Forest Fuel Accumulation—A Growing Problem

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Fire fighters in the western forests are doing an effective job. They have not yet reached the goal of total exclusion of fire, but over 95 percent of the wild fires are extinguished while small. The 3 to 5 percent that get out of control cause 95 percent of the damage.

This small percentage does tremendous damage. The 1967 fire season in the Pacific Northwest and Northern Rockies was a blow to the national economy as well as to the local timber and recreation industries. The year 1970 saw a repeat of huge fires in eastern Washington during the summer. Southern California was declared a disaster area by President Nixon. The final toll for California was 14 lives lost, 800 homes and buildings destroyed, and 242,000 hectares (600,000 acres) of timber and watershed cover burned.

More disastrous fires may be expected in future years. A major factor contributing to this prediction is the accumulation of dead fuels taking place in the wildland areas of the western United States. The fire control agencies may be making the situation worse. William E. Towell, chairman of a fire study group for the American Forestry Association, said (*1*), ". . . a fire control agency's worst enemy may be its own efficiency. The longer forests go without burning, the greater the fuel accumulation and the greater the hazard."

Forest Fuels

The fuels that burn in a forest fire are generally separated into two classes, living fuels and dead fuels. The living fuels, consisting of leaves, twigs, and stems of growing plants, are difficult to ignite and do not burn readily by themselves. When the moisture content of living plants is reduced by drought and when they are further heated and dried by a fire in dead fuels beneath them, they can burn, sometimes very intensely.

The real problem is dead material, consisting of fallen leaves and needles, dead twigs and branches, dead stems either standing or fallen, and dead grass and weeds. Fires start easily in dry, dead fuels and spread readily. The fuels that contribute most to fire intensity and rate of spread are those about 1 centimeter in diameter and smaller, plus the outer few millimeters of larger branches and logs. Larger fuels do not contribute to intensity or rate of spread since they burn after the main fire front has passed. These larger fuels do cause the fire to persist and are difficult to extinguish. They may also provide a source of burning embers for further fire spread.

A general formula for fire intensity (*1*) was developed by Byram (*2*):

$$I = HWR$$

where H is the heat or energy value of the fuel, W is the weight of fuel per unit area, and R is the rate of spread. Thus, increasing the fuel loading increases the intensity of the fire. However, not all the relations for free-burning fires have been worked out. According to Hodgson (*3*), Australian fire researchers found that doubling the amount of fine fuels (such as leaves, twigs, and long strips of bark) also doubled the rate of spread. This produces a fourfold increase in intensity. This relationship has not been verified by experiments in the United States, nor have the effects of large volumes been adequately explored.

Conditions for Fuel Accumulation

All plants produce yearly increments of dead material. Annuals leave the whole plant body as fuel at the end of the growing season. Perennials shed leaves or needles and dead twigs every year, some species throughout the year, and others seasonally. At greater intervals the perennials contribute dead branches that have been shaded out by subsequent growth and, eventually, the stems or trunks of the dead plants that have completed their life cycles.

The normal annual increment of dead fuel may be increased tremendously by events that kill a sizable proportion of the plants growing in the area. Insect and disease epidemics, blowdown during storms, timber harvesting, and wildfire all contribute great quantities of dead material.

Very few studies have been made of the annual accumulation of litter. Accumulation rates of 1.1 to 3.2 tons per hectare were found in the chaparral of southern California by Kittredge (*4*). Studies by Biswell and his colleagues (*5*) of several species in the central Sierra Nevada showed that 2.2 to 6.9 tons of litter per hectare are contributed each year to the forest floor.

Climate plays an important part in the accumulation of dead fuels. Both Kittredge (*4*) and Olson (*6*) have pointed out that in warm, moist climates, which provide an optimum environment for decomposition, there is little or no litter. Where conditions are less favorable for decomposition, as in a cool, moist climate, there is a greater accumulation of dead materials. A climatic pattern of warm, dry summers and wet, cool or cold winters leads to maximum accumulations of dead fuels or stored energy that may be released by wildfires. Thus we should expect the greatest potential for disastrous wildfires in the western United States.

There have been few measurements or estimates of the quantities of dead fuel under growing forests or brush fields. Weaver, discussing the ecology of the ponderosa pine (*Pinus ponderosa*), pointed out the great increase in fire hazard which results from fuel accumulation under almost complete fire protection (*7*). He found fuel quantities large enough to make control nearly impossible if a fire should start during critical weather conditions (*8*). In studies of the giant sequoia (*Sequoiadendron giganteum*) groves as much as 56 to 94 tons of dead fuel per hectare were found (*9*). Southern California has a reputation for devastating forest and brush fires, yet only two studies have been made of the amount of material fueling these fires (*10*).

Although the figures are sparse for California, there is an even greater lack

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of quantitative data for fuel loadings in the Northwest and the Rockies. The only published data are those obtained in a brief study of a small area in northern Idaho by Anderson (*11*). In 1967, during an extensive air and ground survey of forest conditions on a transect from western Montana across northern Idaho into eastern Washington, I found that nearly half the area has loadings of dead fuel ranging from 90 to 135 tons per hectare. And many sites have up to 225 tons of dead fuel per hectare beneath the overmature standing timber.

Critical fire weather, long periods of drought culminating in a few days of very low humidities and strong winds, only occurs on an average of once in 10 or 15 years in the Pacific Northwest and Northern Rockies. But when a fire does start in these conditions in an area with large quantities of dead fuels, it will be so intense that little or nothing can survive.

Fire History

Forest fire was a regular phenomenon in the western United States before the white man arrived. Show and Kotok (*12*), in one of the earlier studies of fire chronology for California, found that fires have occurred at intervals of about 8 years since 1685, which was as far back as they could reliably date the trees studied. They stated that forests persisted in spite of the numerous fires, which indicates that most were light surface fires. The pine forests of California, Oregon, and eastern Washington (*13*) and of the Southwest (*14*) all have long histories of fire. In the Southwest, areas of pine forest with periodic fires were still open and parklike, but well stocked with young pines, in 1951 (*14*).

Great arguments have raged over whether Indians set fires or whether fires were all started by lightning. Readers may wish to refer to articles by Burcham (*15*) and Stewart (*16*) for examples of opposing views. However interesting this history may be, it has little bearing on today's problems. The management practices (or lack thereof) of a hunter-gatherer culture were determined by conditions entirely different from those prevalent now. Today's management decisions must be made with regard to present economic and social conditions and must be based on sound principles and definite goals, not nostalgic recollections of a rather vague historic past.

Conditions changed drastically with the arrival of white men in the West. Extensive forest areas were cut for building materials for new towns and farms, mine timbers, and fuel wood. The western forests also supplied wood for the continued economic growth of the East and Midwest. Logging left great quantities of slash—treetops, limbs, and waste—on the ground. The opening of the crown canopy permitted greater insolation and drying of the increased amounts of dead fuel on the ground, and the removal of obstructing trees also produced higher wind velocities at ground level. The result of these more severe conditions was a series of devastating fires over the years. According to Davis, who compiled a list of the large forest fires in the past (*17*), "It is a significant fact that every one of the fires listed started in slash or other debris resulting from logging and land clearing and gained initial momentum from such fuels."

The destruction wrought by these early logging-slash fires undoubtedly created the sentiment and reasoning that led to the policy of total fire protection. While this concept of complete exclusion of fire was probably the only practical solution at the time, it has created other problems, some of which are just beginning to be recognized now. As discussed above, dead fuels have accumulated and present a serious hazard in many areas. Fire exclusion has also altered the ecological relationships of the forests, changing drastically the composition and growing conditions of many timber stands (*18*).

Fire has been essential for perpetuating valuable species (*19*). For example, Haig stated that Douglas fir (*Pseudotsuga menziesii*), western white pine (*Pinus monticola*), and lodgepole pine (*P. contorta*) have been maintained in more or less pure form by fire (*20*). He further observed that foresters have been reluctant to accept the idea that fire may aid regeneration. Observations of giant sequoias have indicated that reproduction occurs primarily on burns or mechanically disturbed areas (*21*).

Since reproduction occurs on mechanically disturbed sites as well as on burned areas, we must consider fire as only one means of securing a mineral seedbed. However, many other ecological considerations have been studied very little. Hartesveldt *et al.* (*21*) referred to the occurrence of pathogenic fungi in soil and the beneficial effect of fire in sterilizing soil. Baker (*22*) suggested that leaving large quantities of slash and debris may produce an unfavorable carbon/nitrogen ratio.

Greatly increased growth rates in fire-thinned patches of pine compared to unthinned stands were reported by Weaver (*8*). He suggested that the elimination of fire-thinning of sapling and pole-sized trees has led to greatly increased competition, subsequently weakening the trees and making them more vulnerable to insect attack (*7, 14*). Stocking rates, giving the optimum number of trees per hectare for best vigor and growth, support his views (Table 1). In addition, corrective measures, such as deliberate thinning, may increase the fire hazard. It was found that slash produced in thinning ponderosa pine in the Northwest greatly increases fire intensities and also resistance to fire-control efforts since the jackstrawed stems are difficult to clear for fire lines (*23*).

Present Approaches

Many fire control men recognize that a problem of fuel accumulation exists. Brown (*24*) stated that "The amount of fuel that is allowed to accumulate and its continuity are recognized by fire control men everywhere as fundamental in determining the cost of effective fire control and in fixing the losses that are bound to occur over a period of years." In the wildland research plan for California (*25*) it was pointed out that the stockpiles of dead fuels continue to accumulate, and Edward P. Cliff, then chief of the Forest Service, commented that (*26*) "Disposal of logging slash and reduction of fuel build-up through prescribed burning or other means constitute special challenges."

Even though the problem has been recognized, little has been done to measure its magnitude or extent. Proposed solutions have taken a number of directions. Efforts to find efficient chemical or biological digesters of dead fuels have not been successful. Mechanical chipping and shredding is quite expensive, with estimated costs running from \$148 to \$222 per hectare when prison labor is used. Efforts have been made to crush and chop slash and brush with heavy mechanical equipment (*27*). No cost figures have been published, but one administrative study by the California Division of Forestry showed costs of \$73 to \$99 per hectare.

The old concept of firebreaks permanently cleared on ridgetops has been extended to fuel breaks. These are strips

30 to 91 meters or more in width where the heavy fuels have been removed to break up large expanses of brush or timber (*28*). They are often seeded to grass to minimize erosion, with only a narrow strip in the middle cleared to mineral soil. The cost of clearing and maintaining them runs from $3500 to $5000 per kilometer. And fuel breaks do not eliminate the problem of fuel accumulation, they merely divide it up.

Another possible solution, prescribed burning, has been a subject of tremendous controversy. Weaver has often proposed the use of fire both as an ecological tool and for hazard reduction (*7, 8, 14*), and Biswell (*29*) has pointed out that the removal of dead fuel by prescribed burning reduces the damage from wildfire. These proposals have often been greeted by an emotional reaction and the view that all fires are raging monsters that destroy everything. The critics fail to recognize the differences between high-intensity wildfires that do destroy everything and low-intensity fires that may cause little or no damage.

Several studies of logging-slash flammability have been made, and there is a considerable amount of prescribed burning on clear-cut blocks where no vegetation remains (*19, 30*). However, these are all high-intensity fires, and less attention has been given to fuel accumulations outside of logging areas or to the use of low-intensity fires.

In two studies, low-intensity fires have been used in timber areas. Gordon's study in dense, stagnated stands of ponderosa pine saplings and poles is difficult to evaluate as few data are given on the sizes or number of trees (*31*). The photographs included in the report seem to indicate that the stands were extremely thick and that burning thinned the suppressed trees effectively. The costs on small plots (about 0.4 hectare) ran from $51.91 to $69.72. Schimke and Green (*32*) discussed the use of prescribed fire for maintaining fuel breaks in the central Sierra Nevada. They gave recommendations for weather conditions suitable for maintaining low-intensity fires and reported average costs of $10.45 per hectare.

Attempts by the National Park Service to restore natural ecosystems are encouraging. Houston (*33*) has reported on efforts with prescribed burning and natural fires in Sequoia and Kings Canyon national parks. Studies are being conducted in Yosemite National Park to obtain definite data on the effects of fire by using different weather and fuel conditions according to Schimke and Green's prescriptions (*32*). No results of these studies have been published to date, but my examination of several treated areas showed effective thinning and hazard reduction.

Table 1. Density of trees for full stocking (*37*). Diameter, average diameter at breast height; *N*, number of trees; ha, hectare.

Diameter (cm)	Density (*N*/ha)	
	Ponderosa pine	Douglas fir
10.2	4700	3110
15.2	2470	1865
20.3	1480	1300
25.4	990	956
50.8	247	296
76.2	106	173

High-intensity fires have been used widely in brush areas for range conversion and hazard reduction. Since the passage of enabling legislation, nearly 800,000 hectares have been burned by private property owners in California (*34*). This activity is decreasing, probably because most of the areas in which it is economically feasible have been treated and because of the increasing financial liability associated with high-intensity fires. An economic study of controlled brush burning showed steadily decreasing costs with increasing size of the burn up to 178 hectares, where costs totaled $1.48 per hectare. Above that size, costs again rose slightly (*35*). These costs for high-intensity burns contrast sharply with those given for small plots and illustrate clearly the differences in scale. On a large scale, low-intensity fires would be considerably easier and cheaper to manage.

It must be recognized that there are many areas where high volumes of fuel would cause severe damage with any attempt at burning. However, little valid work has been done on the effects of low-intensity fires in the West. There are possible damages and disadvantages in the use of fire, but we may be forced to accept them as the premiums due for insurance for the whole forest. Evidence that a program of prescribed burning is compatible with modern economic and social objectives is given in Australia. Heavy losses in a series of disastrous fires prompted a study of management objectives. Their attempts at total fire exclusion had made changes in the nature of the forest and, while reducing the area of forest burned annually, had produced more severe and damaging bush fires (*36*). They concluded that complete fire protection is almost impossible to achieve and is undesirable ecologically. Hence, they have started a program of prescribed burning to reduce the fire hazard and restore the ecological conditions needed by the forest and wildlife.

Conclusions

Fire has been part of the western forests, probably for thousands of years. Apparently these frequent fires consumed much of the dead fuels and prevented large fuel buildups. Since fire protection agencies started their policy of total fire protection, dead fuels have gradually accumulated in many areas and represent a serious hazard. Studies and surveys should be started to obtain data on fuel volumes and distributions.

The large quantity of stored energy in accumulated fuels is released rapidly by fires, producing very high fire intensities. It is reasonable to predict that, where fuels are permitted to accumulate, fires will become more severe and more damaging and will be more difficult to control. More men and more fire trucks will not solve the problem of bigger and more damaging fires, although they may delay the ultimate results. The only big improvement possible in forest fire protection lies in the area of hazard reduction.

Intensified efforts to find economical and practical ways to reduce the fuel hazards are needed. The relatively neglected use of prescribed burning should be considered, particularly the use of low-intensity fires. Advantage should be taken of large wildfires that have reduced the fuel hazards, and vigorous efforts should be made to prevent future fuel accumulations.

References

1. W. E. Towell, *Amer. Forests* **75** (6), 12, 40 (1969).
2. G. M. Byram, in K. P. Davis, *Forest Fire: Control and Use* (McGraw-Hill, New York, 1959), pp. 61–89.
3. A. Hodgson, *J. Forest.* **66**, 601 (1968).
4. J. Kittredge, *Forest Influences* (McGraw-Hill, New York, 1948).
5. H. H. Biswell, R. P. Gibbens, H. Buchanan, *Calif. Agr.* **20** (9), 5 (1966); J. K. Agee and H. H. Biswell, *ibid.* **24** (6), 6 (1970).
6. J. S. Olson, *Ecology* **44**, 322 (1963).
7. H. Weaver, *J. Forest.* **41**, 7 (1939).
8. ———, *ibid.* **45**, 437 (1947).
9. H. H. Biswell, R. P. Gibbens, H. Buchanan, *Nat. Parks Mag.* **42** (No. 251), 16 (1968); J. K. Agee, thesis, University of California, Berkeley (1969).
10. Progress Report 5, Operation Firestop, California Division of Forestry and Cooperative Agencies (1955); L. R. Green, *U.S. Forest Serv. Res. Note PSW-216* (1970).
11. H. E. Anderson, *U.S. Forest Serv. Res. Pap. INT-56* (1968).
12. S. B. Show and E. I. Kotok, *U.S. Dep. Agr. Circ. 358* (1925).
13. W. W. Wagener, *J. Forest.* **59**, 739 (1961).

14. H. Weaver, *ibid.* **49**, 93 (1951).
15. L. T. Burcham, in *Proceedings of the Society of American Foresters*, San Francisco (1959), pp. 180–185.
16. O. C. Stewart, *Geogr. Rev.* **41**, 317 (1951); in *Man's Role in Changing the Face of the Earth*, W. L. Thomas, Ed. (Univ. of Chicago Press, Chicago, 1956), pp. 115–133.
17. K. P. Davis, *Forest Fire: Control and Use* (McGraw-Hill, New York, 1959).
18. M. Oberle, *Science* **165**, 568 (1969).
19. D. S. Olson and G. R. Fahnstock, *Univ. Idaho Forest Wildl. Range Exp. Sta. Bull. 1*, (1955).
20. I. T. Haig, *J. Forest.* **36**, 1045 (1938).
21. R. Hartesveldt, H. T. Harvey, H. S. Shellhammer, R. E. Stecker, *Science* **166**, 522 (1969).
22. F. S. Baker, in *Regional Silviculture of the United States*, J. S. Barrett, Ed. (Ronald, New York, 1962), pp. 460–502.
23. G. R. Fahnstock, *U.S. Forest Serv. Res. Pap. PNW-57* (1968); J. D. Dell and D. E. Franks, *Fire Control Notes* **32** (1), 4 (1971).
24. A. A. Brown, *J. Forest.* **45**, 342 (1947).
25. California Division of Forestry, "Wildland Research Plan for California" (California Division of Forestry, Sacramento, revised, 1969).
26. E. P. Cliff, *Amer. Forests* **75** (6), 20 (1969).
27. K. O. Wilson, *J. Forest.* **68**, 274 (1970).
28. U.S. Forest Service, "Progress Report on Fuel-Break Research" (U.S. Forest Service, Pacific Southwest Station, Berkeley, 1969).
29. H. H. Biswell, *Calif. Agr.* **13** (6), 5 (1959).
30. G. R. Fahnstock, *U.S. Forest Serv. Intermt. Forest Range Exp. Sta. Res. Pap. 58* (1960); E. R. De Silvia, *Proceedings of the Tall Timber Fire Ecology Conference*, Tallahassee, Florida (1965), pp. 221–330; R. W. Steel and W. R. Beaufait, *Univ. Mont. Mont. Forest Conserv. Exp. Sta. Bull. 36* (1969).
31. D. T. Gordon, *U.S. Forest Serv. Res. Pap. PSW-45* (1967).
32. H. E. Schimke and L. R. Green, "Prescribed Fire for Maintaining Fuel-Breaks in the Central Sierra Nevada" (U.S. Forest Service, Pacific Southwest Station, Berkeley, 1970).
33. D. B. Houston, *Science* **172**, 648 (1971).
34. California Division of Forestry, "Brushland Range Improvement Annual Report" (California Division of Forestry, Sacramento, 1969).
35. A. W. Sampson and L. T. Burcham, "Costs and Returns of Controlled Brush Burning for Range Improvement in Northern California" (California Division of Forestry, Sacramento, 1954).
36. R. G. Vines, *Aust. Sci. Teach. J.* (November 1968), reprint.
37. G. A. Craig and W. P. Maguire, *The California Pine Region Handbook* (California Division of Forestry, Sacramento, 1949).

The Politics of Projection: A Critique of Cartter's Analysis

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In a series of articles from 1965 to 1971 (*1*, *2*), Allan M. Cartter has advanced the thesis that American graduate education is oriented toward the systematic overproduction of Ph.D.'s. This overproduction is, he asserts, already evident and, unless policies are altered drastically, is destined to become an acute problem in the early 1980's.

Cartter's thesis, phrased in a progressive tone, has gained widespread acceptance because it is supported by certain demographic data and by the difficulties that some recent recipients of the doctorate have experienced in securing employment. But Cartter's argument can be faulted on a number of critical points. He ignores fundamental social changes already under way within American society, changes that are likely to erode the very bases of his projections. Moreover, his implicit assumptions about the future relations among politics, the economy, and education are open to serious question. Our intention is to point out the serious weaknesses in Cartter's analysis and to demonstrate that it represents a highly unreliable point of departure for policy-making in graduate education.

The Essentials of Cartter's Argument

The serious imbalance between supply and demand of Ph.D.'s is, according to Cartter, occasioned by the continuation of outdated expansionist policies, particularly on the part of state planning agencies, which have overlooked the markedly changed conditions that will surround higher education in the 1970's and 1980's. The basic pattern, one that has already begun to undermine present policy, is a decrease in the rate of growth of the college-age population (18 to 21) in the decade between 1968 and 1978 and an absolute decline in its numbers during the decade to follow. Thus, Cartter concludes, at the very time that the need for new faculty in higher education is declining, the number of Ph.D. degrees granted is continuing to increase. This trend will lead to a situation wherein "only about one doctorate in four will find suitable academic employment, and in the 1980's it could be less than one in ten" (*1*, p. 136).

Cartter contends that neither higher rates of college enrollment nor maximum hiring levels will correct the imbalance. Although he does not believe that either of these developments is likely, he concludes emphatically that (*1*, p. 137):

> Even if all junior colleges were converted to 4-year colleges, every high school graduate went to college, and every new college teacher hired in the future possessed the Ph.D., by 1980 a smaller percentage of doctoral degree recipients would be likely to find academic positions than has been true for the preceding 25 years.

Furthermore, the nonacademic employment sector will be incapable of absorbing the surplus of Ph.D.'s who will graduate in the years to come.

In light of his pessimistic conclusions, Cartter suggests certain means for dealing with the oversupply of Ph.D.'s. Professional associations should establish manpower study commissions with a view toward monitoring the production of doctorates within the disciplines related to their professions; colleges and universities should consider both restricting graduate programs and opening up more positions for younger Ph.D.'s through earlier retirement of faculty and changed tenure procedures; and, what is perhaps most important, the federal government should assure a certain level of support for "national universities" or for selected departments within various disciplines. These national universities would become the major centers for graduate education.

The Impact of Cartter's Argument

Although Cartter expresses concern that his argument will be ignored or its policy implications deferred, an accumulating body of evidence suggests that Cartter's views have already begun to inform policy considerations. Cer-

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