Restoration of Southwestern Ponderosa Pine Ecosystems With Fire

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Abstract.— Heavy grazing and timbering during settlement by Europeans, and a policy of fire exclusion shortly after caused extensive structural and compositional changes to the southwestern ponderosa pine ecosystem. These changes have resulted in forest health problems, such as increased insect and disease epidemics, reduced wildlife habitat, and a serious wildfire hazard. Prescribed burning can reduce heavy fuel accumulations, provide adequate sites for natural regeneration, thin dense stagnated thickets, and create an edaphic and stand environment conducive to better forest health and productivity. Although presettlement conditions may never be restored, forest condition and health can be improved by means of prescribed fire.

Prior to European settlement, the composition and structure of southwestern ponderosa pine (*Pinus ponderosa)* forests were quite different from today. The open, park-like presettlement stands, characterized by well-spaced older trees and sparse pockets of younger trees, had vigorous and abundant herbaceous vegetation (Biswell and others 1973, Brown and Davis 1973, Cooper 1960). These forest conditions were maintained by naturally-ignited fires burning on a frequent, regular basis in light surface fuels of grass and pine needles. Light surface fires burned at intervals averaging less than 10 years and as often as every 2 years (Dieterich 1980, Weaver 1951). Warm, dry weather common to the Southwest in early summer, the continuity of grass and pine needles, and the high incidence of lightning caused this short fire interval. Light surface fuels built up sufficiently with the rapid resprouting of grasses and the abundant annual pine needle cast. Large, woody fuels in the form of branches or tree boles, which fall infrequently, rarely accumulated over a large area. When they were present, subsequent fires generally consumed them, reducing grass competition and creating mineral soil seedbeds which favored ponderosa pine seedling establishment (Cooper 1960). These effects created an uneven-age stand structure composed of small, relatively even-aged groups.

The decline of the natural fire regime in southwestern ponderosa pine ecosystems started with extensive livestock grazing in the late 19th century when fine, surface grass fuels were reduced (Faulk 1970). Subsequently, ponderosa pine regeneration increased because of reduced understory competition, less fire mortality, and more mineral seedbeds (Cooper 1960). In the early 1900's, forest practices, primarily fire suppression, further reduced the ecological role of fire. These practices lead indirectly to stagnation of naturally regenerated stands and unprecedented fuel accumulation (Biswell and others 1973).

Stand stagnation has been reported on tens of thousands of acres throughout the Southwest (Cooper 1960, Schubert 1974), and still persists where natural or artificial thinning has not taken place. Sites with dense thickets are not only unproductive but also represent a severe wildfire hazard.

For several decades, trees of all sizes have been showing signs of stress with generally poor vigor and reduced growth rates (Cooper 1960, Weaver 1951). This condition is likely due to reduced availability of soil moisture caused by intense competition and by moisture retention in the thick forest floor (Clary and Ffolliott 1969). Thick forest floors also indicate that soil nutrients, especially nitrogen, may be limiting because they are bound in unavailable forms (Covington and Sackett 1984, Covington and Sackett 1992).

During the last 75 to 100 years with a greatly altered natural fire cycle, unprecedented and unnaturally large amounts of surface and ground fuels have accumulated (Kallander 1969). Sackett (1979) reported average loadings of naturally fallen fuels

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at 22 tons per acre for 62 southwestern ponderosa pine stands. Harrington (1982) verified the heavy fuel loadings with an average of 34 tons per acre in southeastern Arizona.

Forest floor fuels can accumulate to 9 tons per acre in sapling thickets and to more than 50 tons per acre on old-growth sites. Annual fuel accumulation on those sites can range from 0.6 to more than 3.5 tons per acre (Sackett and Haase in preparation). The decomposition rate (k) (Jenny and others 1949) in these forests is extremely slow, resulting in the large buildup of forest floor fuel. K values range from 0.076 to 0.059 and 0.050 for sapling, pole, and old-growth substands respectively (Sackett and Haase, in preparation).

Large, woody fuels, formerly uncommon in the Southwest, now average about 8 tons per acre but are frequently found at twice that loading (Sackett 1979). Much of the heavy fuels have accumulated in sapling thickets, creating an even more severe hazard.

A combination of heavy forest floor fuels and dense sapling thickets, coupled with the normally dry climate and frequent lightning- and human-caused ignitions, has resulted in a drastic increase of severe wildfires in recent decades (Biswell and others 1973, Harrington 1982). Data summaries from USDA Forest Service Smokey Bear Reports show (fig. 1) a great increase in the number of acres burned by wildfire since 1970. Of all the years since 1915 with over 100,000 acres burned, almost 70 percent occurred between 1970 and 1990, indicating a worsening problem.

A final characteristic of the present southwestern ponderosa pine stands is the sparseness of understory vegetation, including pine regeneration. The thick organic layers and dense pine canopies have suppressed shrubby and herbaceous vegetation (Arnold 1950, Biswell 1972, Clary and others 1968). In openings left by overstory mortality where pine regeneration is desired, conditions for establishment are poor, again because of the deep forest floor (Sackett 1984, Haase 1981). This condition has reduced the wildlife, range, and timber production value of these forests and has generally resulted in minimal biodiversity.

REESTABLISHING FIRE TO ITS NATURAL FUNCTION

Because natural fire was the major presettlement factor in shaping and maintaining southwestern ponderosa pine ecosystems, it is logical to consider applied fire in a management scheme to relieve the serious problems that plague these forests due to years of fire exclusion. Fire has been used in the southeastern United States for many years to maintain pine in an environment that would naturally shift to hardwoods. It is also recognized as the key factor in keeping healthy, seral ponderosa pine stands from becoming stressed, wildfire-prone, mixed-conifer stands in the interior West (Arno 1988).

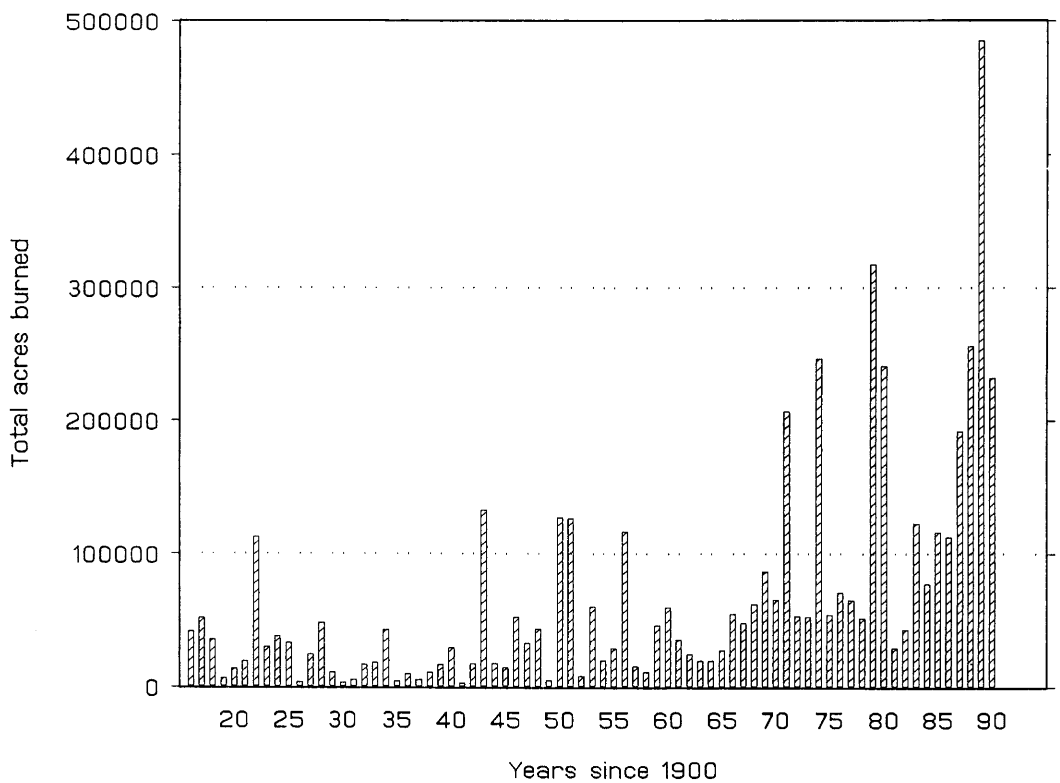

Figure 1. — The total number of acres burned by wildfires in Arizona and New Mexico from 1916 to 1990. Data obtained from USDA FS Smokey Bear Reports.

The hazardous conditions described make the wide-spread application of prescribed fire difficult and costly. Heavy fuels and dense stands can create control problems, and overstory mortality from excessive above- and below-ground heating is a certainty. An acceptance of these risks and economic losses, however, seems necessary in the short-term if ecological sound management is sought.

For prescribed fire to be an effective natural force in ponderosa pine, it must be applied at regular intervals — as were presettlement fires — and, most importantly, its use continued once started (Sackett 1975, Sackett 1980). Too often, fire use means one treatment with no consideration for future applications. Frequently, the fire hazard remains high after one application because of the addition of fire-killed fuels (Harrington 1982). To be effective, maintenance burning is necessary to keep recurring fuels to a minimum (Davis and others 1968, Gaines and others 1958, Harrington 1981, Sackett 1975, 1980). Generally, repeat burns in light, needle fuels are easily manageable.

Historically, natural fire in presettlement times probably burned during the period just after the spring dry season, just as the first storms developed announcing the start of the monsoon season in the Southwest. These first storms are typically dry, and the accompanying lightning could start numerous fires. With the increased fuels and dense stands of today, spring prescribed burning would be unwise because the most severe part of the wildfire season is imminent. Fuel reduction and overstory thinning have to be done in stages over time. Fall, then, becomes the season of choice when weather and fuel moisture conditions are more moderate, and high winds not as likely. Once stands have been conditioned over a period of years of regular, close-interval burning, spring burning becomes a more realistic option to lengthen the burning season. Summer prescribed burning can also be successful as an alternative to fall when conditions are often poor for burning (Harrington 1981, 1987).

The real premise of prescribed fire in ecosystems that naturally had frequent fire, is to provide for interval burning on a rotation that promotes healthy, wildfire-resistant, productive forests.

TWO CASE STUDIES

In 1976 and 1977, companion studies were established near Flagstaff, Arizona, to investigate the effects of reestablishing fire in ponderosa pine. Study areas were established on the Fort Valley Experimental Forest in 1976 on a basalt soil site now referred to as Chimney Spring. One year later, a research site was established on the Long Valley Experimental Forest on a limestone/sandstone soil now known as Limestone Flats (Sackett 1980).

The initial objective of these sister studies was to determine a burning interval that would adequately manipulate fuels and stocking of a post-settlement ponderosa pine stand so that it would survive a stand-replacing wildfire. The study objective assumed the need for reestablishing fire as a natural, necessary function in southwestern ponderosa pine ecosystems. The primary focus of the study was to deal with the most apparent problem in the pine ecosystem, that of heavy, unnatural forest floor fuels.

Initially, both Chimney Spring and Limestone Flats had essentially the same forest floor fuel loadings, 15.2 and 15.7 tons per acre, respectively. Limestone Flats had more than 16 tons per acre of woody fuels greater than 1-inch diameter, whereas Chimney Spring had about 7 tons per acre (Sackett 1980). The importance of fuel moisture on fuel consumption and fire effects was demonstrated when all the interval burning treatment plots (1-,2-,4-,6-,8-, and 10-year) were initially burned in 1976 at Chimney Spring and in 1977 at Limestone Flats. A dry summer and fall in 1976 caused fuel moistures to remain low, the initial burn at Chimney Spring was therefore done at night when the humidity was higher and temperatures were lower. As a result, 63 percent of the forest floor fuel was consumed, as was 69 percent of the woody fuels greater than 1-inch diameter. In contrast, the Limestone Flats area was burned in fall 1977 after an extremely wet summer that continued into fall. As a result, only 42 percent of the forest floor material and 44 percent of the woody fuels greater than 1-inch diameter were consumed.

FIRE BEHAVIOR

Annual burning (1-year interval) is a rotation established to determine the feasibility and effects of such frequent burning. We have found that annual burning is not possible, not because of insufficient fuels to carry a fire, but because weather and fuel conditions in certain years are too damp. Windspeeds compensate sometimes for damp fuel conditions, allowing fire to carry in these light fuels.

Repeat burns every 2 years are generally more successful because of the slightly heavier fuel loads. Again, marginal weather in fall makes biennial burning dubious. Biennial burns may be effective in wildland/urban interface situations.

The most effective prescribed burning rotation observed at Chimney Spring is the 4-year interval. Although this rotation has burned well each interval and has not damaged the healthy overstory, it is not certain whether optimal weather has occurred synchronously with those years or if 4 years is the optimum burning cycle. This rotation appears to be effective because of the consistent ease of carrying out the treatment in keeping fuels to a minimum. To test whether each rotation meets the objective of reduced wildfire hazard, heading fires are ignited for each burn to determine if the stand is protected from a wildfire situation. To date, 4-year-rotation burns have done well to meet the objectives.

Six-year burning rotations begin to accumulate fuel loads that stretch the fire intensities to an upper limit that may cause undesirable damage to the residual overstory. The two

6-year-intervals burned have yielded contrasting results. But, fuel loads are such that, under severe fall conditions, fires could be a control problem and lead to undesirable fire effects.

This high fire intensity problem occurred in the fall of 1992, which was warm and dry, and frequently windy. With 42 rainless days, the heavy, woody fuels had thoroughly dried out from the summer monsoons. Rotations of 1-,2-,4-, and 8-years were burned at the same time. All except the 8-year rotations burned well and did not result in excessive crown scorch. However, 8 years of fuel accumulation (5 tons per acre), low fuel moisture (4 percent to 6 percent), low humidity (21 percent), and only moderate winds, resulted in a .1-chain-deep strip heading fire that heavily scorched most of the pole and smaller size trees in a one-half-acre area. Continuing with heading fires would have completely devastated the entire plot. By allowing the fire to continue as a backing fire well into the night, the 8 years of fuel accumulation was safely consumed. The severity of this 8-year-interval burn points out clearly the need for continuous, short-interval burning in an ecosystem so demanding of fire for its existence.

The only test of 10-year burning intervals occurred in 1986. Fall conditions were too damp for effective fire spread. Forest floor fuel had accumulated in 10 years to more than 7 tons per acre, so experience from the 8-year burns would suggest severe overstory damage would have occurred if conditions had been warm and dry.

REGENERATION

Regeneration of ponderosa pine has obviously been sufficient to perpetuate the ecosystem over many thousands of years. Except in isolated situations, attempts to regenerate southwestern ponderosa pine stands naturally or by direct seeding have failed (Heidmann and others 1977). Schubert (1974) identified several conditions necessary for successful regeneration of ponderosa pine. In the past, fire functioned to prepare competition-free, mineral microsites that gave the highest probability for pine seedling establishment. Prescribed fire can provide mineral soil seedbeds for superior germination and early growth.

Especially at Chimney Spring and to a lesser extent at Limestone Flats, natural regeneration and seedling survival have been satisfactory. As a result of the initial burns at Chimney Spring, mineral soil was exposed on 19 percent of the area, mostly around large, mature, old-growth trees and where rotten logs were consumed (Sackett 1980). Seedlings began to appear soon after summer rains started in the year succeeding the initial burns, and were concentrated in areas where forest floor consumption was sufficient to expose mineral soil (Sackett 1984). First inventories made in August 1977 indicated that an equivalent of 2,600 seedlings per acre were present on the 18 burned plots. To become established and survive, seedlings must develop a long tap root to avoid desiccation from fall drought and to resist frost heaving. Seedlings excavated on burned sites had long tap roots, giving them a survival advantage. Roots of seedlings in unburned plots generally remained in the heavy forest floor and never penetrated mineral soil, resulting in high fall and winter mortality.

In 1993 at Chimney Spring, many of the 1977 seedlings are now 4- to 8-foot-tall saplings. The trees that have survived are found on sites where large, old-growth trees were killed by the initial burns. On these sites, fine needle fuels have not been available for fire spread. Obviously, these are the very sites where pine regeneration is desired.

Since 1976, there have been two other good seed years where seedlings have flourished at Chimney Spring. On one burned plot, the equivalent of 650,000 seedlings per acre were counted (Sackett and Haase, data on file). Seedbeds remain viable for up to 7 years after a fire (Sackett and Haase, data on file). Needles cast during this interval do not have time to combine as heavy, tightly held mats like old, undisturbed forest floor material does. Seeds are able to fall through the loose mat of new needles to settle on mineral soil (Haase 1981). Without fire as a natural disturbance to the forest floor, pine regeneration will be unsuccessful.

THINNING OF STANDS

A major role of natural fire in the presettlement era was the thinning of young trees, giving the landscape the open, park-like look. The dense structure and composition of southwestern ponderosa pine forests today forces managers to consider alternative methods of thinning. Much of our forest lands are thinned mechanically. Prescribed burning can be used effectively, however, to thin stands back to some reasonable density. Naturally ignited fires in past centuries merely eliminated excess seedlings where fuels were sufficient to carry fire over the seedlings. Where heavy fuels and fallen trees burn out, seedlings are able to germinate and become established because of the elimination of fuels and competition. Using prescribed fire within stands as they exist today is different because of dense "dog hair thickets" of pine saplings that resulted from good seed years (1914 and 1919) after curtailing heavy grazing. Although the saplings in these thickets are of small diameter due to close spacing and competition, the bark is relatively thick. Prescribed fires in dog hair thickets are usually not as intense as in open stands. Shade, higher fuel moistures, and minimal amounts of humus in the forest floor prevent temperatures around the bases of most trees from being high enough to girdle them. We have found that heavy crown scorch and/or consumption is necessary to thin dog hair thickets.

Initial burns at Chimney Springs reduced the number of stagnated reproduction and sapling stems from an average of 1553 to 912 stems per acre (Harrington and Sackett 1990). Small poles, many of which are also stagnated in thickets, were reduced from 192 to 156 stems per acre. Limestone Flats, as mentioned previously, did not burn well due to wet conditions; an average of only 180 stems per acre were killed by the fire in reproduction/sapling size classes.

It has become apparent that only the newly cast needles (L layer) and upper portion of the fermentation layer (F) actually burn as flaming combustion in heavy, old forest floor accumulations. The lower F layer is matted and bound tightly together by mycelium hyphae. As a result, the lower portion of the F layer acts more like a solid piece of fuel rather than as individual particles, and does not burn well (Harrington and Sackett 1990).

In an undisturbed, well-developed forest floor, newly cast needles become rapidly colonized and bound by mycelium and therefore less burnable. Fire spreading over the forest floor destroys most of the fungi. Needles that fall after a fire do not become readily infected and a much deeper layer of pure litter accumulates. Under good burning conditions, repeat fires consume most of the needles and small twigs. Fire behavior, rate of spread, fire intensity, and flame lengths are much higher in response to the greatly increased amount of available fuel. This increased fire behavior potential can be used advantageously to eliminate stagnated, dense sapling crowns.

At both prescribed fire research areas, thinning of dense stands has been an objective to relieve the dense, stagnated condition. Ability to manipulate the fire through ignition techniques and the fire environment to achieve slow-dissipating, high temperature air in the crowns is necessary to use fire as a thinning tool (Harrington and Sackett 1990, Sackett 1968). Adjusting the direction of fire spread relative to windspeed is the most common technique. Heading or uphill fires move at a speed commensurate with windspeed, creating more intense fire behavior. On the other hand, backing fires, moving against the wind (or downhill), progress with short flames and low intensities, and seldom thin stands.

Season of burning can also affect thinning. Burning at different times of the year to take advantage of various phenological and physiological conditions of the trees to modify their susceptibility to fire damage is an added condition to consider when thinning. Although it was mentioned that fall burning was recommended for initial burns, repeat burns might well take advantage of spring and summer conditions for thinning (Harrington 1987).

Skillful manipulation of prescribed fire techniques and conditions is required to thin dense ponderosa pine thickets. It is, however, another way prescribed burning can be used to relieve unnatural conditions in a fire-dependent ecosystem.

UNDERSTORY VEGETATION RESPONSES

In southwestern ponderosa pine forests, understory vegetation has declined steadily from the presettlement era. The decline has long been attributed to the exclusion of fire and the subsequent increase in heavy forest floor accumulations, and increased overstory densities (Cooper 1960, Biswell 1972). Burning at Chimney Spring and Limestone Flats has resulted in substantial changes in the understory. Most evident is the abundance of disturbance invader species like mullein (*Verbascum thapsus* L.), toadflax (*Linaria dalmatica* L. Mill), and thistle (*Circium pulchellum* [Greene] Woot and Standl.). Mullein and toadflax are dominant on heavily burned sites around large, old-growth trees that have died since the initial burns. Although some animals use these plants (Patten and Ertl 1982), none are considered favored by wildlife or cattle.

Grass species respond to prescribed fires and wildfires differently, as noted throughout the literature. Generally, production is increased, but this depends on fire severity, season of burn, and overstory characteristics. Individual species will also respond differently. Arizona fescue (*Festuca arizonica* Vasey.) and squirrel tail (*Sitanion hystrix* [Nutt.] J.G. Smith) usually show an increase in production 1 year after a fire (Harris and Covington 1983, Sackett and Haase, unpublished data, Vose 1984) whereas mountain muhly (*Muhlenbergia montana* [Nutt.] Hitchc.) requires a longer recovery period.

In 1992, vegetation was surveyed at Chimney Spring study area on the control, 1-,2-,4-, and 8-year rotation plots before burning. Individual plant occurrences were measured on subsample plots. Preliminary review of the data substantiates previous research. Production of mountain muhly and buckbrush (*Ceanothus fendleri* Gray) was reduced immediately following the prescribed burn. On the 4-year-interval plots, mountain muhly had almost recovered to the level of the control plots (46 observations on burned plots, 53 observations on control plots), and the 8-year-rotation plots had a much greater number of observations (92-burned, 53-control). The 2-year-interval plots showed a small increase in number of observations from the 1-year-interval plots (38 and 32 respectively). Buckbrush appears to require a longer recovery time also. The 1-,2-, and 4-year rotations had substantially fewer observations (6, 2, and 6 respectively) than the 8-year rotation and the control plots (17 and 19 respectively).

These data reflect density differences between burning treatments. Evaluation by cover class should show that overall biomass production is greater in the burned plots because plants were visibly larger than those in the control plots. Much of the current vegetation response research takes into consideration the effect of the small, even-aged groups of ponderosa pine (Oswald and Covington 1984, Harris and Covington 1983, Vose 1984). The greatest vegetation response occurs in open mature timber stands or directly beneath the mature timber canopies. Generally, little change in vegetation is seen in pole stands or in the dense sapling stands.

Most current studies have measured responses on fall prescribed fires. It would seem that if we are able to increase understory vegetation production by burning in this unnatural time of year, we may see a larger increase in production when burned earlier in the year when green grass is not readily consumed.

CONCLUSIONS

Very few forest ecosystems compare with southwestern ponderosa pine in the frequency of presettlement fire, which substantiates its importance for maintenance of forest health and stability (Harrington and Sackett 1990). Fire history studies from this region confirms this. Prescribed fire, then, can be an ideal tool for changing the ecosystem back to a more natural condition. Although exact presettlement conditions may never be achieved, forest condition and health can be improved using prescribed fire.

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