Lessons learned from fire use for restoring southwestern ponderosa pine ecosystems

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Abstract. Since European settlement, the southwestern ponderosa pine ecosystem has experienced large scale alterations brought about by heavy grazing and timbering and a policy of attempted fire exclusion. These alterations are most evident as large increases in tree numbers and in forest floor organic matter. 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 used in ecosystem restoration can reduce heavy fuel accumulations, provide adequate microsites for natural pine regenerations, nonselectively thin dense stagnated thickets, and create an edaphic and stand environment conducive to better forest health and productivity. Research reported here indicates the improved forest conditions that result from burning. Conditions that more closely resemble those of presettlement will require other activities in association with fire.

With fire application, it is important to monitor conditions before, during, and after burning in order that positive fire effects can be replicated or adaptations to the prescriptions can be made.

Introduction

Prior to European settlement, the composition and structure of southwestern ponderosa pine (*Pinus ponderosa Laws. ex Doug.*) 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 et al. 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 created 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 et al. 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.

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For several decades, trees of all sizes in untreated stands have been showing signs of stress with generally poor vigor and reduced growth rates (Cooper 1960, Sutherland 1983, Weaver 1951). This condition, which often results in increased insect and disease attack, 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 site 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 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 approaching 9 tons per acre have been measured in sapling thickets and more than 50 tons per acre on old-growth sites. Annual fuel accumulation on those sites can range from 0.6 tons per acre to more than 3.5 tons per acre (Sackett and Haase in preparation). The decomposition rate (k) (Jenny et al. 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 per year for sapling, pole, and old-growth substands respectively (Sackett and Haase, in preparation). These rates are less than some of the slowest decay rates reported in the literature which are 0.18 and 0.08/year in young stands and old-growth stands of ponderosa pine, respectively, in northern California (Hart et al. 1992).

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, further increasing the potential for crown fires.

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 et al. 1973, Harrington 1982). Data summaries from USDA Forest Service Smokey Bear Reports in Figure 1 show a great increase in the number of acres burned by wildfire in Arizona and New Mexico 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.

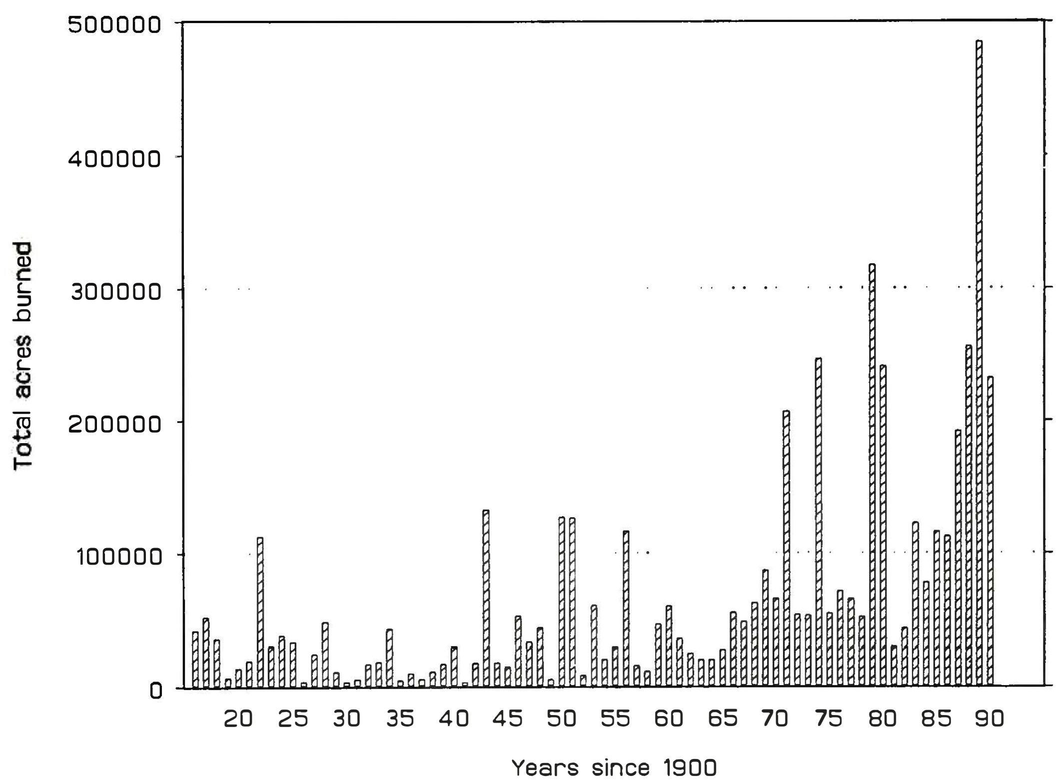

FIGURE 1. The total number of acres burned as wildfires in Arizona and New Mexico from 1916 to 1990. Data obtained in USDA Forest Service Smokey Bear Reports.

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 et al. 1968). In openings left by overstory mortality where pine regeneration is desired, conditions for establishment are poor, again because of deep organic layers which quickly dry out (Haase 1981, Sackett 1984). This condition has reduced the wildlife, range, and timber production value of these forests and has generally resulted in minimal biodiversity.

Reintroducing fire as an ecological process

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 on sites that would successively shift to hardwoods without fire. In the Interior West it is also recognized as the key factor in keeping healthy, seral ponderosa pine stands from becoming stressed and prone to severe wildfire because of increases in tree density and changes in species composition (Arno 1988).

The hazardous conditions described make the widespread application of prescribed fire difficult and costly. Heavy fuels and dense stands can create control problems, and mortality of the stressed overstory from anticipated 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 effective in reducing the fire hazard and improving stand health, consideration must be given to a sequential burning program which would somewhat replicate presettlement fire activity (Sackett 1975, Sackett 1980b). One burn typically will not be sufficient to reduce fuels and stand density initially and certainly not over the long term. 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 et al. 1968, Gaines et al. 1958, Harrington 1981, Sackett 1975, 1980b). 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 exceptionally high fuel loading and dense stands of today, spring would not be the preferred season for the initial fire entry because the most severe part of the wildfire season is imminent. Fuel reduction and overstory thinning should be accomplished 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 with one or two effective fuel reduction burns, 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 use in fire adapted ecosystems is to provide for interval burning on a rotation that promotes healthy, wildfire-resistant, productive forests.

Two examples

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 1980b).

The initial objective of these sister studies was to determine a burning interval that would adequately manipulate fuels and tree density in an overstocked post settlement ponderosa pine stand so that it would survive a wildfire that would otherwise be stand-replacing. The hypothesis of this research was that reestablishing prescribed fire as a surrogate to natural fire would be beneficial to southwestern ponderosa pine ecosystems. The primary focus of the study was to deal with the most apparent problem in the pine ecosystem, that of unnaturally heavy forest floor fuels.

Fuels and fire behavior

Initially, loadings of forest floor fuels, which includes all organic matter less than 1 inch in diameter, in both Chimney Spring and Limestone Flats were similar, 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 1980b). The importance of fuel moisture on fuel consumption and, therefore, 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 resulted in low fuel moistures so that the initial burn at Chimney Spring was 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. In contrast, the Limestone Flats area was burned in the fall of 1977 after a wet summer and fall. As a result, only 42 percent of the forest floor material and 44 percent of the woody fuels were consumed.

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 moisture in certain years are too damp. Increased windspeeds can sometimes compensate for marginally damp fuel conditions, allowing fire to carry in these light fuels.

Burns attempted on a 2-year rotation are generally more successful because of the slightly greater fuel loads. Again, marginal weather in fall makes biennial burning dubious. Biennial burns may be effective in wildland/urban interface situations, where precise control is important.

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 that objective.

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

An example of this condition 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, with 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, a 1-chain deep strip heading fire heavily scorched most of the pole and smaller size trees in a one-half-acre area. Continuing with heading fires would have resulted in extensive stand mortality. 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 sustained by fire.

The only test of a 10-year burn interval 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; and a freely spreading surface fire was allowed.

Monitoring fuel loading and consumption, burning conditions and fire behavior are all essential parts of learning from the adaptive management process of using prescribed fire. Before establishing a prescribed fire program on a particular site, forest floor fuel loadings can be determined easily in undisturbed, natural fuels using depth-loading relationships (Sackett and Haase, data on file). Using prediction equations, depth measurements can be converted to fuel loadings. Measurements after the burn can be subtracted from preburn measurements to determine fuel consumption. A simple sampling grid system can be used to measure the depth. Sampling should be stratified by stand type (old-growth, sapling thicket, large pole, etc.) because of differences in forest floor bulk density. Knowledge of the amounts and fate of woody fuels is also important and should be monitored using the planar intercept sampling scheme (Brown 1974).

During the fires, weather and fuel moisture conditions should be monitored allowing comparisons, correlation, or prescription modifications. Fuel moisture is typically measured using Nalgene sampling bottles, a balance, and a standard drying oven. Other rapid response moisture analyzers are also available (Norum and Fischer 1980, Sackett 1980a). Moisture content sampling should be stratified to show expected differences from different crown closure conditions, fuel depths, layers, and/or geographic location. Measurements or estimates of rates-of-spread and flame lengths can be important in assessing fire impacts and methods as described in Rothermel and Deeming (1980).

Natural pine regeneration

Regeneration of ponderosa pine has obviously been sufficient to perpetuate the ecosystem for thousands of years. Except in isolated situations, attempts to regenerate southwestern ponderosa pine stands naturally or by direct seeding have failed (Heidmann et al. 1977). Schubert (1974) identified several coincidental 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, old-growth trees and where rotten logs were consumed (Sackett 1980b). Seedlings began to appear soon after summer rains started in the year succeeding these 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. Seedlings excavated on burned sites had long tap roots, allowing them to avoid desiccation from fall drought and to resist frost heaving, giving them a survival advantage. Roots of seedlings in unburned plots generally failed to significantly penetrate the heavy forest floor and into mineral soil, resulting in high fall and winter mortality.

Many of the 1977 seedlings have been killed by subsequent fires, but of the survivors, many 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. Where pine litter fuels are produced, stocking is generally adequate, so the killing of seedlings with subsequent fire is inconsequential and, in fact, desired to prevent overstocking.

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 form only a loose, highly porous mat which allows seeds to fall through and settle on mineral soil (Haase 1981). Without fire as a natural disturbance to the forest floor, pine regeneration will only be successful with highly impactive and ecologically questionable mechanical scarification.

Again, monitoring is the key to verifying the success of restoration efforts. If mutual regeneration is desired, monitoring cone crops and burning to coincide with a good crop would be beneficial. Then surveys of seedling survival and growth on various microsites would assist in future forest planning.

Thinning of stands

At Chimney Spring many of the smaller overstory trees were severely crown scorched and, as desired and expected, died. The crowns of the large, young-growth and old-growth trees, however, were not greatly affected. A noteworthy observation was that the forest floor from the bole to the dripline around each of the 405 large trees was completely consumed (Sackett and Haase 1992). About 1 1/2 years after the burns, a number of large pine began to fade and die. None of the same size trees on control plots exhibited these symptoms. Since the crowns were not scorched during the 1976 fires, other living parts of the trees, roots and cambium, sustained damage. To date, 39 percent of the large, overmature trees are dead on plots burned, whereas 16 percent are dead on unburned, control plots (Sackett and Haase, data on file). Increased mortality on burned plots can be attributed to the initial burns. This example establishes the desirability of long-term fire effects monitoring, not just immediate effects. Long-term monitoring is needed to verify changes attributed to the adaptive-management treatment.

A major role of natural fire in the presettlement era was the thinning of young trees, giving the landscape the open, park-like character. The dense structure of southwestern ponderosa pine forests today, which is the primary cause for poor forest health and severe wildfire hazard, forces managers to consider alternative methods of thinning. Much of our forest lands are thinned mechanically, but prescribed burning can also be effectively used as a thinning agent. Because of the frequency of presettlement fires, most trees were killed in the seedling stage by the common low intensity fires. Where heavy fuels and fallen trees burn out, seedlings are able to become established because of the elimination of fuels and competition. Using prescribed fire within stands as they exist today is different because the stands needing thinning are dense "dog hair thickets" of 80-year old pine saplings. Although the saplings in these thickets are of small diameter due to close spacing and competition, the bark is disproportionately thick. Prescribed fires in those thickets are usually not as intense as in open stands. Shade, higher fuel moistures, and minimal amounts of humus in the forest floor prevent lethal temperatures from being produced around the tree bases. We have found that crown scorch and/or consumption in excess of 75 percent is necessary to thin dog hair thickets.

Initial burns at Chimney Spring 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. As mentioned previously, burning at Limestone Flats was less effective due to wet conditions; an average of only 180 stems per acre were killed by the fire in reproduction/sapling size classes.

In an undisturbed, well-developed forest floor, newly cast needles become rapidly colonized and bound by mycelium and therefore less burnable. On a burned site, pine litter that falls after a fire does not become readily bound by mycellia and a much deeper layer of pure litter accumulates. Under good burning conditions, repeat fires consume most of the needles and small twigs in a flaming front, so that fire behavior, rates-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 to purposely increase crown scorch in stagnated thickets.

At both prescribed fire research areas, thinning of dense stands has been an objective to relieve the stagnated condition. The 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 have an affect on thinning. Burning at times of the year when tree susceptibility to fire damage is high, adds other dimension to thinning with fire. Although fall burning is recommended for initial burns, repeat burns might well take advantage of spring and summer conditions for thinning when rapid growth leaves trees susceptible to scorching (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.

Establishing permanent sample points with stem counts in sapling thickets is a simple method to monitor changes in stem numbers to evaluate the success of restoration attempts. Where concerted efforts are underway to reduce the number of sapling stems, permanent photo points provide a valuable record of how stand structure and composition change with each successive burn.

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, 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 severely burned sites around fire-killed, old-growth trees. Although some animals use these plants (Patton 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.] Hitche.) requires a longer recovery period.

In 1992, a vegetation survey was made at Chimney Spring study area on the control, 1-, 2-, 4-, and 8-year rotation before burning. 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 after four consecutive burnings, 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 after two burns 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), but this may be due to the reoccurring fire treatments.

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 (Harris and Covington 1983, Oswald and Covington 1984, 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. This further indicates the need for stand density reductions.

Photo records over time are a good way to visually judge success of fire use in restoration and can complement quantitative methods which are necessary in evaluating these effects. Many sampling schemes are available to monitor vegetation changes. It is important that the sampling be done at an adequate scale, done each year at the same physiological time of the major plant species, and done at permanently established points.

Conclusions

Very few forest ecosystems compare with southwestern ponderosa pine in the frequency of presettlement fire. Written and photographic chronicles indicate the importance of this fire regime for maintenance of forest health and stability (Harrington and Sackett 1990). In the past 75 to 100 years of attempted fire exclusion, these forest qualities have greatly degenerated. Prescribed fire, then, should be considered as a primary agent for restoring ecosystem health and biodiversity similar to the presettlement condition. Additionally, a more sustainable ecosystem should result with the reduction of severe wildfire potential.

After 18 years of burning on two sites with greatly altered vegetation and organic layer compositions, it is evident that presettlement conditions or a desirable likeness would be difficult to achieve with prescribed fire alone. The monitoring scheme has allowed this evaluation to be made and points towards activities that may include a fire program supplemented by low-impact mechanical thinning.

The intent of restoration ecology is to return an altered ecosystem to one that exhibits functioning, natural processes and the products of those processes. In southwestern ponderosa pine forests, fire should be viewed as a distinct ecosystem process and not simply as an alternative management tool. Its direct and indirect impacts on key parts of the forest (vegetation, forest floor, and soils) are unique and can determine the quality of the ecosystem. The use of ecologically sound, adaptive management complete with detailed, long-term monitoring should increase the probability of achieving desired future conditions.

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