Fire Ecology in Ponderosa Pine-grassland

HAROLD H. BISWELL

Professor of Forestry (Ecology),
School of Forestry and Conservation,
University of California
Berkeley, CA. 94720

THE ponderosa pine-grassland is characterized by the occurrence and distribution of ponderosa pine, *Pinus ponderosa.* It is widely spread covering some 36 million acres from the Fraser River Basin in British Columbia to Durango, Mexico, and from Nebraska to the Pacific Coast. These are highly valuable multiple-use lands, suitable for livestock grazing, timber production, wildlife habitat, improved water production, recreation, and sight seeing. My objective is to discuss the fire ecology of this vegetation type and explain how one can fit prescribed burning and management together to have a productive harmony between man and nature.

FIRE IN ABORIGINAL FORESTS

One of the most interesting and important aspects of this vegetation type, or *ecosystem,* is its relationship with fire. Before European man arrived, fires set by lightning and Indians, were common occurrences (Kotok 1934; Reynolds 1959; Wagner 1961; Weaver 1955; Komarek 1967; Biswell 1963, 1967). These were described as light and creeping surface fires; however, they played a major role in determining the structure and composition of the ponderosa pine-grassland (Biswell 1959; Cooper 1960,1961). From accounts of early travelers and researchers we know that the structure of that forest was one of open and parklike stands (Beale 1858; Dutton

1887; Muir 1894). Early explorers usually described the forest scenery in glowing terms. For example, Dutton (1887) wrote in his physical geology report on the Grand Cañon District in Arizona as follows:

> "The trees are large and noble in aspect and stand widely apart, except in the highest parts of the plateau where the spruces predominate. Instead of dense thickets where we are shut in by impenetrable foliage, we can look far beyond and see the tree trunks vanishing away like an infinite colonnade. The ground is unobstructed and inviting. There is a constant succession of parks and glades–dreamy avenues of grass and flowers winding between sylvan walls, or spreading out in broad open meadows. From June until September there is a display of wild flowers which is quite beyond description. The valley sides and platforms above are resplendent with dense masses of scarlet, white, purple, and yellow. It is noteworthy that while the trees exhibit but few species the humbler plants present a very great number, both of species and genera. In the upper regions of the high plateaus, Mr. Lester F. Ward collected in a single season more than 600 species of plants, and the Kaibab, though offering a much smaller range of altitude and climate, would doubtless yield as rich a flora in proportion to the diversity of its conditions.
>
> At a distance of about eight miles from its mouth, the ravine we have chosen has become very shallow, with gently sloping sides. At length we leave it and ascend its right bank to the upper platform. The way here is as pleasing as before, for it is beneath the pines standing at intervals varying from 50 to 100 feet, and upon a soil that is smooth, firm, and free from undergrowth. All is open, and we may look far into the depths of the forest on either hand."

Tree reproduction in aboriginal forests was in small even-aged groups where fire, windfall, insect attacks, or mortality from old age had created openings in the forest (Cooper 1961; Weaver 1943, 1959, 1964). These areas of various sizes were then swept clean by fire and were left in a condition suitable for regeneration. Thus, the aboriginal forest was one of uneven-aged trees occurring in even-aged groups (Figs. 1,2,3).

In addition to this role, fire had several other important functions in the forest. Fire reduced heavy needle mats, windfalls and snags and aided in recycling nitrogen and other nutrients tied up in the

FIG. 1. Typical of aboriginal ponderosa pine-grasslands where recurring fires have burned. Principal grass is mountain muhley (*Muhlenbergia montana*).

litter. Precipitation easily reached the soil because there was little litter to intercept and retain it. This, in turn, encouraged the growth of grasses and nitrogen-fixing leguminous plants. The shrubs that sprouted back after surface fires were more tender and available for browse (Biswell 1959; Weaver 1967). Also, because the forests were kept open and parklike, more sunshine reached the forest floor and the understory plants were generally more palatable and nutritious to grazing animals than those growing in more shaded areas (Lawrence and Biswell 1972). Because the surface fires reduced fuel accumulations on the forest floor, fire hazards were kept at a low level (Biswell 1963; Weaver 1957). Fire also served to keep shade-tolerant trees and shrubs out of the understory and, in this way, insured the dominance of ponderosa pine. One final role of fire in aboriginal ponderosa pine-grasslands was as a natural thinning agent

FIG. 2. Typical pattern created by periodic prescribed burning.

(Weaver 1947). When reproduction in openings developed to an early sapling stage, needles on the ground were sufficient to carry a low, creeping fire through the reproduction stand, killing the smaller or more thin-barked saplings and, in this way, thinned the stand to keep the forest vigorous. Fire brought about the production of extremely large individual trees by limiting competition.

Thus, ponderosa pine-grasslands in stable condition were highly dependent on frequent fires. It is interesting to note also that through the evolutionary process of natural selection extending over thousands of years, these plant communities have developed characteristics that make them highly flammable, and have been referred to as fire-dependent (Mutch 1970). Such plant communities burn more readily than non-fire-dependent communities because natural selection has favored development of characteristics that make them more flam-

FIG. 3. A silvan glade in the background, prescribed burned twice since 1956.

mable and at the same time more fire-tolerant. Thus, we have here an interesting interaction. Ponderosa pine-grasslands are dependent on frequent surface fires for their health and stability, and on the other hand, frequent surface fires are dependent on the plant community that produces the fuels that carry fire, each being dependent on the other.

Characteristics of ponderosa pine communities that make them highly flammable are two things: a heavy drop of pine needles each year, and large needles with resinous properties. Because the needles are large they compact poorly and dry quickly; this insures a well ventilated and dry fuel source for a large part of the year. Also, being resinous, they decay slowly and ignite easily.

Fire scar and ring count studies have shown that fires were widely spread in aboriginal ponderosa pine-grasslands about every 8 years on the average. I suspect, however, that this method gives results that are much too conservative; in other words, they were more frequent than the data indicate. Van Wagtendonk (1972) has recently reported a fire occurence of about every 4 years. Since healthy, normally stocked stands of ponedrosa pine produce enough needles every year to carry significant surface fires, as will be seen later, and lightning fires are wide spread each summer, as they are in the Sierra Nevada (Biswell 1963; Komarek 1967), I think that naturally occurring and Indian set fires must have burned portions of about every section of land of ponderosa pine forests in the Sierra Nevada each summer. Based on this analysis, the Sierra Nevada pine forests could easily have burned every 2 or 3 years on the average with many spots burning every year for 2, 3 or more years in succession.

RESULTS OF FIRE EXCLUSION AND SUPPRESSION

With the coming of European man, policies of fire exclusion and suppression were initiated. This meant the removal of one of the most important environmental factors that had functioned over the centuries to maintain balance and stability in this kind of forest. As often happens when the natural balance is upset, these policies have resulted in serious consequences for ponderosa pine-grassland ecosystems. Without surface fires, fuels have accumulated in many places (Figs. 4,5) making damaging wildfires extremely difficult and costly to control (Dodge 1972). In many areas, grasses and herbs have been choked out by increasing forest density and needle mats. Also, in some places, the understory has been invaded by shade tolerant trees and their competition has weakened the ponderosa overstory, making the trees more susceptible to insect attacks. Often reproduction becomes stagnated in dense thickets (Fig. 6). It is under these conditions that prescribed burning has been proposed as a useful and beneficial tool in ponderosa pine-grassland management.

Prescribed burning is the use of fire for certain planned benefits, and is carried out in selected places and at selected times. It should not be confused with slash burning following clear cutting nor with debris burning such as we might see along highways. The term *prescribed burning* was first used in connection with the use of surface fires in the understory of trees. I think it still should be.

FIG. 4. Heavy accumulations of debris and pine needles make for high fire hazards and little herbaceous vegetation. An ideal situation for prescribed burning.

HARMONIZING PRESCRIBED BURNING AND MANAGEMENT OF PONDEROSA PINE-GRASSLANDS

We have seen that surface fires were originally an important factor in the natural development and stability, or balance, of ponderosa pine-grasslands. This raises the question, would it not be wise to work in harmony with nature and use fire as a tool in ponderosa pine-grassland management? Or, expressed in another way, wouldn't it be wise to manage ponderosa pine-grasslands in such a way that prescribed burning is easy and could be useful in maintaining stability in this ecosystem? Fire could be used to preserve or develop a natural forest type, such as the National Park Service is doing in certain places, or, it might be used in timber and forage production. One of

FIG. 5. Managed under a policy of fire prevention and suppression, shade tolerant incense-cedar and white fir increase in the understory of ponderosa pine.

the biggest problems of the present day, created as a result of strict fire exclusion and suppression, is the buildup of fuels which make wildfires extremely damaging and costly to control. This serves as an excellent example of how man can unknowingly upset the natural balance and end up with severe and difficult management problems. Unfortunately, fire exclusion was adopted as a management policy with hardly any research or knowledge that it would be a *wise* policy. However, we have seen in the past few years that fuels can accumulate over a long period of time to a point where a wildfire burning under low humidity and high wind conditions can hardly be controlled until the weather changes or until the fire runs out of fuel. Perhaps this is demonstration enough! Certainly it is convincing evidence that more needs to be done to reduce fuels and restore more natural conditions in these forests.

Fuels that Carry Surface Fires

One of the most important considerations in prescribed burning is the fuel that carries the fire. Usually the objective in a forested

Fig. 6. A "dog hair thicket" of ponderosa pine.

area is to keep the fire on the ground surface and out of the crowns of the trees. Since ponderosa pine needles are an excellent fuel for prescribed burning, special studies of needle fall and distribution and their relationships to thinning of trees and prescribed burning, were made in second growth pole-size ponderosa pine forests. Plots were established at both Hoberg's in the North Coast Range of California, and on the Teaford Forest in the foothills of the Central Sierra Nevada. Plot studies extended over 4 successive years and then for 1 year several seasons later. The results can be summarized, as follows: most of the yearly pine needle drop occurs between the middle of September and the middle of December. Total needle drop in a dense stand varied from 1,875 to 3,249 pounds per acre. As a result of removing 48 to 77 percent of the basal area of trees by thinning, needle fall consistently averaged about 45 percent of that on the unthinned control plots, so that reducing the basal area by an average of 65 percent reduced needle fall 55 percent. Thinning delayed the "peak" needle fall 1 month during the first year. Thereafter, the difference in intervals between the peaks for control and thinned plots shortened each successive season. Three years after thinning there was practically no difference in time of peak needle fall between the two treatments. Fresh current-year needles covered from 80 to 95 percent of the ground litter on the control plots. On the thinned plots the area covered by fresh needle fall ranged from 35 percent on the most heavily thinned plots to 65 percent on those most lightly thinned. On the thinned plots the average depth of needles was 0.42 inch compared to 0.90 inch on the control plots for a 3 year accumulation.

The thinned and unthinned control plots were all prescribe burned when established and again 3 years later. All the plots burned competely after 3 years except one which was thinned to 55 ft^2 basal area and then by mortality to less than 50 ft^2 basal area. This would indicate that selective thinnings should not reduce the stocking to less than about 50 ft^2 basal area per acre if uniform fires are required for brush control or other management objectives.

Pine needles are not the only fuels that will carry surface fires. In some places it may be grasses alone or in combination with pine needles. In North Central Arizona for instance, mountain muhley

(*Muhlenbergia montana*) will carry surface fires in November, and perhaps during the winter and spring, while in the Blackhills of South Dakota, warm season grasses will carry fire when dormant in winter and spring. However, surface fires in needle mats under dense canopies of ponderosa pine are more intense than those in the more open areas where grasses predominate. In dense needle mats, surface fires may be intense enough to girdle suppressed pines and hardwood trees several inches in diameter, but in open grassy spots without pine needles the fires may be so light as only to thin reproduction where the trees are not over 3 or 4 feet tall. If the grasses are closely grazed surface fires may not spread at all in the openings.

In the Sierra Nevada, bear clover (*Chamabatia folilosa*) will also carry surface fires, and if draped with pine needles, it is very flammable. Loose mats of grasses in meadows also may be highly flammable. They may dry quickly after spring showers and will burn when the surrounding forests are still too wet to carry fire. This was experienced in El Capitan meadow in Yosemite National Park; in early spring, the tall dormant grasses dried quickly after rain and and burned fiercely with a light wind, but the fire stopped at the edge of the forest where the fuels became too wet to carry the fire.

Effect of Surface Fires on Forest Stand Structure

Surface fires tend to create uneven-aged forests composed of even-aged groups of trees, as was seen earlier. Reproduction gets started in openings where there are few or no pine trees to produce fuels. The young trees survive in these openings simply because there is not enough fuel to carry surface fires into them, or the fires are so light that they only thin, even if the trees are very small. When the reproduction is 12–15 feet tall, enough pine needles are dropping so that surface fires will carry gently through the new stands. The very small suppressed trees will be killed and this is the beginning of the thinning process. As the forest trees grow with frequent surface fires the thinning process continues and no new reproduction becomes estabished in the understory. Since openings may occur any year, new stands are continually becoming established to create many even-aged groups of reproduction.

Working in harmony with nature, the land manager can use surface fires to keep reproduction out of the understory of well stocked stands. He should seek reproduction only in openings (Figs. 7, 8). The harvesting process should be one of frequent thinnings, perhaps every 10 years carried out in such a way as to maintain a complete needle cover over the ground. As the trees reach maturity, at the end of the rotation cycle, the final harvest cuts can be in patches, the debris removed with fire and reproduction obtained in the newly created openings. Thus, clear cutting is never necessary in this system of management. Fire should be kept out of new reproduction for a few years, perferably until the trees are 12 to 15 feet tall, but this is easy because of the lack of surface fuels in those areas.

The common practice in forestry of having advanced reproduc-

FIG. 7. The grazing capacity is shrinking as ponderosa pine spreads and increases in density in response to curtailment of prairie fires in the Black Hills of South Dakota. Principal grass is little bluestem (*Andropogon scoparius*).

FIG. 8. A surface fire effectively killed the seedlings in the undertsory where there was an abundance of pine needles but burned lightly through the reproduction in back of the opening.

tion in the understory of trees at the time of timber harvesting is not biologically sound. It leads to buildup of heavy fuels that sooner or later will give rise to severe wildfires, and it makes logging operations exceedingly difficult, producing and leaving unsightly accumulations of debris.

SOME OVERSTORY-UNDERSTORY RELATIONSHIPS

Along with increasing forest density and crowding that results from fire exclusion, the percentage of crown cover and the amounts of litter on the ground also increase. These changes, along with shading and competition for nutrients and moisture (Van Sickle et al. 1959), have all combined to choke out most, if not all, of the understory herbaceous vegetation in many areas. To determine the extent to which the overstory reduces herbage production in the understory (Cooper 1960; Pase 1958), and Thompson and Gartner (1971) determined the amounts of herbage produced in open areas in ponderosa pine as well as in varying densities of trees. Interestingly, herbage production was found to be quite consistent in open areas in all of the above studies despite the different geographical areas and climates and soils.

In California measurements on Teaford Forest showed herbage production to be 1,350 to 1,700 air-dry lbs per acre in open spots but in areas about properly stocked with trees it declined to 200 to 250 air-dry lbs per acre (Figs. 9, 10). In many heavily stocked stands of trees, understory herbaceous vegetation was negligible. Cooper, 1960, working in North Central Arizona found forage production to be 1,620 pounds per acre in openings and this decreased by about 21 lbs per acre for each one percent increase in the canopy

FIG. 9. This area on the Teaford Forest was selectively logged in 1951 and prescribed burned in November, 1956.

FIG. 10. The logging slash on the Omak ridge in Washington was burned in 1944 and reburned in Oct., 1965, one year before the picture was taken. The principal grass is pine grass (*Calamagrostis rubescens*). Photo courtesy Harold Weaver.

cover. Pase (1958) has noted a decrease in herbage from 1,660 lbs per acre where there was no canopy cover to only 35 lbs per acre in an area with a canopy density of 70 percent. Arnold (1950) found the amount of herbaceous vegetation to be about five times greater on an acre of 10 percent tree canopy as opposed to an area of full canopy. The depression in understory herbaceous vegetation with increase in canopy cover is due in part to shading, but the accumulation of forest litter on the ground also depresses the understory herbaceous growth. Clary et al. (1968) found that herbage production decreased from over 300 to less than 10 lbs per acre as total forest floor accumulations increased from essentially zero depth to 2.5 inches. They also found that removal of the entire forest floor debris accumulations by a prescribed fire gives a higher increase in under-

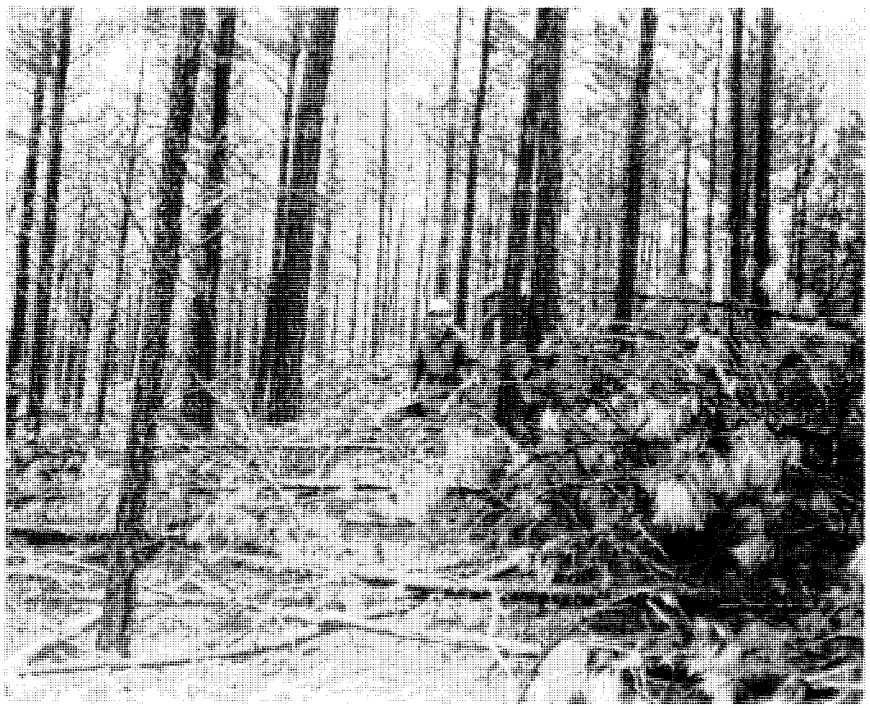

FIG. 11. Critical fire hazard caused by thinning. One could ask, is this a wise forestry practice?

story herbaceous production than removing only the upper layers. On the Teaford Forest in California, herbage production declined rapidly as the needles increased in amount up to about 6,000 lbs per acre. With heavier accumulations there was only a trace of understory vegetation.

Species composition of the understory vegetation is also influenced by the degree of forest stocking. In Washington, McConnell and Smith, 1965, found grasses to be the primary understory producers where crown cover was less than 45 percent, but where it exceeded 45 percent, they found forbs to be the main producers. In California, on the Teaford Forest, we found shade tolerant annual sunflowers in areas of dense shade and several annual legumes under moderate to light canopies.

FIG. 12. Thinned, burned, and fertilized. The principal grass is creeping wildrye (*Elymus triticoides*). Unthinned controls produced a negligible amount of understory vegetation after similar applications of fertilizers.

Herbaceous vegetation in a pine forest can be valuable for livestock grazing and wildlife and it can also have other benefits such as increasing organic matter and nutrients in the soil. Grass roots normally extend down 2–5 feet and since their weight is about two-thirds that of the tops it is obvious that they can greatly build up the organic matter in the soil as well as increase its porosity. It is possible also that the understory vegetation can have value in adding nutrients to the soil. With this in mind, we made analyses of the nitrogen content of various herbaceous plants and trees from Teaford Forest (Table 1.).

Modifying the needle cover by prescribed burning has two additional effects. Although total nitrogen in the system is temporarily decreased, there is an increase of available nitrogen in the substrate.

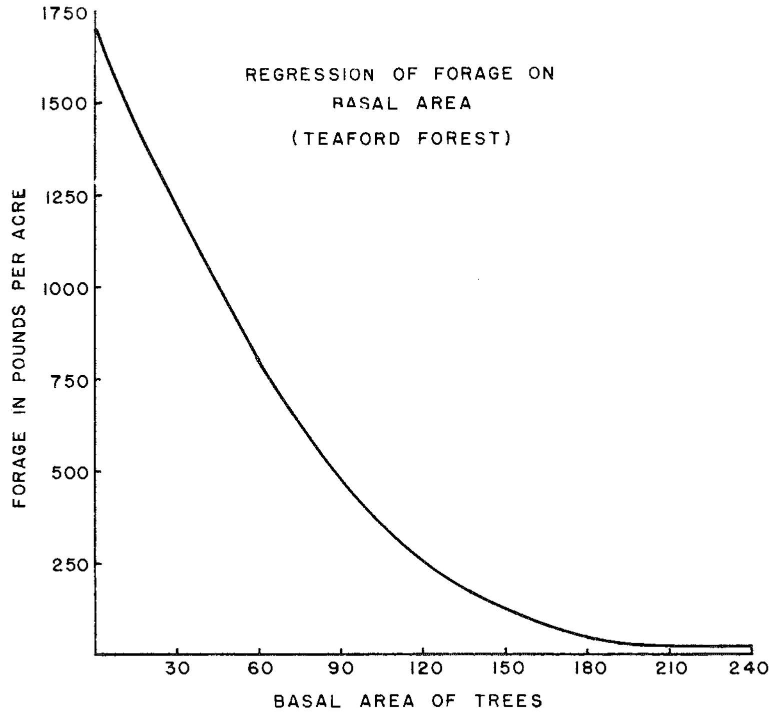

FIG. 13. Relationship between forage production and basal area of trees in pole size stands of ponderosa pine.

TABLE 1. NITROGEN CONTENT OF HERBACEOUS PLANTS AND TREES FROM TEAFORD FOREST

Species	Percent Nitrogen
Dry pine needles	.65
Green pine needles	.85
Green oak leaves (*Quercus kellogii*)	1.82
Bracken fern (*Pteridium aquilinum*)	1.38
Sunflower (*Helianthus annuus*)	1.68
Bedstraw (*Galium aparine*)	1.39
Brome grass (*Bromus* spp.)	.70
Vetch (*Vicia* spp.)	3.08
Lupine (*Lupinus* spp.)	2.85
Lotus (*Lotus* spp.)	2.82
Clover (*Trifolium* spp.)	2.00
Average–herbaceous vegetation	2.00%
legumes	2.70%

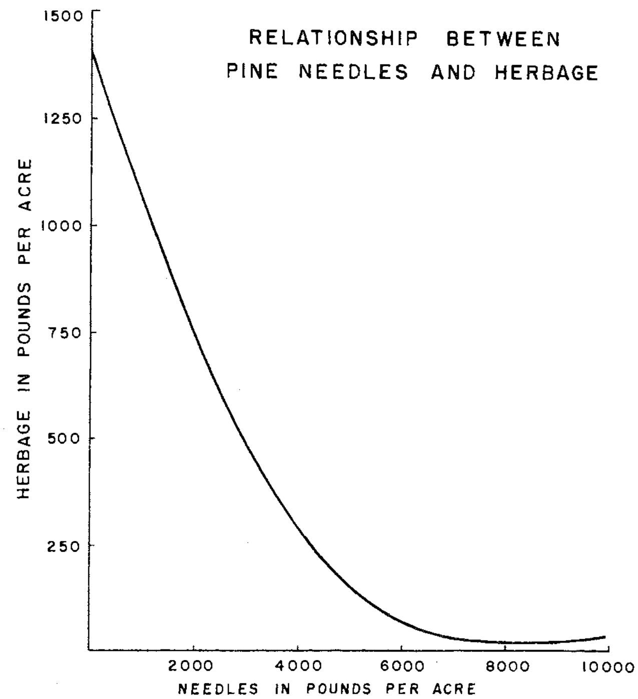

Fig. 14. Relationship between forage production and pine needles on the ground.

In pot tests with lettuce as the indicator, yields on soils that had been burned by a light surface fire were five times as large as those on unburned controls when the only limiting nutrient in the pot was nitrogen. In soils where piles of debris had been burned, the yield was 10 times as large. This is equivalent to adding 200 lbs per acre of nitrogen in the form of ammonium nitrate. Available phosphorus is also increased by prescribed burning on soils that do not fix phosphorus (Vlamis, Biswell, and Schultz 1955).

Fire is an effective tool in controlling shrubs and hardwood trees in the understory of pines (Biswell 1958). In some cases the objective might be to reduce or to remove non-sprouting shrubs like white-leaf manzanita, *Arctostaphylos viscida*, or to greatly reduce those sprouters like snowbush, *Ceanothus velutinus*. Whatever the objective, surface fires should be used when there are fuels to carry them. If more shrubs are the objective, they should be established in

FIG. 15. Herbage production in the opening was 1700 lbs of air-dry material per acre, but under the dense forest canopy in the background there was hardly any herbage.

openings where surface fires will not spread through pine needles. With many shrubs the seeds are hard and will not germinate unless cracked by fire or some other means whereby they will imbibe water and germinate. In removing undesirable shrubs, it may take two or three surface fires in succession to deplete the supply of seeds in the duff.

For shrubs that are highly desirable, such as bitterbrush, *Purshia tridentata,* it would seem desirable that any fire should be used in the fall after the seeds have been cached by rodents. They are then under the ground and protected against fire and will germinate the next spring. More studies are needed in ponderosa pine-grasslands where bitterbrush occurs in the understory.

The impact of the overstory is not, however, limited to grasses, forbs, shrubs and shade tolerant trees. After many years of work in ponderosa pine in Arizona, Pearson (1935; 1950) found that different degrees of shading can cause slow germination of pine seeds, slow growth and abnormal development, and even death. Subsequently, he found that the amount of side shading was relatively unimportant as long as there was plenty of sunlight from directly above. Good side shading induced good stem form and fine branching, but overhead sunlight was necessary for survival. Therefore, he concluded that the ideal situation for growing good timber trees was to have taller, mature trees around to establish side shading and, at the same time, an opening in the overstory above to provide sunlight and insure survival. This is very significant because this is exactly the situation that exists in the ponderosa pine-grasslands when periodic surface fires are present.

The whole story of prescribed burning and overstory-understory relationships is not known at present. There is evidence that these may be related to forest diseases (Froelich, et al. 1966), such as *Fomes annosus* (root rot) which is widespread in many pine forests. Recent studies in the pine forests of the Gulf states indicate that the presence of prescribed burning, understory vegetation, and soils of high organic content all increase biological activity in the soil, and this tends to inhibit the spread of *Fomes annosus*. This same relationship may be true for this disease in ponderosa pine-grasslands.

DISCUSSION

For the past 20 years I have done research on the judicious use of fire in ponderosa pine-grasslands in California. One of the most interesting aspects of this research has been observations on people, mainly professional land managers and others interested in environmental conservation and preservation. We must realize that people and their politics are an important ecological and sociological component of any wildland ecosystem.

Some people are entirely against any and all fires in forests. Why? This was asked of a prominent German silviculturist. The reply: "In California, with its dry summers and high danger of wildfires, I think prescribed burning might be a good thing. However, I wouldn't be able to do it myself. My early training led me to believe that all forest fires are bad and when I see charcoal in a forest it simply rubs me the wrong way." Perhaps this would indicate that we should be giving more emphasis to fire ecology in our teaching and not quite so much to "Smokey the Bear" syndrome.

In another case a prominent forester wanted to discuss "all the hearsay being taught about fire." For a full hour he told about the bad effects of fire. It turned out to be a summer wildfire. One purpose of prescribed burning, of course, is to reduce fuels and shape the forests so that wildfires are not so damaging and are more easily controlled. After this introduction the conversation concerned wildfires and prescribed fires and agreement was easily reached on all matters. This would lead one to believe that some people are not aware of the differences between the two kinds of fire. Neither are they aware that good fire suppression over a long period of time can lead to difficult wildfire problems.

Effects of Prescribed Fires on Soils

One of the arguments against prescribed burning some 20 years ago was that the soil would be ruined. In particular, the soil would be depleted of its organic matter. In fact, we see now that prescribed burning and thinning of the trees allows more herbaceous vegetation in the understory and this can be very beneficial in adding organic matter to the soil through decay of roots. Also the high nitrogen content of some of the herbaceous plants can improve the nitrogen content of the soil. A slightly higher pH from prescribed burning increases biological activity in the soil, and this together with the increase in herbaceous vegetation might be beneficial in inhibiting certain forest diseases, such as *Fomes annosus*, mentioned earlier. Furthermore, prescribed fires might reduce other diseases by destroying fungi in the debris and duff. In a dry climate it is probable that much of the surface debris never becomes incorporated into the soil as organic matter but is simply lost into the atmosphere through oxidation. Prescribed burning could remedy this situation by reducing surface debris to its basic elements and thereby facilitate its incorporation into the soil.

We have heard much about the ill effects of mono-cultures. In some situations we do have pure stands of ponderosa pine without understory herbaceous vegetation (Fig. 5). However, with the use of prescribed burning for the removal of heavy accumulations of surface needles and to aid in the thinning of the trees, understory vegetation increases and adds great variety to any ponderosa pine-grassland.

Tree Reproduction

Another argument against prescribed burning is that tree reproduction in the understory is destroyed. Well, in restoring and maintaining natural balance in ponderosa pine ecosystems we do not want reproduction in the understory. We want it only in the openings that have been swept free of debris by surface fires.

Cost of Prescribed Burning

Still another argument against prescribed burning has been that it is too costly. The only place in ponderosa grasslands where prescribed burning has been on a large enough scale to evaluate the cost has been on Bureau of Indian Affairs lands in North Central Arizona. From 1948 to 1966, inclusive, this agency prescribed burned 229,790 acres and reburned another 63,140 acres (Kallander 1969). The cost was 10 to 20 cents per acre (Truesdell 1969). It was concluded that a prescribed fire is effective in reducing wildfire hazards for about 5 years, thus if the 10 to 20 cents per acre is amortized over a 5-year period the yearly cost is 2 to 4 cents per acre. This cost was very low, indeed, because the forests are uniform and the ridges and slopes make ignition and control easy. Large areas were burned with a minimum of fire line construction. The burning was done mainly in November.

In California, the cost of prescribed burning would be considerably higher than that in North Central Arizona. However, at the same time the benefits could be much greater. This aspect of prescribed burning is in need of study.

Danger of Fire Escape in Prescribed Burning

Another argument against prescribed burning is that it is too dangerous because of possible escapes. With the extremely high fire hazards that now exist in California there is some danger from escapes, but if the burning is done by experienced people the chances are not unbearable. However, isn't it much more dangerous to try to live with the high fire hazards through periods of low humidity and high winds in late summer than to burn them out under prescribed conditions? Wouldn't it be better to manage ponderosa pine-grasslands in such a way that wildfires could be easily controlled, even in years when the average rainfall is below normal?

Smoke from Prescribed Burning

Wood smoke is another argument against prescribed burning. We must keep in mind that wood smoke in late summer and early fall is natural to the environment. Perhaps there are some good things about wood smoke of which we know very little at present. Professor John Parmeter (1972) in plant pathology, University of California, Berkeley, told me recently that he thinks wood smoke might have protective qualities about which we know very little. With this hypothesis, he started studies of the effects of wood smoke on certain disease organisms. Spores of the Western gall rust fungus failed to germinate on substrates exposed to smoke for as little as 5 seconds. Spores of other fungi were similarly inhibited on substrates exposed to smoke for longer periods.

Wood smoke may also play an important role in cloud formation and precipitation. Mason (1957, 1962), a physicist, has studied this to some extent. He states that for clouds formed inland, salt nuclei contribute perhaps only one-tenth of those involved in cloud formation; the rest are probably combustion nuclei which are produced in vast numbers by natural and man-made fires. His studies can lead to all sorts of speculation. For example, could heavy smoke in the atmosphere in late summer in California be beneficial in bringing early fall rain to this area?

As far as I know wood smoke in normal amounts is not harmful to human health. It can be rather dense at times but if one moves aside a few feet it is not intolerable. Studies over the past several years (Murphy 1972) indicate that emissions from prescribed burning are quickly diluted and are not harmful in the concentrations thus far measured. The test results indicate that most hydrocarbons measured from forest burning are chemically saturated and, as such, are unimportant to the formation of photochemical smog which typifies the southern California smog problem. Carbon monoxide measured at 60 feet from the edge of a prescribed burn was found to be about 40 ppm on the average. This decreased to 10 ppm 150 ft from the fire. Industrial health standards, on the other hand, allow human exposure to carbon monoxide levels of 100 ppm over an 8-hour period. Carbon dioxide concentrations, measured 60 feet from the fires' edge, were 1,000 ppm, and diluted to 500 ppm at 150 feet. Industrial health standards allow human exposure of 8,000 ppm over an 8-hour period.

The particulate matter in wood smoke can reduce visibility and it might even reduce crop production by its shading effect. However, most prescribed burning in California has been done in late fall, winter, and early spring when the trees are dormant and there is little other growth to be damaged.

I am quite concerned and fearful that smog control officials will establish regulations whereby prescribed burning with surface fires in the understory of trees becomes impossible. This would be a grave mistake and would probably lead to more damage and smoke from wildfires in summer than we have at present. I agree with Dr. Bruce Kilgore (1972) when he discussed the impact of prescribed burning on a sequoia-mixed conifer forest:

> "The choice is not whether to burn or not to burn; the choice is merely when, how, and under what condtions. Fire is a *part* of the giant sequoia-mixed conifer forest ecosystem, regardless of what man may wish or attempt to do about it. In the absence of prescribed burning, wildfires will burn. If fuel levels and successional processes are returned as nearly as possible to that which was found prior to the impact of our fire suppression efforts, then perhaps lightning fires will once again be effective in maintaining the natural cycling of nutrients and energy within this ecosystem. But until this has taken place, prescribed burning in this forest type seems essential."

Impairment of Aesthetics

Another recent argument against prescribed burning is that its effects are unsightly, in particular, people don't like to see small dead trees in the understory. However, if one loves nature and realizes that this is a part of the natural process of forest development it may look good. I must confess that many dead incense-cedars in the understory of ponderosa pine after a prescribed fire looks *good* to me. After all, the purpose was to kill the small incense-cedar and thereby favor the pines and reduce the fire hazards.

The Public Won't Let Us Burn

Some people think we have to train the general public to the idea of prescribed burning. They maintain that the general public has listened to Smokey the Bear so long that it will be difficult for them to see any beneficial effects of using fire as a tool. However, I have found that the general public grasps the idea very quickly and often asks, "Why didn't you start it long ago?" The ravages of forest wildfires that we see so often on television are convincing people that something must be done to reduce wildfire hazards if we are going to survive in this fire-type environment. My experience is that it is not difficult to explain this to the general public; but, on the contrary, it is easy. All we need is more information by television, radio and other news and information media.

We Need More Research

The idea that we need more research before any prescribed burning is done seems to be a stalling technique. The fact is, that light surface fires burned through ponderosa grasslands for millions of years and various elements of the environment were in adjustment with them, because fire itself was a part of the environment. Of much greater need are studies of the effects of fire exclusion on the forest ecosystem because keeping fire out introduced a new dimension to the environment.

SUMMARY AND CONCLUSIONS

The aboriginal ponderosa pine-grasslands were kept open and parklike and stable by recurring surface fires. The ecology of this process is discussed and explained. It seems we should work in harmony with nature and use fire to reshape and stabilize our debris laden forests. It is only through this technique that we can have productive harmony between man and nature. Our greatest need at present is to teach this concept and how it works and to train land managers in the science and art of prescribed burning.

ACKNOWLEDGMENT

The author wishes to thank Mike Harvey, U.C. student in Natural Resources, for his help on various aspects of this article.

LITERATURE CITED

Arnold, J. F., 1950, Changes in Ponderosa Pine Bunchgrass Ranges in Northern Arizona Resulting From Pine Regeneration and Grazing. J. Forestry 48:118–126.

Beale, E. F., 1858, Wagon Road from Fort Defiance to the Colorado River, 35 Cong. 1 Sess., House Exec. Dec. 124.

Biswell, H. H., 1958, Manzanita Control in Ponderosa. California Agric. 12, p. 12.

———, 1959, Man and Fire in Ponderosa Pine in the Sierra Nevada of California. Sierra Club Bull. 44:44–53.

———, 1963, Research in Wildland Fire Ecology in California. Tall Timbers Fire Ecol. Conf. Proc., no. 2, pp. 62–97.

———, 1967, Forest Fire in Perspective. Tall Timbers Fire Ecol. Conf. Proc. no. 6, pp. 42–63.

Clary, W. P., P. F. Folliott, and D. A. Jameson, 1968. Relationship of Different Forest Floor Layers to Herbage Productions. United States Dept. Agric. For. Ser. Res. Note RM-123. p. 1–3.

Cooper, C. F., 1960, Changes in Vegetation Structure and Growth in Southwestern Pine Forests Since White Settlement. Ecol. Monog. 30:129–164.

———, 1961, Patterns in Ponderosa Pine Forests. Ecology 42:493–499.

Dodge, M., 1972, Forest Fuel Accumulation—A Growing Problem. Science 177:139–142.

Dutton, C. E., 1887, Physical Geology of the Grand Cañon District. United States Geol. Surv., 2nd Ann. Rept:49–166.

Froelich, R. E., T. R. Dell, and C. H. Walkinshaw, 1966, Soil Factors Associated with *Fomes annosus* in the Gulf States. For. Sci. 12:356–361.

Kallandar, H., 1969, Controlled Burning on the Fort Apache Indian Reservation, Arizona. Tall Timbers Fire Ecol. Conf. Proc. no. 9, pp. 241–249.

Komarek, E. V., 1967, The Nature of Lightning Fires. Tall Timbers Fire Ecol., Conf. Proc. no. 7, pp. 5–41.

Kotok, E. I., 1934, Fire, a Major Ecological Factor in the Pine Region of California. *In:* Proc. Fifth Pacific Sci. Cong., Canada, University of Toronto Press.

Lawrence, G. and H. Biswell, 1972, Effect of Forest Manipulation on Deer Habitat in Giant Sequoia. J. Wildlife Manag. 36:595–605.

Mason, B. J., 1957, The Physics of Clouds. The Clarendon Press, Oxford. 481 pp.

———, 1962. Clouds, Rain, and Rain Making. Univ. Press., Cambridge.

McConnell, Burt and Justin Smith, 1965, Understory Response Three Years After Thinning Pine. J. Range Manag. 18:21–27.

Morris, W. G., and E. Mowat, 1958, Some Effects of Thinning a Ponderosa Pine Thicket with a Prescribed Fire. J. Forestry 56:203–209.

Muir, J., 1894, The Mountains of California. Doubleday and Inc., Garden City, New York, 1961.

Murphy, J. L., 1972. Heavenly Valley, U.S.A. American Forests 78(8):20–22, 56.

Mutch, R. W., 1970, Wildland Fires and Ecosystems--A Hypothesis. Ecology 51:1046–1051.

Parmeter, J., 1972, Some Relationships of Wood Smoke to Forest Diseases. Personal Communication.

Pase, C., 1958, Herbage Production and Composition Under Immature Ponderosa Pine in the Black Hills. J. Range Manag. 11:238–243.

Pearson, G. A., 1935, Some Observation on the Reaction of Pine Seedlings to Shade. Ecology 17:270–276.

———, 1940, Shade Effects in Ponderosa Pine. J. Forestry 38:778–780.

Reynolds, R., 1959, Effect Upon the Forest of Natural Fire and Aboriginal Burning in the Sierra Nevada. Masters Thesis, Dept. of Geography, Univ. of California, Berkeley.

Sweeney, J. R. and H. H. Biswell, 1961, Quantitative Studies of the Removal of Litter and Duff by Fire Under Controlled Conditions. Ecology 42:572–575.

Thompson, W. W., and F. R. Gartner, 1971, Native Forage Response to Clearing Low Quality Ponderosa Pine. J. Range Manag. 24:272–277.

Truesdell, P. S., 1969, Postulates of the Prescribed Burning Program of the Bureau of Indian Affairs. Tall Timbers Fire Ecol. Conf. Proc. no. 9, pp. 235–240.

Van Sickle, F. S. and R. D. Hickman, 1959, The Effect of Understory Competition on the Growth Rate of Ponderosa Pine in North-Central Oregon. J. Forestry 57:852–853.

Van Wagtendonk, J. W., 1972, Fire and Fuel Relationships in mixed Conifer Ecosystems of Yosemite National Park. PhD Thesis, School of Forestry and Conservation, University of Calif., Berkeley.

Vlamis, J., H. H. Biswell, and A. M. Schultz. 1955, Effects of Prescribed Burning on Soil Fertility in Second-Growth Ponderosa Pine. J. Forestry 53:905–909.

Wagener, W., 1961, Past Fire Incidence in the Sierra Nevada Forests. J. Forestry 59:739–747.

Weaver, H., 1943, Fire as an Ecological and Silvicultural Factor in the Ponderosa Pine Region of the Pacific Slope. J. Forestry 41:7–15.

———, 1947, Fire—Nature's Thinning Agent in Ponderosa Pine Stands. J. Forestry 45:437–444.

———, 1951, Observed Effect of Prescribed Burning on Perennial Grasses in the Ponderosa Pine Forests. J. Forestry 49:267–271.

———, 1955, Fire as an Enemy, Friend and Tool in Forest Management. J. Forestry, 53:49–504.

———, 1957, Effects of Prescribed Burning in Second-Growth Ponderosa Pine. J. Forestry 55:823–826.

———, 1958, Effects of Burning on Range and Forage Values in the Ponderosa Pine Forest. SAF. Proc. pp. 212–215.

———, 1959, Ecological Changes in the Ponderosa Pine Forest of the Warm Springs Indian Reservation in Oregon. J. Forestry 57:15–20.

———, 1964, Fire and Management Problems in Ponderosa Pine. Tall Timbers Fire Ecol. Conf. Proc., no. 3, pp. 62–97.

———, 1967, Fire and Its Relationship to Ponderosa Pine. Tall Timbers Fire Ecol. Conf. Proc., no. 6, 127–149.