized by a particular vegetative ensemble and regular pattern of fire behavior. Such vegetative ensembles are often referred to as cover types or fuel types and to transform vegetation deliberately from one cover type to another is known as type conversion. When, because of its fire pattern, a fire regime maintains a certain type of vegetation cover that, in the absence of fire would give way to other cover types, then that biota is referred to as a fire climax and the particular vegetation as a fire type. … When a consistent pat-*

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> *tern of reburning is established, the outcome is a fire cycle. … Controlled fire that is introduced under a predetermined set of conditions (prescription) is referred to as a prescribed fire.*

The evolution of prescribed fire in the South transcends the cattle industry, the agricultural industry, and, later, the timber cutting that eliminated most of the commercial forests. After the timber harvest that peaked in 1900, the use of fire continued and thus prevented any reforestation. The land became a timber desert.

Fire was declared illegal and fire prevention was the thrust to protect the new forest. Because of the mosaic that existed across the South, game (quail and turkey) became plentiful and game management became profitable. Many "hunting plantations" developed that catered to the rich "'Yankee tourist" and others who could afford to participate. As the population of wildlife began to decline, however, this economic windfall became short lived.

Hunting plantation owners banded together to find the cause for this decline. Herbert Stoddard was commissioned to study the problem in 1924. Seven years later, he published "The Bobwhite Quail, Its Habitat, Preservation, and Increase." He concluded that quail populations depend on land management practices and that "fire may well be the most important single factor in determining what animals or vegetable life will thrive in many areas" (Stoddard 1931).

Evidence began to mount that the growth of "rough" contributed to damage caused by wildfire and that the use of prescribed fire could reduce this damage by reducing the amount of fuel under less severe conditions than may exist when a wildfire occurs. Thus, "wood burning" has come full circle and is now practiced by most land management agencies.

The three physiographic regions of the Southeast all have their own unique requirements for the use of prescribed fire.

The Five-Step Method

"A Guide for Prescribed Fire in Southern Forests" (Mobley 1978) suggests a five-step method for a successful prescribed fire. I plan to describe this procedure as carried out by the USDA Forest Service in the Southern Region.

Analysis. An inventory of all national forest land in the South is conducted on a 10-year rotation. During this inventory, as much information as possible is gathered about each stand and forest type. Each ranger district is subdivided into compartments of about 1,000 acres (400 ha) each. Each compartment is broken down into stands of 10 to 80 acres (4–32 ha) each, depending on the vegetative type.

The maximum size of a regeneration cut (usually a clear cut) is dictated by law in the Forest and Rangeland Planning Act of 1974. The act limits clear cuts in the pine type to 80 acres (32 ha), and 40 acres (16 ha) in the hardwood type. However, the average is much less—about 30 acres (12 ha).

Ten acres (4 ha) is a minimum because any smaller area is more difficult to manage and inventory. Smaller areas, however, are mapped as inclusions in larger stands as wildlife openings or food plots referred to as key areas. Riparian areas (streamside zones) are also mapped. A detailed description is made of all stands and inclusions.

During this inventory process, a thorough analysis is made of each stand to determine needs and what actions should be taken to meet those needs. Many alternatives to fire that provide acceptable effects are mowing, herbicide, and mechanical treatments. Generally, fire is the most economical or has fewer side effects. Due to the risk from smoke, however, its use is limited.

Grazing. Improving grazing is one of the oldest uses of prescribed fire and at one time the most extensive. Mowing can produce a similar effect to fire on the grass area, provided machinery can be used. However, mowing leaves the "thatch" and mowing residue (waste). Waste has a detrimental effect on most plant life (Komarek 1981). Fire has the effect of removing both the excess growth and the old thatch.

Wildlife Habitat Improvement. Prescribed fire applied when the plants are dormant generally only top-kills the species that are desirable by wildlife, i.e., the plants will sprout again, providing the browse needed for wildlife. However, summer burns tend to root kill and eliminate most hardwood species and many forbs. A low-intensity fire that does not burn deeply into the duff is desirable. This type of fire will cause sprouting and kill fewer plants.

Timber Management. Fire is used for site preparation and to remove undesirable competition. The site prep burn is applied in the summer if possible and a hot fire is desired to kill as much competing vegetation as possible. A fire to reduce the undesirable competition is first applied during the dormant season when the pine overstory is about 3 inches (7.6 cm) in diameter at the ground. Fire is applied on a 3- to 5-year cycle in the summer when the trees are 6 to 8 inches (15–20 cm) in diameter. This technique will produce almost a pure stand of pine and less competition for reforestation after harvest time.

Fire Protection. A pine plantation is most vulnerable to fire when the trees are young and have the normal grass and small plants associated with young pines. A cool prescribed fire applied as soon as possible, usually when the trees are 2 to 3 inches (5 to 7.6 cm) in diameter at the ground, will fire proof the plantation for about 3 years. Even then, a heading wildfire will cause considerable damage. Fire prevention is still necessary. A rotation of fuels reduction burning must be carried out on a 3 to 5 year cycle.

Esthetics. In areas of high visitor use, the concern is to keep down the understory and provide a pleasing view. Flowering plants and shrubs respond differently to fire applied at different times of the year. If fire is applied after flower buds are set in late summer, the bud will be killed and there will be no flowers the next spring. Timing is critical when fire has such an effect. Maintenance of openings and mountain balds is accomplished with fire. Herbicide use following a fire will help convert the area to grass, if desired.

Disease Control. Longleaf pines are infected with brown spot blight (*Scirrhia acieola*) when they are in the grass stage, about 1 to 3 years old. Prescribed fire is used to burn off the infected needles and kill the blight. However, this applies only to the current crop of trees; the next crop will again need the same treatment. *Armillaria mellea* (root rot) is thought to be reduced by prescribed fire.

Rare and Endangered Species. Prescribed fire is used to maintain the habitat of several rare plants and animals. The red-cockaded woodpecker requires a certain vegetative condition that is perpetuated by the use of fire. Rare plants such as mountain golden heather (*Hudsonia montana*) and pitcher plant (*Sarricia* sp.) can be perpetuated by fire.

> Smoke from the fire, a seemingly harmless element, has become as important and as potentially dangerous as the fire itself.

Prescription. This is a complex document and probably the most important single ingredient in the prescribed fire process. Generally, the prescription refers to the environmental conditions affecting how a fire will behave in a given fuel bed. The prescription is only a single part of the prescribed fire plan. The prescription is usually written as open as possible to take advantage of the few days that are favorable for burning.

Timing. In the Southeast, there are generally about 22 to 28 days that are considered suitable for burning in the fall and winter months. Some burning is done in the summertime, which accounts for additional days, but the amount of burning is limited because of the already high temperatures. Experience may lead to more summer burning because some very desirable effects can be accomplished during this time.

Because temperatures are critical—live tissue will be killed at about 145 ° F (63 °C)—the prescription becomes very important. One of the most important elements in the prescription is fuel moisture. Fuel moisture is dependent on type of fuel, days since rain, and relative humidity.

Fuel moisture serves to dampen heat and the rate of fuel consumed and thusly limits, to a large degree, the amount of heat produced. Windspeed has the next critical role in fire behavior. The faster the wind blows, the faster and hotter the fire—provided the fuel moisture is low enough to allow combustion to take place.

Firing Techniques. Experience has shown that fire may be applied with a variety of combinations of fuel moisture and windspeed with varying results. Combinations of low fuel moisture and high wind speeds, however, generally cause unacceptable damage to overstory species. Firing techniques can be used to control heat in many cases. Here the experience of the burner must be applied. Large-scale weather patterns must be observed to keep abreast of wind changes and approaching storm centers.

Prescription writers—the prescribed fire planners—should be the most qualified persons available. Their qualifications must include both actual experience and access to research data and training by other disciplines, such as wildlife biology, silviculture, etc. The prescription (prescribed fire plan) must include all the elements to be considered before, during, and after the burn. A simple, short form will not suffice for this documentation.

Smoke Hazards. Smoke from the fire, a seemingly harmless element, has become as important and as potentially dangerous as the fire itself. Recently, several people have been killed as a result of smoke blocking visibility on major highways. Lawsuits in the millions of dollars have resulted against the companies responsible for the prescribed fire, and some states have proposed legislation to eliminate the use of fire as a management tool in the forest. Fortunately, no laws have passed that would severely limit management of southern pine forests and other habitat improvements.

Data and guidelines have been developed to allow the user of prescribed fire to manage smoke. Areas that are affected by smoke such as highways, hospitals, and airports, should be identified. A wind direction is chosen that will blow the smoke away from the smoke sensitive area. Other efforts include mitigating measures such as closing roads.

Preparation. Another seemingly simple process becomes critical when one takes into account the damage caused by the use of a plow to construct a fire line. Soil erosion may become a problem or the visual effect of the plowed line may be unacceptable. Many techniques are employed. For instance, in sensitive areas hand lines are constructed and, in some cases, a water expansion system (foam) is used.

Regardless of the system employed, the line must be capable of holding the fire. The type of fire used, (backing fire, slow ignition, etc.) should be considered. Natural barriers such as rivers, bays, and roads can also be used to lessen the impact on the environment.

When access is available, the fire may be controlled by water pumping equipment. Other equipment used in fire line construction includes the mist blower, which works best in hardwood leaves. Blasting (Primacord) has also been used but is not readily available and requires highly qualified personnel.

Lines are constructed when only a backing fire is to be used—plowed at approximately 10-chain (200-m) intervals perpendicular to the wind direction. Firing is done from each line to maintain a low-intensity backing fire.

Lines should be constructed at some time prior to the planned burn, but not so early that leaf and needle fall will fill the lines. If the lines do become filled, a mist blower can be used to again open up the lines. The burn plan should contain a map that depicts the locations of all fire lines and how they are to be constructed. Cross drainage ditches should be incorporated at the time of construction to prevent erosion.

Preparation also includes gathering weather data. Weather station equipment can be located on the burn site to determine rainfall, relative humidity, wind speed, and fuel moisture.

Execution. When the time to ignite the fire has finally arrived, this may only be obvious to a few experienced individuals. The time to burn is when the weather is favorable—"in prescription"—and a weather forecast predicts that conditions will remain favorable during the time of the burn. The wind direction must be correct to prevent smoke from affecting smoke sensitive areas, and the atmosphere must be capable of dispersing the smoke.

The firing technique and firing device were previously listed in the burning plan; the necessary equipment must also be ready. If aerial ignition is planned, the extensive organization required must be put together prior to ignition time. Communications must be established with all participants.

Test Fire. Assuming that all the logistical problems have been solved, a test fire should be conducted to confirm that all the planning and predictions are true. If the test fire does not indicate that the fire will achieve the objectives of the plan, the fire must be extinguished. Generally, an area has been previously set up for the test fire, or, at this time, a fire plow or water equipment will be needed to extinguish the fire.

Ignition. Once the decision to burn is made, the preplanned ignition pattern is executed, i.e., backing fire, strip-head fire, or spot fire. Ignition is primarily done with the hand-held drip torch. More use is being made of aerial ignition in the past few years.

The helitorch and the Ping-Pong ball machine offer the capability to burn areas inaccessible or unsafe for foot travel and can burn large areas in a short time. The best rate of burning to date is 3000+ acres (1,200+ ha) in 1 hour on the Kisatchie National Forest in Louisiana. Normal operations, however, are about 3,000 to 4,000 acres (1,200–1,600 ha) per day for underburning and 300 to 400

acres (120–160 ha) per day for site preparation. Many variables are involved in burning, and experience is needed in each area to know what to expect.
The helitorch, which requires the mixing of gasoline and Alumagel or Sure-Fire, a thickener, requires 2 to 4 persons to work around the heliport. This expense, plus the risk of fire or explosion, has given us good reason to use the Ping-Pong ball machine.

This machine reduces the risk and the number of people involved. Only one person is needed to operate the machine with no exposure to flammable materials. The machine injects the plastic ball, which contains potassium permanganate, with ethylene glycol and then ejects the ball from the helicopter.

The balls ignite after reaching the forest floor, causing a spot fire. Results of all types of ignition are similar and the decision to choose one over the other depends on needs, availability, type of fuels, and terrain involved. Aerial ignition will permit more heat to be generated and is used when high fuel moisture conditions exist. In fact, the helitorch can be used when moisture is too high for other ignition sources.

Firing Pattern. The firing pattern will have a great deal of influence on the results of the burn. Strip-head fire is the most commonly used when firing with the handheld drip torch and the helitorch. This technique is used for underburning when the overstory is large enough—6 to 8 inches (15–20 cm) or larger—to withstand considerable heat. The backing fire, generally, must be used for plantation—2 to 3 inch (5–8 cm)—and poles—3 to 6 inch (8–15 cm).

Fuel loading will also determine the type of fire to use and the effects of the fire. Heavy fuel loading, when an overstory exists, should not be planned to be consumed in a single burn. Several burns may be necessary to reduce the loading to a safe level.

The Ping-Pong ball machine starts a series of spot fires spaced according to desired intensity. Spots closer together provide less intensity than spots at wide intervals (Johansen 1984).

The backing fire spreads at about 1 to 3 chains (20–60 m) per hour in all fuels regardless of wind speed (Hough 1968). When a backing fire is planned, fire lines must be plowed perpendicular to wind direction at intervals that will allow the burn to be accomplished in the specified time. A ring fire may be used for clearcut slash areas—especially if danger exists to crews crossing the area.

Most common is the use of the helitorch to ignite the slash unit as quickly as possible using the strip method. This represents an "area fire" and creates considerable heat with a large convection column. Again, some experience will be necessary to conduct a successful burn. Selection of the firing technique must consider the effects of the fire on all resources—soil, water, air quality, timber, wildlife, and so forth.

Evaluation. The evaluation should be a part of the original prescribed fire plan. The objectives of the burn should be defined so that they may be evaluated after the burn, both immediately and at some later date. Clearly defined objectives, of course, will make this job easier. An evaluation form should be attached to the burning plan with several items to be evaluated after the burn. Data on characteristics such as flame length and rate of spread must be gathered during the burn. Several items that should be evaluated:

- ***Weather parameters.*** Were they within prescribed guides during the burn? Data should be recorded during the burn to insure that unforeseen conditions do not cause resource damage or cause the fire to escape control.
- ***Effects on vegetation.*** Did the fire accomplish the objectives set out in the prescription? Were trees killed or scorched beyond desirable levels? Was lesser vegetation consumed or killed as desired? Information should be related to weather parameters for future reference. An evaluation after the growing season will indicate effects concerning sprouting and other conditions not known at the time of burn.
- ***Effects on fuels.*** Did the fire consume—more or less—the fuels as desired? Consumption will be related to fuel moisture, wind speed, and days since rain (drought conditions). Consumption of all fuel will expose mineral soil and could later lead to erosion problems.
- ***Escape.*** Did the fire escape the control lines? Why? What were conditions when escape occurred? Was line incorrectly located or constructed? A weather forecast prior to burn time should predict possible weather changes that may cause erratic fire behavior.
- ***Effects on other resources.*** Was excessive mineral soil exposed? A later evaluation may indicate erosion or other problems. Did the fire affect wildlife such as ground nesting birds? Were there smoke related incidences? Were smoke sensitive areas affected? We are responsible for our actions even though the effects may be subtle,

Fire in the southern forest is responsible for the propagation of the southern pine forest ecosystem.

such as aggravating one person's lung problems, dirtying the clean laundry hanging outside or depositing soot and ash on nearby cars.

Legal Responsibilities

Regulations pertaining to the use of fire differ in almost every State. Some States require permits to burn that are issued only when burning conditions are low. Some have a prohibition against burning when air quality standards will be violated. Some air quality regulations prohibit any kind of pollution that constitutes a "public nuisance." Some States require notification of adjacent landowners.

Two forms of liability must be addressed, criminal and civil. Criminal liability exists when a State law is violated, such as failing to acquire a burning permit. Violation of state law may be either a misdemeanor or felony. The basic difference is that a misdemeanor has a jail sentence of less than 1 year. A felony has a jail sentence of more than 1 year. Both are accompanied by a fine.

Civil liabilities exist when the fire causes personal injury or property damage. Damage could occur on adjacent land if the fire escapes, or the smoke could cause an accident at some distance from the fire. However, to be liable, a person must first be judged to have been negligent. Some State laws say negligence is not present if the burner has taken all the necessary precautions that a "prudent person" would have taken under the circumstances. Other States' laws say a violation of the law constitutes negligence. Thus, if the burners fail to acquire a burning permit, they are automatically negligent and responsible for any damage (Siegel 1985). The best defense against liability is to follow the law and the prudent person concept.

Conclusion

Fire in the southern forest transcends all human records and is responsible for the propagation of the southern pine forest ecosystem, especially the longleaf pine. This species, known as a fire climax type, would probably pass from existence without fire.

To perpetuate the pine type, fire can be applied by management but only under acceptable conditions. Because of the liabilities associated with fire, the user is responsible for acting in a prudent manner and not inflicting personal or property damage.

A five-step system is suggested to minimize the risk when using prescribed fire. An inventory of needs should be undertaken to determine the amount of burning needed and the compatibility with other resources. A detailed plan must be prepared to insure all necessary requirements are met. This plan must include labor and equipment needs, burning parameters, smoke management requirements, and an evaluation list.
Preparation must be done in advance of the burn to insure completion prior to burn time and should be sufficiently permanent to last until the burn is completed. Prevention of erosion from plowed lines can be done when construction of line is completed.

Execution of the burn will be in compliance with the plan or with approved changes. Ignition can be either handheld or aerial, as prescribed in the plan. An evaluation should be made immediately after the burn and also at some later date. The evaluation should determine if the objectives of the burn were met and if any corrections or adjustments should be made on future burns. We must be aware of our legal responsibilities in order to insure that we'll be able to continue to use prescribed fire as a management tool.

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HOW TO ESTIMATE TREE MORTALITY RESULTING FROM UNDERBURNING*

Elizabeth D. Reinhardt and Kevin C. Ryan

Prescribed burning beneath standing timber is widely used to accomplish objectives such as preparing land for reforestation, reducing fuels, improving livestock range, and modifying wildlife habitat. Such burning is usually guided by written plans that set forth general objectives and a firing pattern to accomplish them. The plan typically specifies acceptable levels of mortality in standing trees and describes desired fire behavior, particularly flame length.

This article offers two nomograms to facilitate effective planning and successful burning. One nomogram is intended for estimating levels of mortality for various scorch heights among tree species common to the Northwest. A second nomogram is useful for determining the flame length that will keep tree mortality within specifications.

The nomograms can also be used to estimate numbers, sizes, and species of trees to leave in a partial cut, and also to identify trees that will die and should be salvaged after an unplanned fire.

How the Nomograms Were Developed

The mortality nomogram was derived from a study of 2,356 trees from 43 prescribed fires in Washington, Idaho, Oregon, and Montana. Species included were both Pacific Coast and Intermountain varieties of Douglas-fir (*Pseudotsuga menziesii* (Mirb) Franco), western larch (*Larix occidentalis* Nutt), western red cedar (*Thuja plicata* Donn.), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), Englemann spruce (*Picea engelmannii* Parry), lodgepole pine (*Pinus contorta* Dougl.) and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.).

Fire kills trees in several ways: crown injury, cambium injury, and root injury.

Tree height ranged from 20 to 220 feet (6–67 m), and tree diameter from 3 to 65 inches (8–165 cm). Based on species, diameter at breast height, and published equations, computed bark thickness ranged from 0.1 to 4.3 inches (0.3–10.9 cm).

Crown volume scorched was measured visually in the field and ranged from 0 to 100 percent. Fuels ranged from light natural accumulations to moderate logging slash. Fire behavior fuel models (Anderson 1982) included 8, 11, and 12. The 10-hour time lag National Fire Danger Rating System (Deeming et al. 1977) moisture content ranged from 5 to 25 percent, and the 1,000-hour moisture content from 11 to 30 percent. Fires were conducted from May through October. Mortality was monitored for at least 2 years following the fires. Mortality on the 43 individual plots ranged from 0 to 97 percent. Mortality for the individual species ranged from 15 percent for western larch to 87 percent for western hemlock and Engelmann spruce.

How Fire Kills Trees

Fire kills trees in several ways: crown injury, cambium injury, and root injury. Trees of different species and ages vary in resistance to fire injury. Larger trees have proportionately more foliage above lethal scorch height in a given fire. The amount of crown injury a tree receives depends on scorch height, tree height, and crown base height.

Species differ in the timing of bud break and also in the degree to which their buds are shielded from heat. Species with large buds and twigs tend to be more resistant to fire injury. Shallow-rooted species have greater susceptibility to root injury than deep-rooted species.

Fire resistance among trees of different species and sizes mainly depends on differences in bark thickness. Large trees of thick-barked species may have bark 100 times as thick as small trees of thin-barked species. Field determination of bark thickness is time consuming and may be impractical in operational situations, but bark thickness can be estimated from species and diameter.

When this article was originally published in 1988, Elizabeth Reinhardt and Kevin Ryan were research foresters for the USDA Forest Service, Intermountain Fire Sciences Laboratory, Missoula, MT.

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Moderate logging slash area being prescribed burned.

Area prescribed burned approximately 1 year ago. Note low scorch height on trees.

The Model

The model assumes that differences in mortality between species are due only to differences in bark thickness. We used published equations to compute bark thickness from species and diameter. Computed bark thickness was then used with observed crown volume scorched (percent) to predict tree mortality.

The prediction equation generated was:

$$P_m=1/(1 + exp(-(1.466 - 4.862\ B + 1.156\ B^2 + 0.000535\ C^2)))$$

where P_m is the predicted probability of mortality, B is bark thickness in inches; and C is percentage of crown volume scorched. For each species, the difference between predicted and observed mortality was less than 15 percent—except Engelmann spruce, which was 30 percent. Predicted mortality was within 20 percent of observed mortality for all except 5 of the 43 sample fires.

The model has an underlying assumption of a fire of average duration. Fires of very long duration can kill cambium through even the thickest bark and can result in higher than predicted mortality. Thick layers of dry duff may result in long periods of smoldering even after the flame front has moved through the stand. Heavy concentrations of logs near trees will also result in extended duration of burning and a corresponding under-prediction of mortality. Conversely, mortality will likely be over-predicted in light, patchy surface fires.

> Once an acceptable level of mortality has been chosen for a particular species, the nomogram can be used to develop a burning prescription.

Mortality Nomogram

The equation was used to develop the mortality nomogram (fig. 1). The nomogram allows the manager to determine the maximum scorch height compatible with a chosen level of mortality, using inputs of species, diameter, tree height, and crown ratio.

The lower left quadrant of the nomogram shows diameter and bark thickness for the seven species studied. These relationships were taken from the literature (Ryan 1982). The upper left quadrant shows the relationship between bark thickness, percentage crown volume scorched, and tree mortality. This is the graphical representation of the mortality prediction equation. The curved lines are mortality contours showing probability of mortality for various combinations of bark thickness and crown volume scorched.

The right side of the nomogram shows the relationship between percent crown volume scorched, crown ratio (upper right quadrant), and tree height and average scorch height (lower right quadrant). We assumed that tree crowns take the form of symmetric parabolas and that scorch heights are uniform within a tree.

Scorch Height Nomogram

Figure 2 is a nomogram for predicting scorch height. The nomogram is based on Van Wagner's (1973) equation for predicting crown scorch height from air temperature, windspeed, and Byram's (1959) fireline intensity.

The relationship is shown in terms of both fireline intensity and flame length, based on Byram's (1959) relationship between the two. The figure was developed for midflame windspeeds of 5 miles per hour (8 km/h), an average value for prescribed underburns.

Higher windspeeds result in lower levels of crown scorch height for a given flame length or fireline intensity. The differences are small for windspeeds between 0 and 10 miles per hour (0–16 km/h). Managers who are interested in solutions for other windspeeds should refer to Van Wagner's equation or graphical representations by Albini (1976).

How To Use the Nomograms

To use the mortality nomogram (fig. 3), choose an acceptable level of mortality (e.g. 20 percent or a 0.2 probability of mortality). Acceptable mortality will depend on the value of the trees and the objectives of the fire. Successful underburning involves choosing and staying within a reasonable level of mortality. Data from these fires indicate that it is unreasonable to expect to underburn without some mortality. It is not possible, therefore, to select zero mortality.

Once an acceptable level of mortality has been chosen for a particular species, the nomogram can be used to develop a burning prescription. For example, consider a shelterwood harvest with Douglas-fir leave trees averaging 17 inches (43 cm) in diameter, 100 feet (30 m) tall, with a crown ratio of 0.5.

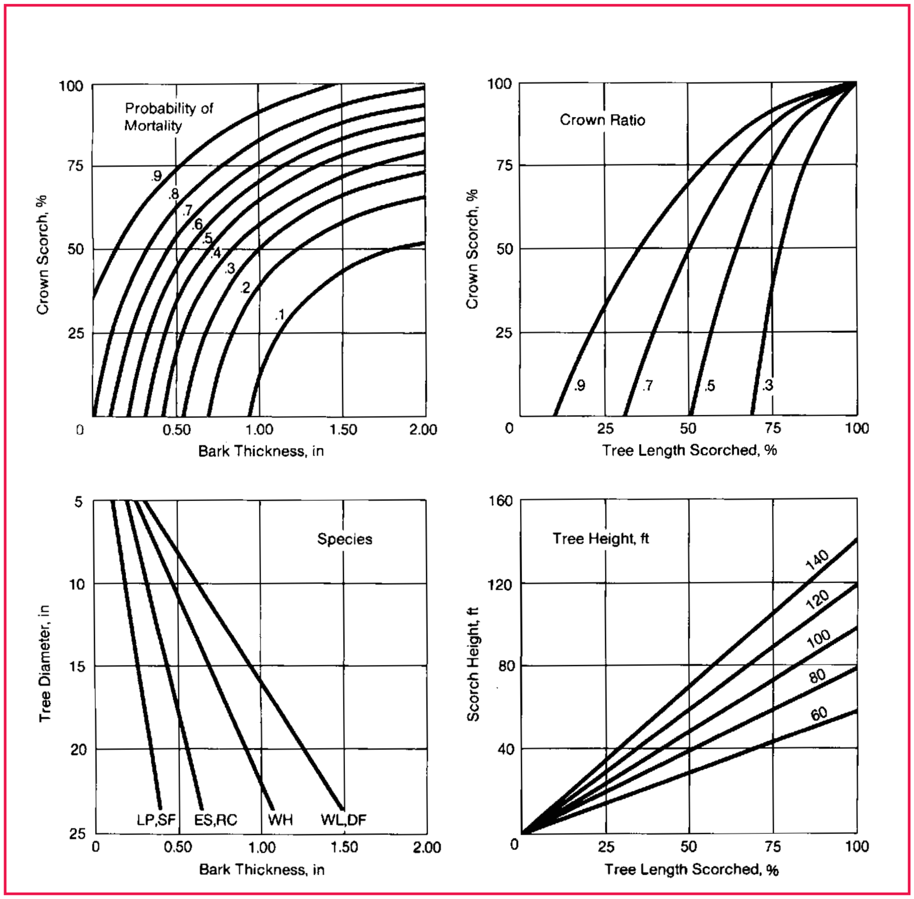

Figure 1—*Tree mortality nomogram for use in prescription development. Key to symbols: LP identifies lodgepole pine; SF, subalpine fir; ES, Englemann spruce; RC, western red cedar; WH, western hemlock; WL, western larch; and DF, Douglas-fir. Figure can be enlarged on copier paper for field use.*

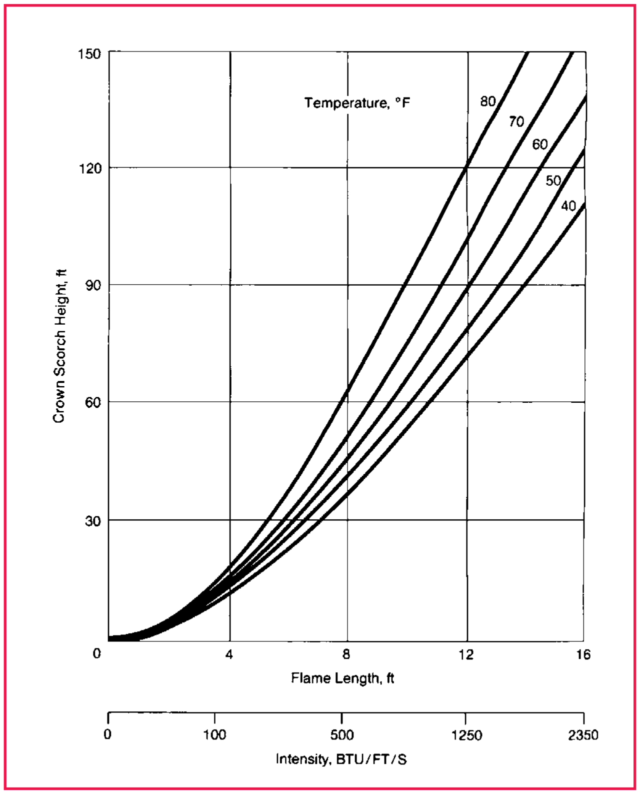

Figure 2—*Van Wagner's crown scorch height model, shown for a midflame windspeed of 5 miles per hour (8 km/h) and a range of ambient temperatures. Figure can be enlarged on copier for field use.*

Entering the nomogram at the lower left at observed tree diameter, draw a horizontal line until you intersect the correct species line. Then turn a right angle and draw a line straight up. Where the line crosses the top edge of the lower left box, bark thickness can be read, if desired, but it is not necessary to do so.

In this example, bark thickness of a 17-inch (43-cm) Douglas-fir is about 1.1 inches (2.8 cm). Continue the line straight up until it intersects the target mortality rate curve (0.2). At this point, turn a right angle again, to the right. This time, when passing from the upper left to the upper right quadrant, it is possible to read off crown volume scorched (percent).

This example shows that a little more than 40 percent of the crown volume of these trees may be scorched with out exceeding the target mortality of 20 percent. If that is all you want to know, stop there.

To convert percentage crown volume scorched to scorch height, continue working clockwise through the nomogram. Make a right angle turn down, intersecting the curve representing the appropriate crown ratio. Then continue down to the appropriate tree height curve. Make another right angle turn to the left. Read allowable scorch height (in this example 60 feet [18 m]) off the vertical axis of the lower right quadrant. This is the maximum available scorch height that can still limit the mortality to the desired level.

If desired, continue on to figure 4 and determine the maximum allowable flame length. To keep scorch heights to 60 feet (18 m) on a 60 °F (15.5 °C) day, flame lengths should be kept between 9 and 10 feet (2.7–

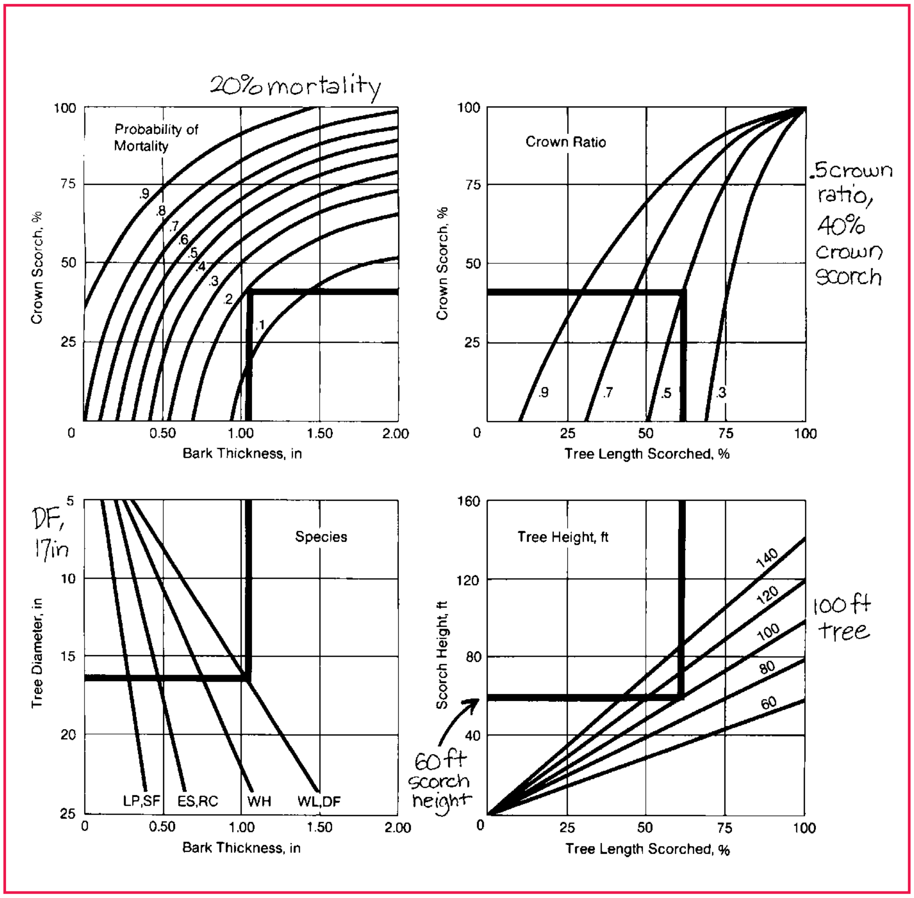

Figure 3—*This figure illustrates the use of the mortality nomogram to set scorch height limits for a prescribed underburn in which the target leave trees are Douglas-fir, 17 inches (43 cm) in diameter at breast height, 100 feet (30 m) tall with a crown ratio of 0.5, and an acceptable mortality of 20 percent.*

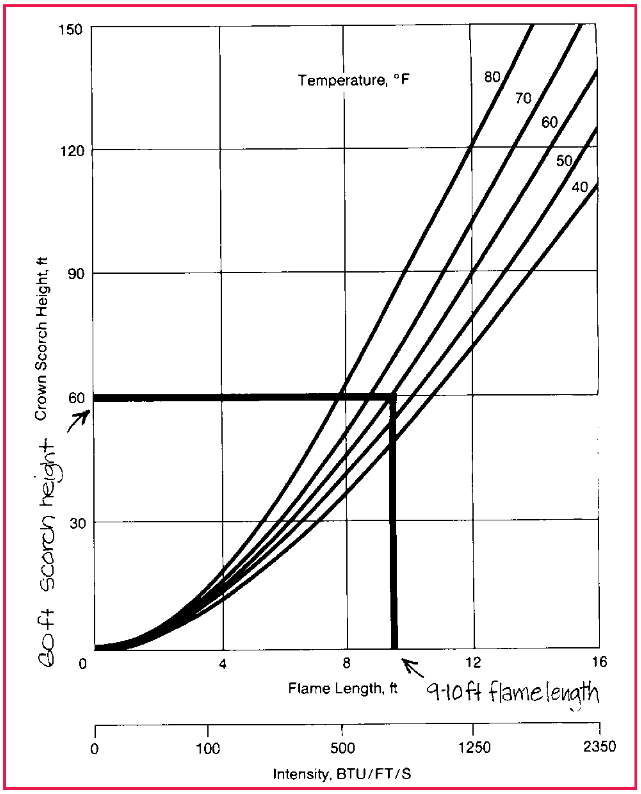

Figure 4—*This figure illustrates the use of the scorch height nomogram to set flame length limits for a prescribed underburn on a 60 °F (15.5 °C) day, in order to limit scorch height to 60 feet (18 m).*

3 m). This value can be used in conjunction with fuel models and fire behavior predictions to develop a prescription for burning (Pucket and others 1979; Rothennel 1983; Andrews 1986). Field crews can attempt to limit the flame length to this level through ignition pattern modifications.

Additional Applications

In some applications of prescribed fire, tree mortality is desired. For example, a manager may wish to eliminate encroaching Douglas-fir from a grassland. In these situations, a nomogram can be used to determine the minimum flame lengths necessary to achieve the fire objectives.

A nomogram can also be used earlier in the planning process, at the time of developing the silvicultural prescription. One can determine how many trees of each species to leave to achieve the desired number and species proportions after fire treatment. To do this, select a reasonable expected crown scorch height. For each component of the stand, work in from both sides to find the expected mortality level in the upper left quadrant of the nomogram (fig. 1).

The nomogram can also be used to develop a marking guide for a salvage sale after fire injury has occurred. In this case, crown volume scorched can be observed. Therefore, the right side of the nomogram is not needed. Work backward through the left half of the nomogram to find the minimum diameter for leave trees.

> Acceptable mortality will depend on the value of the trees and the objectives of the fire.

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Summary of Steps in a Successful Prescribed Burn*

1. The general objectives of management for a given piece of land should come from overall land use planning and the basic philosophy of the organization.
2. A reconnaissance is necessary to decide if the unit needs treatment. Measurements and evaluation may be needed at this point.
3. General objectives of the treatment should be developed and should involve several resource disciplines.
4. A decision should be made on the tools to be used and specific objectives of the treatment delineated. An environmental analysis report may be prepared at this point.
5. A prescription that will meet the objectives should be developed. Several estimation techniques are available.
6. Written plans should be developed and reviewed.
7. Preparations must be made for burning.
8. The burn is conducted.
9. The burn is evaluated and mopped up.
10. Feedback on various steps of the planning process will aid in future burning.

*From: Martin, R.E.; Dell, J.D. 1978. Planning for prescribed burning in the Inland Northwest. Gen. Tech. Rep. PNW–76. Portland, OR: USDA Forest Service, Pacific Northwest Forest and Range Experiment Station.

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GUIDELINES FOR CONTRIBUTORS

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Fire Management Today (*FMT*) is an international quarterly magazine for the wildland fire community. *FMT* welcomes unsolicited manuscripts from readers on any subject related to fire management. Because space is a consideration, long manuscripts might be abridged by the editor, subject to approval by the author; *FMT* does print short pieces of interest to readers.

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Managing editor:
USDA Forest Service
Attn: Hutch Brown, Office of the Chief
4NW Yates, 201 14th Street, SW
Washington, DC 20024
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Try to keep titles concise and descriptive; subheadings and bulleted material are useful and help readability. As a general rule of clear writing, use the active voice (e.g., write, “Fire managers know…” and not, “It is known…”). Provide spellouts for all abbreviations. Consult recent issues (at <http://www.fs.fed.us/fire/fmt/index.html>) for placement of the author’s name, title, agency affiliation, and location, as well as for style of paragraph headings and references.

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Contributors Wanted

We need your fire-related articles and photographs for *Fire Management Today*! Feature articles should be up to about 2,000 words in length but may be longer. We also take very short items. Subjects of articles published in *Fire Management Today* include:

- Aviation
- Communication
- Cooperation
- Ecosystem management
- Equipment/technology
- Fire behavior
- Fire ecology
- Fire effects
- Fire history
- Fire science
- Fire use (including prescribed fire)
- Fuels management
- Firefighting experiences
- Incident management
- Information management (including systems)
- Personnel
- Planning (including budgeting)
- Preparedness
- Prevention/Education
- Safety
- Suppression
- Training
- Weather
- Wildland/urban interface

To help prepare your submission, see “Guidelines for Contributors” in this issue.

THIRTEEN PRESCRIBED FIRE SITUATIONS THAT SHOUT WATCH OUT!*

John Maupin

1. You are burning with a plan that has not been approved by the appropriate line officer.
2. You are not a qualified burning boss but have been told to go ahead and burn.
3. The objective of the burn is not clear.
4. There are areas of special concern within the burn that cannot be burned.
5. Private land or structures adjoin the burn.
6. You are uncomfortable with the prescription.
7. You have not requested spot weather forecasts.
8. You decide a test fire is unnecessary.
9. You decide all your people are old hands and no briefing is necessary.
10. Escape probability is small so you don't bother with escape planning.
11. You, or the firing boss, are beginning to lose control of your torch people.
12. Mop-up and patrol instructions are not specific or understood by the mop-up boss.
13. You haven't lost one in a long time and are starting to feel smug.

When this article was originally published, John Maupin was a fire staff officer for the USDA Forest Service, Ochoco National Forest, Prineville, OR.

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* The article is reprinted from *Fire Management Notes* 42(4) [1981]:10.

WEBSITES ON FIRE*

A Guide for Prescribed Fire in Southern Forests

This well-compressed "how to" guide provides time-proven information to help resource managers plan and execute prescribed burns within ecosystems in the Southern States. But its insights can benefit prescribed fire practitioners in all regions.

The guide's topics include various techniques for implementing prescribed fire, prescribed fire's environmental effects, and the importance of weather when prescribe-burning. Its overriding purpose: to provide the basic information to help one become technically proficient in the proper use of prescribed fire. Its information—including a comprehensive glossary and suggested reading list—is well presented.

Originally written in 1966, the guide was revised throughout the 1970s and rewritten in 1988 by Dale D. Wade of the USDA Forest Service's Southeastern Forest Experiment Station and James D. Lunsford of the Forest Service's regional office, Fire and Aviation Unit, Southern Region. In 1990, the National Wildfire Coordinating Group's Prescribed Fire and Fire Effects Working Team sponsored the guide's publication.

Found at **<http://www.bugwood.org/pfire>**

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* Occasionally, *Fire Management Today* briefly describes Websites brought to our attention by the wildland fire community. Readers should not construe the description of these sites as in any way exhaustive or as an official endorsement by the USDA Forest Service. To have a Website described, contact the managing editor, Hutch Brown, at USDA Forest Service, Office of the Chief, Yates Building, 4th Floor Northwest, 201 14th Street, SW, Washington, DC 20024, 202-205-0878 (tel.), 202-205-1765 (fax), hutchbrown@fs.fed.us (e-mail).

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