Modifying WildFire Behavior – The Effectiveness of Fuel Treatments

The Status of Our Knowledge

by Henry Carey and Martha Schumann




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Executive Summary

This paper assesses existing research on the effectiveness of hazardous fuel reduction in changing wildfire behavior. Over two years, we reviewed more than 250 papers that evaluated three types of fuel treatment in relation to fire behavior in western forests – prescribed fire, mechanical thinning, and a combination of thinning and burning. We also surveyed the literature to evaluate recent suggestions by policy makers that commercial logging can be used to treat dense forest fuels.

This assessment focused on ponderosa pine – a "fire adapted" forest type where periodic, low-intensity fires were the ecological norm in presettlement times. Nonetheless, studies in other forest types were reviewed if the research provided useful information on the relationship between fuel treatments and fire behavior.

Findings:

- Although the assertion is frequently made that simply reducing **tree density** can reduce wildfire hazard, the scientific literature provides tenuous support for this hypothesis.

- The literature leaves little doubt, however, that fuel treatments can modify fire behavior. Thus, **factors other than tree density**, such as the distance from the ground to the base of the tree crown, surface vegetation and dead materials play a key role. Research has not yet fully developed the relationship among these factors in changing fire behavior.

- The **specifics** of how treatments are to be carried out and the **relative effectiveness** of alternative prescriptions in changing wildfire behavior are not supported by a significant consensus of scientific research at this point in time.

- Substantial evidence supports the effectiveness of **prescribed fire,** a treatment that addresses all of the factors mentioned above. Significantly, several **empirical** studies demonstrated the effectiveness of prescribed fire in altering wildfire behavior.

- By contrast, we found a limited number of papers on the effects of **mechanical thinning alone** on wildfire behavior. The most extensive research involved mathematical simulation of the impact of mechanical thinning on wildfire behavior. However, the results of this research are highly variable.

- A more limited number of studies addressed the effectiveness of **a combination of thinning and burning** in moderating wildfire behavior. The impacts varied, depending on the treatment of thinning slash prior to burning. Again, crown base height appeared as important a factor as tree density. The research community is still building a scientific basis for this combination of treatments.

- The proposal that **commercial logging** can reduce the incidence of canopy fire was untested in the scientific literature. Commercial logging focuses on large diameter trees

and does not address crown base height – the branches, seedlings and saplings which contribute so significantly to the "ladder effect" in wildfire behavior.

- ♦ Much of the research on the effectiveness of fuel treatments uses dramatically different methodology, making a comparison of results difficult. To provide a basis for analysis, we structured our review of the literature into four general groupings: observations, case studies, simulation models and empirical studies. **Empirical studies** provide the strongest basis for evaluating treatments whereas **personal observations** are the least reliable.

- ♦ We found the fewest studies in the most reliable class **– empirical research**. We found the greatest number of studies in the least reliable class of research – reports of **personal observation**. Several other reviews of the literature confirm this finding, stating that the evidence of the efficacy of fuel treatment for reducing wildfire damage is largely **anecdotal**.

- ♦ The results of **simulation studies** are highly variable, in terms of such factors as fire spread, intensity and the occurrence of spotting and crowning.

- ♦ Scientists recognize that large scale prescribed burning and mechanical thinning are still experimental and may yet reveal unanticipated effects on biodiversity, wildlife populations and ecosystem function.

<u>Recommendations</u>:

- · Systematic field research, in combination with synthesis from existing knowledge, is needed to provide a sound scientific basis for evaluating and designing fuel reduction treatments.

- · The notion that mechanical thinning, or a combination of thinning and prescribed fire, reduces the incidence of catastrophic fire should be viewed as **a working hypothesis**. Specific combinations of treatments need to be tested through experimentation using site- and weather-specific data.

- · **Priority** should be given to locating fuel treatments in areas that include a well-constructed, experimentally driven design, so that agencies can **optimize** their ability to learn, providing a higher return on future investment.

- · In 2000, our nation embarked on an emergency $1.6 billion program to reduce fuels on millions of acres. The Western Governors Association calls for sustaining this level of investment over the next ten years. Based on the findings of this paper, a comparable **investment** must also be made **in primary and applied research** to provide a credible scientific basis for the design, implementation and evaluation of alternative treatments.

INTRODUCTION

In recent years the public has become deeply concerned about the potential for severe forest fire. Of particular concern is the possibility of wildfires in the wildland-urban interface – an area where homes and other human development intermix with wildland vegetation. Forest managers, however, are also concerned about fire in the forest area outside of this zone of human habitation because of the long rate of recovery after a stand-replacing event.

A 1995 publication by American Forests helped to crystallize this concern (Clark and Sampson 1995). The authors reflect widespread opinion in describing today's wildfires as "hotter, more lethal to vegetation, more damaging to topsoils, and exceptionally dangerous to human settlements and property." In 1998, Feary and Neuenschwander echoed that "a billion dollar disaster is waiting to happen somewhere."

The regional press across the country has followed in raising public concern about wildfires. In the Southwest, for example, the Taos News described forests all over New Mexico as "prime for devastating wildfires fueled by heavy undergrowth and thick stands of small trees" (Matlock 1998). An article titled "Fiery Forecast" discussed the fear that 1999 would be one of the most dangerous fire seasons ever because low moisture levels would turn forests into "tinder-dry infernos" (Lezon 1999).

The increase in fuel loads in the forests is attributed largely to the Forest Service's policy of intensive timber production, resulting in dense regeneration, and of wildfire suppression (Covington and Moore 1994; Arno 1996; Arno et al. 1997; US GAO 1999). Overgrazing also contributed to an interruption of the normal fire regime (Savage and Swetnam 1990). Prior to European settlement, frequent surface fires occurred in the low elevation pine forest at intervals of 5 to 30 years (Baisan and Swetnam 1997; Covington and Moore 1994; Swetnam and Dieterich 1985; Weaver 1951). In some areas, fires created large, park-like and open stands (Biswell 1972; Cooper 1960; Covington and Moore 1994). Intensive grazing that changed the surface fuel structure, coupled with aggressive wildfire suppression altered the burn pattern (Savage and Swetman 1990). Without frequent fires, dense understories of shrubs and conifers have developed (Anderson and Brown 1988; Arno 1996; Kolb et al. 1998; Romme 2000a). As a result of the build up of fuels, the Forest Service estimates 39 million acres on national forests of the interior West are at high risk of catastrophic fire (US GAO 1999).

To address the problem of catastrophic fire, managers throughout the West are developing vegetation treatments to reduce fuels. The rationale behind fuel reduction is the logical expectation that wildfire behavior will be altered in ways that would assist suppression efforts (Covington and Sackett 1984, 1990; Harrington and Sackett 1990; Sackett et al. 1996). Many land managers advocate reducing the quantity of fuel in all size classes and forest types even though high fuel loads are a natural component of "stand replacement fire" ecosystems such as lodgepole pine, jack pine and aspen. Specific goals of fuel treatments are to decrease wildfire severity, reduce rate of spread, decrease fire intensity and flame length, and make control easier and less costly (Anderson and Brown 1988; Deeming 1990; van Wagtendonk 1996).

A project on the Carson National Forest, for example, proposed to mechanically thin trees less than 12 inches in diameter, leaving approximately 100-150 trees per acre (USDA 2000). In the municipal watershed on the outskirts of Santa Fe, NM, the Forest Service proposed to reduce canopy cover to 30-40 % by thinning trees less than 16 inches in diameter, leaving 50-100 trees per acre (USDA 2001). Both of these projects also included prescribed burning. Burning, under appropriate conditions, is recommended to reduce fuel loadings, thin the stand, remove ladder fuels, and raise the canopy level (Harrington 1981).

The public is in strong support of fuel reduction treatments. In the example given above, public comment on proposed thinning and prescribed burning in the Santa Fe Watershed indicated that approximately a third of the respondents were supportive of the project (USDA 2001). However, many other people brought forward concerns about the treatments, including a desire for further research to support such decisions. In addition, uncertainties about the safety of prescribed fire arising from the Cerro Grande fire in Los Alamos, New Mexico have encouraged managers to reevaluate fuel reduction approaches.

This paper reviews published research on the relationship between fuel reduction treatments and wildfire behavior, specifically the incidence of crown fire. This paper assesses existing research on hazardous fuel treatments in relation to the effectiveness of these treatments in changing wildfire behavior. This analysis focuses on ponderosa pine – a “fire adapted” forest type where periodic, low-intensity fires were the ecological norm in presettlement times. Nonetheless, studies in other forest types are reviewed if the research provides useful information on the fuel treatment/fire behavior relationship.

Research from pine forests in the Southeast and Mid-Atlantic region are not be discussed in this paper. For these regions, a number of case studies and empirical studies evaluate the effectiveness of prescribed burning in reducing wildfire size and cost (Cumming 1964; Helms 1979; Outcalt and Wade 1999; Davis and Cooper 1963; Moore et al. 1955; Martin 1988; Koehler 1992).

Terminology

Terminology is important to the purposes of this paper because of the complexity of concepts used to describe fire and fuel treatments. The public has become familiar with terms like catastrophic fire, fire hazard, fire intensity, fire severity and fire spread. The definition of some of these terms is unclear, in part because they are subjective. For example, catastrophic fire can be defined from three different perspectives: economic (the cost of damage), social (how it is viewed by the public), and ecological (biological effects of the fire). The press may define a wildfire as catastrophic from a social viewpoint whereas an ecologist might perceive a similar fire as an expected occurrence in a stand-replacing ecosystem, such as lodgepole pine. For the purposes of this paper, we will use Covington and Moore’s (1994) definition of catastrophic fire as a fire that kills a majority of the trees in the canopy in the ponderosa pine type or in any dry forest that was, in presettlement times, subject to frequent surface fires.

Wildfire hazard is a rating defined by the kind, arrangement, volume, condition, and location of fuels (Clar and Chatten 1966; Deeming 1990). The hazard rating reflects the susceptibility of a forest to ignition, potential wildfire behavior and severity, and the potential difficulty of suppression (Deeming 1990). Hazard ratings are generally based on the subjective judgments of managers (Sampson et al. 2000).

Fireline intensity is the energy released per unit length of fireline per unit of time (i.e., BTU/ft./sec.), a physical parameter that is related to flame length (Alexander 1983). Fireline intensity must be distinguished from fire severity. Fire severity is an ecological parameter that loosely reflects the effects of fire (Agee 1996). A narrower definition of fire severity is a measure of the heat transmitted into litter, duff, and soil layers, and the plant structures within them (Neuenschwander et al. 2000). Finally, fire spread relates to velocity, measured by a unit of distance per unit of time (Rothermel and Deeming 1980).

Wildland fire behavior is a function of fuels, weather and topography (Rothermel 1983). The behavior of wildland fire varies by the quality and quantity of fuel under differing weather and slope conditions. Topography and weather play an important role in determining fire behavior (Bessie and Johnson 1995). For example, steep slopes or high winds may make fuel reduction efforts ineffective. Nonetheless, since topography and weather cannot be managed, most fire hazard reduction efforts focus on modifying the fuel load.

Generally, fuels are described by whether they are dead or live and by their position under ground, on the surface or in the air (Clar and Chatten 1966). Surface fuels are important because a surface fire can raise crown fuels to ignition temperatures through convective heat transfer, a phenomenon first observed by van Wagner (1977). Examples of dead surface fuels include dead grass, shrubs, and woody debris. Dead aerial fuels consist primarily of dead trees and dead branches in live trees. Examples of live surface fuels are grass and shrubs. Live aerial fuels include suppressed trees and the foliage of dominant trees. A measure of aerial fuels is crown bulk density. Crown bulk density is the mass of crown fuel, including needles, fine twigs, etc., per unit of crown volume (Agee et al. 2000). Crown fuels are important to consider because they are necessary to sustain a crown fire (van Wagner 1977). Crown bulk density is a measure, however, that is relatively difficult to calculate and is unfamiliar to many foresters.

Several fuel characteristics are important in determining fire behavior. Moisture content influences the extent to which fuel is flammable (Biswell 1989). Compactness of fuel particles and their size regulate two important elements of the combustion process, the transfer of heat and the availability of oxygen to the fuel (Clar and Chatten 1966). The continuity of fuel particles affects fire spread (Biswell 1989; Martin et al. 1989; Harrington and Sackett 1992). The vertical arrangement of fuel in relation to tree crowns also influences fire spread. Contiguous vertical fuels are often referred to as ladder fuels (Clar and Chatten 1966). Some shrub species are exceptionally volatile and contribute to crown fire by functioning as ladder fuels (Martin et al. 1988; Harrington and Sackett 1990).

METHODOLOGY

Over the past two years, we reviewed more than 250 papers related to fuels treatment and fire behavior in western forests. The majority of the literature came from two sources. One is literature published by the USDA Forest Service. These documents include reports from research stations and laboratories, as well as proceedings from conferences. The other source consists of papers published in peer-reviewed and non-peer-reviewed journals.

Papers were compiled using several strategies. A broad literature review of fire-related research was conducted using search engines for academic journals at the University of New Mexico library. Topics ranging from fire history to fire ecology and behavior were included in this search. U.S. Forest Service field staff provided suggestions for useful articles, as did colleagues engaged in similar work. In addition, many organizations such as the Grand Canyon Forest Partnership, have compiled bibliographies to support their work. Using this iterative approach, when it became apparent that no "new" articles turned up, our search appeared to have been comprehensive.

We found a wide range of scientific rigor in the studies reviewed, making an evaluation of the research difficult. To assist the reader, we therefore structured our review of the literature into four general groupings: observations, case studies, mathematical models and empirical studies. Articles recounting observations are generally based on the authors' personal experience and typically do not include data about weather conditions or fuel loads. Case studies provide data about a treatment or area but are not replicated and are not experimental in nature. Literature describing simulation models ranges from theoretical projections of fire behavior to studies testing the utility of models in the context of specific data. Finally, empirical studies describe research that includes a testable hypothesis, replication and supporting data.

Observations

Observation-based reports are generally not included in a rigorous review of scientific literature. However, this category includes the greatest number of papers on the effectiveness of fuel treatments. In that they communicate the experiences of forest managers and fire fighters, observations can provide a starting point from which to begin thinking about the effectiveness of fuel treatments.

Observations often do not recount the context of the observed event. For example, an account of a fire dropping from tree crowns to the ground may not include information about the pre-fire stand structure, treatment history, or weather conditions. Observations also have the potential to be selective and biased and often do not provide adequate information to understand the complex variables involved in determining wildfire behavior.

Case Studies

Case studies generally investigate fuel treatments and the observed effects of treatments on wildfire at a single site. Such case studies usually do not provide information on the fuel complex prior to wildfire occurrence and thus fall between observation and empirical research in terms of rigor..

Simulation Models

Due to their destructive nature, studies involving the ignition of actual forest fires are impractical. As an alternative to studies that are field based, many scientists use computer simulation models with climatic, fuel load and forest structure variables to better understand fire behavior and fire effects. Scientists use such models to predict fire behavior, including fire growth, spotting, and crowning.

Models can provide an effective way to assess the potential effects of management on fire behavior, but need to be verified using field research. Several studies illustrate the limitations of models. Some models only consider dead and down woody fuels and litter or live surface fuels, but do not address crown fuels (Andrews 1986; Miller 2000). In this case, the model cannot simulate crown fire, nor the transition from surface fire to crown fire (Miller 2000). Furthermore, simulation studies are limited by the ability of current models to predict extreme fire behavior (Finney 1998).

An inherent limitation of models lies in their restricted capacity to represent the great variation within natural forests, even within a relatively well-defined class such as an even-aged, single-species stand. Such variation places a practical limit on the degree of accuracy of models when used on the landscape level (van Wagner 1993). Ideally the whole fuel complex would be included in a model (Andrews and Williams 1998). In addition, the development of models incorporating non-uniform fuels and spotting has been identified as a research priority (Rothermel 1988). Reinhardt and Ryan (1998) cautioned that models should not be used to provide general conclusions about fuel treatments, although they may be useful in comparing specific alternatives on a single site.

Empirical Studies

Scientific studies based upon measurements that portray or reconstruct fuel conditions both before and after wildfire provide the best insight as to the effectiveness of treatment in modifying fire behavior. Such measurements allow the researcher to develop statistical correlations between specific fuel characteristics, treatments and wildfire behavior. In addition, such studies provide a clear basis for comparing treatments and for communicating the scientific basis for fuel treatments to the public.

OVERVIEW OF THE LITERATURE

The following section is organized according to the various fuel reduction practices identified by research scientists and forest managers for the ponderosa pine type. Treatments used in other forest types are noted specifically. Prescribed burning has been utilized as an effective way to reduce fuel loads (Biswell et al. 1973). Researchers have suggested that mechanical thinning which leaves the large trees in the forest will reduce fire severity (Agee 1996;

Covington et al. 1997). Understory fuel treatments, such as piling and burning slash, also reduce fuel loads. A combination of strategies may be the most effective fuel treatment (Agee et al. 2000; Covington et al. 1997; van Wagtendonk 1996). Most recently, a number of policy makers have suggested that commercial logging would represent the most cost effective method to reduce fuel loads (Bush 2002; USDA Forest Service 2002; Little 2002).

Prescribed Burning

Prescribed burning has a long history of use, initially by Native Americans, and later by land managers who recognized the need for regular fire in some ecosystems. Prescribed fire can be used to reduce dead and down fuels, live surface fuels and dead and live canopy fuels. The extent to which fuels are reduced depends on the characteristics of the fire and the fuels. While studies have shown that prescribed fire is effective in reducing fuel levels (Gaines et al. 1958; Sackett and Haase 1998; Harrington 1981), examining the relationship between prescribed burning and subsequent fire behavior is more complicated.

<u>Observations</u>

Recorded observations generally describe the effects of prior burning on subsequent wildfires. Biswell et al. (1973) described the 1963 Penrod Butte wildfire in Arizona. The wildfire, which covered 2,300 acres before being contained, started on one of the worst fire days of the year. In areas where fuels had been treated by controlled burning in 1956 and 1961, the fire burned on the surface and the majority of dominant and co-dominant poles survived. Where there had been no controlled burning, the wildfire crowned and caused almost total destruction of trees. Another example is provided by the Star Gulch fire in the Boise National Forest. The fire burned into Cottonwood Creek, an area previously treated twice with prescribed fire (Barbouletos et al. 1998). A majority of trees in the treated areas appeared to have survived, whereas many trees in untreated areas did not. Saveland and Bunting (1988) described ponderosa pine communities in the Selway-Bitterroot Wilderness in north-central Idaho where natural ignitions were allowed to burn. Although measurements were not taken, the rate of spread and intensity of wildfires in 1986 and 1987 appeared to be reduced when entering areas previously burned by a low intensity wildfire in 1979.

<u>Case Studies</u>

Case studies conducted on the Fort Apache Reservation in Arizona and the Colville Reservation in Washington document the effect of prescribed burning on subsequent wildfire hazard. Prescribed burning on both reservations was used repeatedly. Weaver reported that, in areas where controlled burns have occurred, the size and associated costs of wildfires were reduced (Weaver 1955, 1957a, 1957b). However, Weaver does not describe how the “cost of damages” was quantified. Kallander (1969), in another study on the Fort Apache Reservation, compared wildfires on a non-treated area with wildfires after controlled burning treatment. He found a 60% reduction in the size of wildfires on treated areas. On 28,500 acres controlled burned in 1956, subsequent wildfires averaged about one-fourteenth as large as fires on the untreated acres. Unfortunately, size is a poor measure of wildfire effects.

Similarly, results of controlled burning on the Colville Indian Reservation in Washington showed a 90% reduction in the number of acres burned by subsequent wildfires and a 94% reduction in damage (Weaver 1957a). Martin et al. (1988) describe the Kelsey Butte site. A wildfire occurred 6 years after treatment, spreading to plots outside of the area that was prescription burned. In the unburned plots, crowns torched, resulting in nearly 100% mortality. Within the perimeter of the prescribed burn, the wildfire remained a surface fire.

Other case studies suggest that prescribed fire, if applied only once, is not adequate or effective for reducing the density or fuels (Ffolliot et al. 1977; Harrington and Sackett 1990). Therefore, hazard reduction can be seen as a continual process that cannot be accomplished by a single treatment.

Simulation Models

Simulation models appear to have been used principally in forest types other than ponderosa pine. Reinhardt and Ryan (1998) linked a mathematical model of stand structure with models of fire behavior to compare the effect of prescribed burning with a control. Model results suggested that prescribed burning would reduce fire intensity, as quantified by flame length. A study by Johnson et al. (1998) simulated wildfire occurrence and effects in mixed conifer in the Sierra Nevada. The simulation suggested that prescribed burning could significantly lower the risk of high-severity fire. Van Wagtendonk (1996), assessing treatments in mixed conifer forests using FARSITE, a fire growth simulation model, suggested that prescribed fire might be the most effective treatment for reducing a fire's rate of spread, fireline intensity, flame length, and heat per unit area. Stephens (1998), also using FARSITE, suggested that a prescribed burn could reduce subsequent fireline intensities, heat-per-unit area, rate of spread, area burned and scorch height in a Sierra Nevada mixed-conifer forest. A study in a giant sequoia-mixed conifer forest used the Rothermel fire model to show that prescribed burning resulted in a reduced potential for crown fire (Kilgore and Sando 1975).

Empirical Studies

An empirical study conducted by Wagle and Eakle (1979) compared the effects of a prescribed burn treatment with an unburned control on the Carrizo-Bibecue wildfire. The study demonstrated that a controlled burn one year prior to the advent of wildfire effectively reduced the impacts on a ponderosa pine forest overstory. One limitation of this study is that the controlled burn occurred only one year prior to the wildfire. Therefore, results support only the short-term effects of prescribed burning. Foxx (1996) studied areas that had experienced previous low intensity wildfires within the perimeter of the 1977 La Mesa Fire in Bandelier National Monument. Plots examined after the La Mesa fire showed that areas burned 1 and 17 years before suffered less damage to crowns than areas that had been burned 40 and 84 years before (Foxx 1996).

A retrospective study by Pollet and Omi (2002) in ponderosa pine on the Kootenai National Forest in Montana quantitatively examined fire severity in a prescribed burn versus a control after the Webb Fire burned through both areas. Fire severity was rated with consideration of both canopy damage and depth of ground char. Canopy damage was classified by describing crown scorch and consumption. Ground char depth was classified by examining needle litter, duff and woody debris condition, the color and texture of the soil and the amount of mineral soil exposure. The stand treated with prescribed fire had lower fire severity ratings than the untreated stand. The lower ratings were attributed to differences in density and tree size.

Mechanical Thinning

Because of the inherent risk and lack of control involved in using prescribed fire as a management tool, many foresters advocate mechanical thinning to reduce fuel loads. Thinning is used primarily to reduce the continuity of aerial fuels and crown bulk density. In general, thinning from below (removing the smallest trees) is assumed to be more effective at altering fire behavior than thinning from above (removing the largest trees). The hypothesis underlying the use of mechanical thinning is that the lack of continuity of vertical and horizontal aerial fuels will reduce the likelihood of sustained crown fire. While researchers can quantify fuel reduction resulting from thinning (Kalabokidis and Omi 1998; Wakimoto et al. 1988), the utility of mechanical fuel reduction for mitigating severe wildfires is not easily evaluated in quantitative terms (Scott 1998; Pollet and Omi 2002; van Wagtendonk 1996).

Assessing the effectiveness of mechanical thinning is complicated by the introduction of surface fuels that result from thinning activities. Without proper treatment, live, aerial fuels are converted by thinning into dead, surface fuels. A number of authors suggest that, when slash is not removed or treated adequately, the resulting fuel complex increases the probability of a more intense, damaging, and extensive wildfire (Wilson and Dell 1971; Maxwell and Ward 1976; Anderson 1982; Kalabokidis and Omi 1998). Fire hazards associated with thinning residues can extend for many years, varying by tree species (Olson and Fahnestock 1955).

Observations

Field observations have recorded the effect of thinning on fire behavior. Agee (1996) describes the 1994 Tyee fires in the Wenatchee National Forest, in which crown fires in unthinned stands dropped to the ground when they reached adjacent thinned stands. Fulé and Covington (1996) describe an event that occurred during the Trick fire of 1993, northwest of Flagstaff, Arizona. A high-intensity crown fire passed across a thinning demonstration area, killing all trees in a densely-spaced stand, but causing only an incomplete surface burn in a stand with more open spacing. Other observations, however, suggest thinning may have little or no effect on crown fire behavior. For example, a fire west of Flagstaff, Arizona was observed to jump a 300 foot fuel break and burn though the crowns of a previously thinned stand (Forest Trust 1999). Similarly, areas that had been mechanically thinned near Denver were observed to be transformed into "…a ghost forest, silent and blackened, devoid of living trees" by the Hayman fire of 2002 (Purdy 2002).

Case Studies

Agee (1996) provided a single case study of the effect of mechanical thinning in a ponderosa pine/Douglas fir forest. Crown fire on the 1994 Wenatchee fire in Washington State was evaluated. In areas where a comparison was possible, crown fires in unthinned stands were observed to drop to the ground when they reached thinned stands. In this study, the threshold for crown bulk density was calculated to be 0.10 kg/m^3, with crown fire more likely above this threshold and surface fire more likely when density fell below this limit.

Simulation Models

Mathematical models have been used extensively to assess the effects of mechanical thinning on simulated wildfires (Graham et al. 1999). Stephens (1998) used FARSITE to investigate the impact of salvage or group selection with slash reduction in a Sierra Nevada mixed-conifer forest. Results of this simulation predicted that mechanical treatments could reduce fireline intensities, heat per unit area, rate of spread, area burned, and scorch height. Simulations conducted by van Wagtendonk (1996), also using FARSITE, analyzed the effect of a 50% removal of the overstory. This simulation indicated that average heat per unit area might be slightly less in the treated area and that crowning might not occur. However, in this simulation, rate of spread, fireline intensity, and flame length increased by comparison with the control, because surface fuels were drier.

Scott (1998) linked models of surface fire behavior (Albini 1976; Rothermel 1972), crown fire rate of spread (Rothermel 1991) and crown fire initiation (van Wagner 1977) to identify the environmental conditions that lead to crown fire activity. Scott then simulated fire behavior in three ponderosa pine stands receiving different treatments: 1) basal area reduced to 100 ft^2/acre, thinned from below; 2) basal area reduced to 75 ft^2/acre, thinned from above; and 3) basal area reduced to 75 ft^2/acre, thinned from below. In this simulation, all three treatments appeared to restrict the potential for crown fire spread by reducing crown bulk density.

By contrast, Graves and Neuenschwander (1999) observed contradictory results from a simulation in ponderosa pine using three models. They observed that "[h]igh crown bulk densities, by themselves, did not support crown fire. Likewise, stands opened up from thinning to reduce crown bulk density did not necessarily have less tree mortality" (*op.cit.*:166). These authors found these results "surprising," indicating that the model predicted an outcome that contradicts common assumptions.

Graves and Neuenschwander (1999) did observe in their simulation that treatment of ladder fuels, however, helped to reduce scorch height and fireline intensity. These findings are consistent with those of Scott (1998), cited above. The results of his simulation indicated that thinning from below resulted in stands that were less prone to crown fire ignition because the average height of tree crowns was raised.

Finally, the positive impact of reducing ladder fuels is also supported by the results of Reinhardt and Ryan (1998) who linked a model projecting stand dynamics with fire behavior and effects models to compare the results of a low thinning (trees up to 8 inches) with an unthinned control. In this simulation, thinning appeared to reduce flame lengths (Reinhardt and Ryan 1998).

As noted above, mechanical thinning results in large amounts of slash that must be reduced before hazardous fuel treatments can be considered complete. Models have been used to investigate the effect of slash from thinning on fire behavior. Kalabokidis and Omi (1998), using BEHAVE, evaluated three thinning and slash disposal treatments on two lodgepole pine stands: thinning with whole tree removal, thinning with stem removal and lopping and scattering, and thinning with stem removal and hand piling and burning. On average, thinning reduced tree density to between 300 and 400 trees/hectare. Results of the model suggested that a failure to implement slash treatments could contribute to accelerated fire spread and difficulty of control.

Empirical Studies

This survey turned up only one empirical study examining how thinning alone affects fire severity. Pollet and Omi (2002) examined one study site treated by whole tree thinning in 1989 and 1990. Slash residues were effectively removed from the site. When a subsequent wildfire burned through this site, the treated plots exhibited lower fire severity ratings and less crown scorch than the untreated plots.

Mechanical Thinning and Burning

A combination of thinning and prescribed burning has been recommended as a tool to restore ponderosa pine forests and reduce fire risk (Fiedler 1996; Fiedler et al. 1998). However, research on the combination of treatments is not well documented in the literature.

Observations

Few recorded observations of the effect of thinning and burning on fire behavior were found. Barbouletos et al. (1998) provided one account of a wildfire in the Boise National Forest. The Tiger Creek area had been thinned and prescription burned prior to the 1992 Foothills fire. When the fire hit the Tiger Creek area, it changed from a crown fire to a surface fire.

Case Studies

Weaver (1957b) described using stand improvement and prescribed burning to reduce fuels in a second growth, ponderosa pine stand on the Klamath Indian Reservation in southern Oregon. Smaller, suppressed trees were thinned, residual trees pruned, and slash piled and burned. After this treatment, prescribed burns were conducted annually. While Weaver did not provide quantitative data, he reported a reduction in fire hazard. In support of this conclusion, Weaver describes a wildfire that occurred 15 years after the initial treatment that was easily controlled.

Simulation Models

Models have been used to evaluate the efficacy of thinning and burning treatments. Johnson et al. (1998), using a simulation model, suggested that prescribed fire and timber harvest reduced the likelihood of high-severity fire better than prescribed fire alone. Stephens (1998) used FARSITE to model the effect of thinning followed by prescribed burning in a Sierra Nevada mixed-conifer forest. Modeling a subsequent wildfire, these treatments were predicted to reduce fireline intensities, heat per unit area, rate of spread, area burned, and scorch height. In this study, the greatest fireline intensities were predicted when slash was not treated.

Fulé et al. (2001) evaluated a combination of thinning and prescribed fire using Nexus. The percent of crown burned and rate of spread was predicted to be reduced in each of the four treatment blocks. The predicted "type" of fire (surface, passive crown fire or active crown fire) did not change after treatment except in one block where an active crown fire was predicted prior to treatment and a passive fire post treatment. The results of this treatment appear anomalous in that the positive effects did not correlate with density of standing aerial fuels expressed either as crown bulk density or as basal area. In fact, in this block, crown bulk density was 147% higher than in the next most dense treated block and basal area was 55% higher. Fulé et al. (2001) suggested that this treatment was predicted to be successful in preventing a crown fire because it raised the crown base height.

Simulations conducted by van Wagtendonk (1996) projected that a 50% canopy reduction with slash removal and prescribed burning would reduce the size and intensity of subsequent fires. In this simulation, scattering the cut and lopped fuels on the surface, rather than removing the slash entirely, had the apparent result of causing fires to spread rapidly, burn intensely, spot ahead of the main fire and move into the crowns.

<u>Empirical Studies</u>

The authors found only one study that systematically and quantitatively examined fire severity in treated versus untreated ponderosa pine stands (Pollet and Omi 2002). Two sites, where the Hochderffer and Tyee wildfires later occurred, received some type of mechanical tree removal in the 1970s, followed by prescribed burning 13 to 25 years later. After the two wildfires occurred, several variables describing residual stand density, basal area, and average diameter of trees on the plot were measured. At the Tyee site, Pollet and Omi (2002) found a high correlation between tree density and fire severity rating. However, at the Hochderffer site, there was a lack of significant correlation between fire severity and the measures of stand density. Fire severity did vary significantly, however, between treated and untreated sites. Thus, the study suggested that something other than stand density, such as fuel moisture, contributed to the differences in fire severity.

Commercial Timber Harvest

As noted above, some policymakers have suggested that commercial logging could be used to reduce the incidence of canopy fire (Bush 2002; USDA Forest Service 2002; Little 2002).

<u>Observations and Case Studies</u>

We did not find any reports of observations or case studies that address the hypothesis that commercial logging could be used to modify fire behavior to reduce crowning.

Simulation Models

Most studies of the interaction between commercial harvest and fire behavior focus on the detrimental impacts of slash residues. A study by Benson (1982) in mature lodgepole pine compared four harvesting and logging residue treatments. The model predicted the potential for extreme fire behavior in areas where residues were not treated. Wakimoto et al. (1988), using the fire model BEHAVE, in a ponderosa pine/Douglas fir forest, suggested that all six alternative slash treatments could provide a significant reduction in the potential for extreme fire behavior following logging.

In a Sierra Nevada mixed-conifer forest, Stephens (1998) used FARSITE to investigate the interaction between slash from logging and fire behavior. When silvicultural treatments were conducted without reducing slash, the simulated fire behavior appeared more extreme than in the area that had not been harvested at all.

We found a single study involving simulation that evaluated the effect of canopy reductions resulting from commercial timber harvest (Jones and Chew 1999). This study, however, simulated vegetation development and not fire behavior.

Empirical Studies

We did not find any empirical studies that evaluated commercial harvesting as a means of altering fire behavior. Numerous empirical studies, however, have investigated fire behavior in slash following logging. A study by Vihanek and Ottmar (1993) provides evidence of severe post-wildfire effects in areas where slash was left compared to areas where slash was treated by broadcast burning. A study by Weatherspoon and Skinner (1995) quantifies fire damage to ponderosa pine and Douglas fir tree crowns in stands that had been commercially harvested. Sites where treatments included complete slash removal had lower fire severity, defined by scorch or consumption of tree crowns, than stands with no slash treatment. Significantly, this study found that uncut stands suffered the least damage from wildfire. The high damage ratings for the cut, versus the uncut, stands were attributed to the added fuels, the altered microclimate, and the fact that the harvest removed large rather than small trees (Weatherspoon and Skinner 1995). These results are similar to an empirical study by Lindenmuth (1962). Lindenmuth described more crowning in a recently cut ponderosa pine stand by contrast to areas where logging had occurred at a significantly earlier time. He attributed the crowning that occurred in the recently cut stand to slash. These studies suggest that slash resulting from logging is a key factor in predicting subsequent fire risk and that removal of large diameter trees alone may contribute to increased fire severity.

SUMMARY

The following summary provides a brief overview of what can be concluded about fuel reduction and fire behavior from the studies that were reviewed. Although we have included reports of observations in this study to this point, such reports are generally not considered sufficiently rigorous to be included in a review of the literature. Therefore, we have not included reports of observations in the following summary.

Prescribed Burning

We found substantial literature on the use of prescribed fire to alter wildfire behavior. A number of case studies (Weaver 1957a; Martin et al. 1988) describe this treatment as reducing subsequent wildfire damage (including crown scorch and tree kill). Other studies in this class found that the use of prescribed fire helped to reduce the area burned by subsequent wildfires, although size was recognized as a poor measure of wildfire effect (Kallander 1969; Weaver 1955, 1957a, 1957b).

A number of studies using simulation models suggested that prescribed burning could reduce flame length, fireline intensity, rate of spread and heat generated per unit area (Kilgore and Sando 1975; van Wagtendonk 1996; Johnson et al. 1998; Reinhardt and Ryan 1998; Stephens 1998).

Significantly, we also discovered several empirical studies of the effectiveness of prescribed fire in altering wildfire behavior. These studies report reduced crown scorch and tree mortality as a result of treatments using prescribed fire (Wagle and Eakle 1979; Foxx 1996). One study reported a reduction in fire severity in more general terms (Pollet and Omi 2002).

Mechanical Thinning

We found a limited range of papers on the effects of mechanical thinning on wildfire behavior. We were able to find only a single case study linking the effects of mechanical thinning to wildfire damage (Agee 1996). This study indicated that thinning which specifically reduced crown bulk density restricted the occurrence of crown fire.

The most extensive research involved mathematical simulation of the impact of mechanical thinning on wildfire behavior. However, the results of this research appeared highly variable. Three studies suggested that mechanical thinning could reduce incidence of crowning or area burned (van Wagtendonk 1996; Scott 1998; Stephens 1998). Several other studies suggested that mechanical thinning would reduce scorch height and fireline intensity (Reinhardt and Ryan 1998; Stephens 1998; Graves and Neuenschwander 1999). Studies by Scott (1998) and Graves and Neuenschwander (1999), however, produced inconsistent results for fireline intensity, rate of spread and flame length. In some cases, thinning prior to wildfire simulation reduced the severity of these variables and, in other cases, thinning appeared to exacerbate these factors depending, in part, on the treatment of the resulting slash.

The single empirical study we were able to find on the effects of mechanical thinning indicated that fire severity was reduced on only one out of several study sites (Pollet and Omi 2002).

Mechanical Thinning and Burning

A limited number of studies address the effectiveness of a combination of thinning and burning in moderating wildfire behavior. We found only one case study and one empirical study. The case study suggested that the ease of controlling wildfire improved after treatment (Weaver 1957b). The single empirical study found that fire severity and crown scorch was reduced after treatment on one site but on another site, this effect could not be linked statistically to reductions in tree density (Pollet and Omi 2002).

The results produced by computer simulation were not consistent. Two of the simulation studies suggested that the area burned and fireline intensity could be reduced by this combination of treatments (Johnson et al. 1998; Stephens 1998). However, one study suggested that fire spread, intensity and occurrence of spotting and crowning would increase after treatment (van Wagtendonk 1996).

Commercial Timber Harvest

The research community has not addressed commercial logging as a method for reducing wildland fuels. Most of the research on logging and fire behavior focuses on the build-up of fuel that results from harvest and on methods for treating slash. We found a single simulation study which touched on the impacts of commercial harvest on fire behavior. We did not find any reports of observations, case studies or empirical on research this topic. The absence of literature may result from the fact that commercial logging focuses on large diameter trees which do not contribute significantly to fire risk.

CONCLUSION

Although the assertion is frequently made that reducing tree density can reduce wildfire hazard, the scientific literature provides tenuous support for this hypothesis. This review indicates that the specifics of how prescriptions are to be carried out and the effectiveness of these treatments in changing wildfire behavior are not supported by a significant consensus of scientific research at this point in time. This conclusion is supported by the work of other researchers.

Deeming (1990), suggested we do not know whether proposed treatments will be effective in reducing the size, intensity, or severity of wildfires. A report prepared for Congress stated: “We do not presume that there is a broad scientific consensus surrounding appropriate methods or techniques for dealing with fuel build-up or agreement on the size of areas where, and the time frames when, such methods or techniques should be applied” (US GAO 1999:56). A research report by Omi and Martinson (2002:1) stated: “Evidence of fuel treatment efficacy for reducing wildfire damages is largely restricted to anecdotal observations and simulations.”

The knowledge needed to carry out prescribed fire activities with any level of sophistication is severely limited because research has historically focused on fire suppression (Paysen et al.

1998). Other scientists acknowledged there is little objective data concerning effective combinations of prescribed fire and different silvicultural techniques (Harrington and Sackett 1990; van Wagtendonk 1996). Jim McIver, a research scientist undertaking a five year study of alternative fuel treatment strategies stated: “At this point, information needed to answer this question is anecdotal or completely absent” (Sonner 2002). Omi and Martinson (2002:3), in a comprehensive overview of the literature concluded that only a “spattering” of studies published since the 1950s report that fire severity was reduced in areas where fuels had been previously treated: “Very little work has been done that would fit into the scope of our research, i.e., wildfire severity variates measured and compared between untreated areas on non-commercial fuel reduction areas such that an hypothesis regarding treatment efficacy may be statistically tested.”

Given the lack of scientific research, it is not surprising that forest managers also appear to lack adequate information concerning appropriate fuel reduction treatments. In a letter, a regional forest manager stated: “Regarding your question about different thinning prescriptions demonstrating relative effectiveness in reducing the intensity of spread of crown fire, I don’t know of any [studies]” (Personal Communication 2000).

In sum, the notion that mechanical thinning, or a combination of thinning and prescribed fire, reduces the incidence of catastrophic fire needs to be viewed as a working hypothesis and needs to be tested through experimentation and site-specific evidence. The proposal that commercial logging can reduce the incidence of canopy fire appears completely untested in the scientific literature.

Research Needs

Covington (1996) suggested that systematic field research, in combination with synthesis from existing knowledge is needed to provide a sound scientific basis for evaluating and designing ecosystem management projects. Some efforts to provide such research have already begun in the Lick Creek area of the Bitterroot National Forest, Montana. Thirty-three research units of several acres each have been established (Arno et al. 1995). Researchers are testing different harvest treatments that leave the majority of overstory pines, followed by burn and no burn treatments. Another such study, the Fire and Fire Surrogates project, is being implemented across the country. This national network of eleven long-term research sites will quantify the consequences and tradeoffs of alternative fire and fire surrogate treatments (Weatherspoon and McIver 2000). This research will be experimental, in that differences among sites will be statistically tested and holds much promise in building a body of knowledge to guide forest management.

Finally, scientists recognize that large scale prescribed burning and mechanical thinning are still experimental and may yet reveal unanticipated effects on biodiversity, wildlife populations and ecosystem function (Romme 2000b; Tiedemann et al. 2000). Few long-term studies document the effect of such treatments over time and across the landscape.

In 2000, in response to the scale of summer wildfires, our nation embarked on an emergency $1.6 billion program to reduce fuels on millions of acres. The total commitment approaches

25% of federal land management funding. The western governors program calls for sustaining this level of investment over the next ten years. Based on the findings of this paper, a comparable investment must also be made in primary and applied research to provide a credible scientific basis for the design, implementation and evaluation of alternative treatments before they are applied on a landscape scale.

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