Fire and Smoke in Montana Forests

By William R. Beaufait[1]

Introduction

The concept of forest fire is especially difficult to deal with in an objective manner because fire has deep psychological associations for most animals, especially man. Moreover, attitudes toward forest fires have been greatly conditioned by what has been called the most effective advertising campaign in history.

I can't match the emotional appeal of some fire prevention campaigns. I can, however, present information on the natural forces operating in Montana forests which predispose them to wildfires, describe the present state of scientific knowledge of the production and dispersion of smoke from forest fires, and, finally, discuss alternative treatments of both fire and smoke in forests managed for water, wood, and wild animals.

I'll begin by defining some of the terms used in this paper. Perhaps these definitions can also be used to help clarify the principles which underlie forest land use — as well as the environment.

Definition of Terms

Managed Forests: The word "managed" comes from two French roots, one meaning "hand" and the other meaning "housekeeping." The sense of these words reflects well what we mean by managed forests where the hand of man performs housekeeping tasks. As the term developed, it came to include manipulation and cultivation. The Society of American Foresters (S.A.F.) (1958, p. 50) defines "forest management" as "the application of business methods and technical forestry principles to the operation of the forestry property." The same terminology is used in the definition of range management, watershed management, and wildlife management, with the appropriate modifier substituting for the term "forestry."

Unmanaged forests may be of two types. In the first the handiwork of man is apparent but completely without plan or benefit

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of professional skills. An example might be forest land which has been harvested with obvious disregard of the technical principles of watershed, silviculture, or soil productivity. Fortunately, there are only a few examples of complete mismanagement in recent Montana forest history.

The second type of unmanaged forest is the familiar wilderness area. Whether legally designated or not, wilderness areas have been defined as areas "where the earth and its community of life are untrammeled by man, where man himself is a visitor who does not remain" (1964 Wilderness Act, 4 U.S.C. § 1131). In this discussion "forest land" includes both managed and unmanaged types. I hope the distinctions have been made clear.

Pollution and Smoke: As does the U. S. Department of Health, Education, and Welfare (1968), the Clean Air Act of Montana (1967) defines "air pollution" as

> the presence in the outdoor atmosphere of one or more air contaminants in such quantities and duration as is, or tends to be, injurious to human health or welfare, animal or plant life, or property, or would unreasonably interfere with enjoyment of life or property, or conduct of business (R.C.M. 1947, § 69-3906).

By this definition almost anything that we don't like in the air can be classified as air pollution. However, the courts have construed "air pollution" to include only contaminants which affect people or property directly and measurably.

One source of air pollution is smoke. This substance is defined by the U.S. Department of Health, Education, and Welfare as "small gas borne particles resulting from incomplete combustion, consisting predominantly, but not exclusively, of carbon, ash, and other combustible material" (1968). Smoke from different sources contains different substances. That from forest fires consists mostly of water, particulates, and carbon dioxide. We will discuss each of these in more detail later.

Wild and Prescribed Fires: "Wildfires" are defined as "free burning fires unaffected by fire suppression measures" (S.A.F., 1958, p. 94). There are many causes of wildfires, yet they can be classified into two main types—natural and man caused. In Montana, most forest fires are of lightning origin. However, those started accidentally by man may cause as much economic loss as natural fires because they often burn on the lower, more valuable slopes.

Wildfire is differentiated from "prescribed fire" in that the latter term usually implies

> skillful application of fire to natural fuels under conditions of weather, fuel moisture, soil moisture, etc. that will allow confinement of the fire to a predetermined area, and at the same time will produce the intensity of heat and rate of spread required to accomplish certain planned benefits to one or more objectives of silviculture, wildlife management, grazing, hazard reduction, etc. Its objective is to employ a fire scientifically to realize maximum net benefits at minimum damage and acceptable cost. (S.A.F., 1958, p. 10).

Energy Systems: A few basic principles must be thoroughly understood before one can view the role of fire in the forests of the northern Rocky Mountains objectively. One of these principles is that the earth operates on energy received from the sun. This energy can never be destroyed—but it can be converted to other forms.

Only about half of the sun's energy which strikes the earth's atmosphere ever reaches the ground. An even smaller portion fuels the factory which produces forests. Less than one percent of the sun's energy is converted through the process of photosyn-

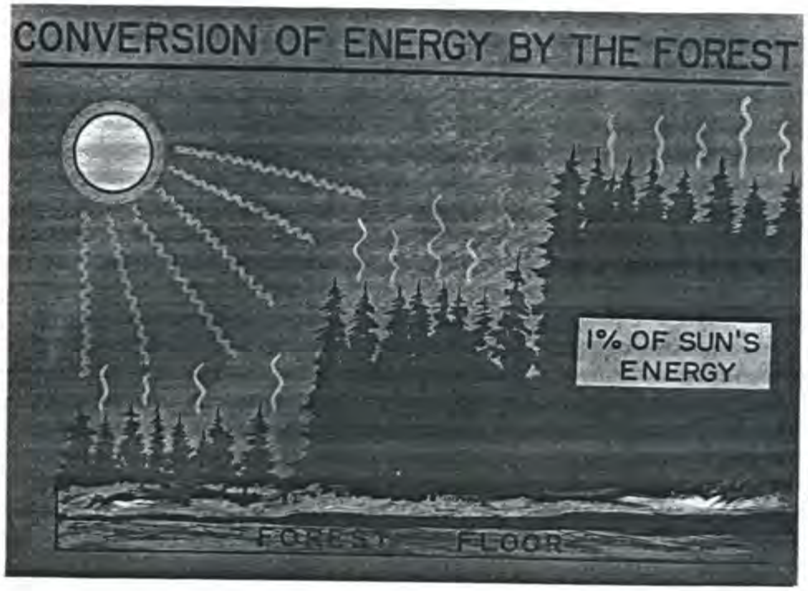

FIGURE 1. Solar energy converted by the forest is stored as organic matter. It accumulates until released by external forces, including fire *(U.S. Forest Service Photo).*

thesis into organic matter (Geiger, 1966). In forested land the rate of conversion is about 10 billion calories per acre per year. That is about the equivalent of 300 gallons of gasoline (Reifsnyder and Lull, 1965, p. 94).

Figure 1 illustrates the annual conversion of solar energy into vegetable matter. This energy is stored in a forest warehouse subject to several kinds of withdrawal and conversion. Thus, energy becomes a part of a system that cycles it through long periods of time and through several forms.

Fuel Accumulation in Northern Latitudes

Still another principle is involved in the frequent occurrence of fire in temperate forests. Part of the energy conversion process consists of decomposition of organic wastes from forest trees and animals. Energy is released in this process.

All living things produce waste products, and, ultimately, all

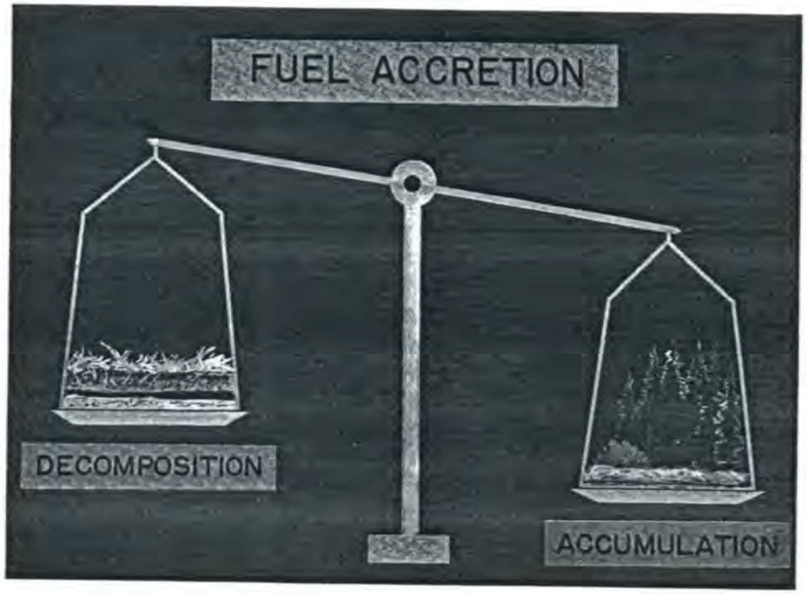

FIGURE 2. In northern forests organic matter does not decay as rapidly as it is manufactured, predisposing these forests to fire *(U.S. Forest Service Photo).*

organisims become the waste products of their community. Thus, the leaves which fall to the ground each year are finally joined by the stems and branches of trees killed by shading, insects, disease, and windthrow. Altogether they constitute what I prefer to call the organic mantle of the forest floor. This mantle decomposes at a rate proportionate to such climatic factors as temperature and moisture.

Bray and Gorham (1964, p. 106) have calculated that the organic mantle is enriched at the rate of three to four tons per acre per year in the North Temperate Zone. These figures have been recently supported by studies conducted in western Montana (Beaufait, 1968). The local data further suggest that, on the average, the decomposition rate is about half that of production. Therefore, the withdrawal rate is less than the stockpiling rate in the local forest storehouse (Figure 2).

By contrast, the decomposition rate in a tropical forest's warm, moist environment is often greater than that of accumulation. Thus, little or no organic matter accumulates on the tropical forest floor. Even fallen trees are rapidly reduced to a lower trophic level by invertebrates and saprophytic fungi. A trophic level represents the state in which energy is stored in organic matter at any point in time.

Nature abhors imbalance in her energy equations. In the past she has dealt with fuel accumulations, where they exist, through wildfires—usually ignited by lightning.

The Natural Role of Fire in Forest Ecosystems

What other evidence is there to demonstrate the existence of fuel accumulation and resulting fire periodicity in Montana forests? Actually, forest scientists have two ways of confirming fire history. First, inspection of forest-soil profiles in this region reveals an abundance of charcoal. This partially consumed material is the remains of a previous forest stand. Above the ground, charred stumps and logs testify to the origin of the present stand. Scars at the bases of living trees are evidence of fires subsequent to the establishment of the stand.

Those who study the characteristics of forest tree species have still another way of ascertaining fire origin. The preponderance of trees in western forests are early successional or seral species; that is, they are usually the first generation from bare ground. In one way or another these species depend upon fire for their establishment and early survival. Many of them have special adaptive genetic characteristics. Examples include lodgepole pine with its serotinous cones and ponderosa pine and western larch with their thick bark. Most of these species are intolerant of shade and,

FIGURE 3. The aftermath of a recent destructive wildfire which destroyed much valuable timber and other property and choked adjacent valleys with smoke. Enlightened fuel management might have prevented this devastation *(U.S. Forest Service Photo).*

through natural selection, have come to depend upon fire for their perpetuation.

People who fly regularly over the northern Rocky Mountains have learned to expect a mosaic of forest patterns on the ground below. Most of these green patches, usually oriented up and down mountain slopes, are not clearcuts. They are tracks of past wildfires. For that matter, the use of clearcutting and burning as a management practice by foresters in this region has been an attempt to simulate the conditions under which the harvested stands were originally produced.

Despite modern technology no reasonable hope exists for isolating accumulated forest fuels from ignition sources. Lightning and man have combined to perpetuate the fire cycles observed in the past. Both history and biological imperatives suggest that man can never completely prevent wildfires. Evidence is also accumulating that, by preventing some fires and by suppressing others, man has abetted fuel buildups. Sixty years of protection have predisposed many forests to such conflagrations as the Saddle Mountain and Sleeping Child fires of 1960 and 1961, the Sundance and Trapper Peak fires of 1967, and the Wenatchee area and southern California fires of 1970 (Figure 3). There is no *direct* evidence that protection has caused recent wildfires in the northern Rocky Mountains to be more destructive than those in the past (Wellner, 1970, p. 56). It cannot be denied, however, that more fuel with greater continuity will support more damaging fires.

The frequency of wildfire cycles depends upon location, climate, and vegetation type—and to a large extent upon chance. Usually the longer fire is postponed, the more intense it becomes because fuel accumulates over longer periods. The mean periodicity of fire in the northern Rocky Mountains is probably less than 150 years. In this region fire cycles of 10 years are common in dry ponderosa pine stands along major river courses and at low elevations, but some moist and naturally protected stands may be spared for up to 400 years. By contrast, the periodicity of fire in the chaparral types in southern California is estimated at about 9 to 15 years.

Another dimension is added to this story by recognition of an "ecology of disturbance." Early forest ecologists such as Weaver and Clements (1938, p. 80) developed a classification of climax types based on local climate and certain soil factors. These climax types define the direction of succession from shade-intolerant to shade-tolerant tree species and from dry and aquatic to moderately moist vegetation types. Succession normally requires several generations of trees and, often, hundreds of years. The climax forest, once evolved, has the theoretical capability of reproducing itself time after time until the climate changes. Presumably, fuel accumulation and decomposition would be in balance in the climax forest.

Calculations made by Olson (1963) suggest that a balance between accumulation and decomposition of organic matter could be achieved in the climate of the northern Rocky Mountains after 500 to 1000 years with no disturbance. In an area with an average fire frequency of less than 150 years this equilibrium has not been, and likely will not be, reached. Indeed, the forests we know today in western Montana would not exist without fire or other regular, major disturbance.

A final blow is dealt to the likelihood of energy equilibrium in western forests by the periodic occurrence of insect and disease attacks and windstorms which suddenly increase stand mortality. The dead fuels which accumulate rapidly on the forest floor after such natural events predispose these areas to forest fires such as the Saddle Mountain and Sleeping Child fires of about 10 years ago which swept beetle-killed lodgepole pine stands in southwestern Montana.

The cyclic history of wildfires has determined not only the plant species but also to a large extent the animal species indigenous to the area. Animal populations vary with the availability of food and shelter. In the case of the deer and elk common to western Montana, and other wildlife species as well, food and shelter are most readily available in a diversified habitat. Diversity breeds in the disturbance created by fire and timber harvesting patterns.

Smoke from Forest Fires

I've shown why there have been forest fires and why there probably always will be. Yet in our concern for the human environment we ask questions about the pollution caused by smoke from forest fires. What does it consist of? How much is there? How is it dissipated? What can we do about it? Let's explore some answers to these questions.

Characteristics of Wood Smoke

Natural principles of energy conservation dictate that when organic matter is oxidized or volatilized, either slowly or rapidly, solid and gaseous products will be evolved. Foremost among these products is carbon dioxide. Carbon dioxide is released from organic matter whether it rots on the floor of the forest or is burned in a forest fire. Modern society should be concerned over the concentration of carbon dioxide in the atmosphere, but any major increase in the concentration will result from rapid combustion of fossil fuels, not from a release of the carbon circulating in modern forests.

Similarly, hydrocarbons are evolved whether forests burn or not. For example, the piney odor so pleasant to the nostrils of those who spend much time out-of-doors is made up of complex substances such as terpenes, olefins, and aldehydes. In high concentrations these substances can be hazardous to human health. However, recent studies of convection-column characteristics and contents reveal that only carbon dioxide, water, and particulates exist in forest fire smoke above background amounts (Beaufait, 1968). The water derives from bound and free moisture in the fuels which is vaporized by the fire.

Particulates remain a major concern to those who deal with air quality. Particulates are microscopic bits of matter ranging in size from 500 microns down to .0002 of a micron. (There are 25,000 microns in an inch.) Particulates are in a size class we call aerosols. They can be suspended in the atmosphere for periods of time ranging from a few seconds to several months, depending upon their size and the altitude at which they are exhausted from a convection column. These particulates may be organic or inorganic and are usually composed of carbon or mineral ash. Particulates are essential to our atmosphere because they form nuclei for the condensation of raindrops and the freezing of ice crystals. However, they are rarely in short supply.

Before man began to burn oil and coal, nuclei in the form of salt from the oceans, dust from deserts and volcanoes, and smoke from forest fires helped provide the weather essential to his existence. Now, in many cities, there are more particulates in the atmosphere than are healthful. Concentrations range from 10 micrograms per cubic meter in non-industrial, non-urban areas to about 100 or 200 micrograms per cubic meter in most urban locations. Some extremely dusty air contains 2000 micrograms per cubic meter (H.E.W., 1969, p. 15).

Particulates may affect visibility and interact with other pollutants to affect human health. A rural concentration of 30 micrograms per cubic meter limits visibility to about 25 miles. One hundred micrograms could limit visibility to 7½ miles. Two hundred micrograms might reduce visibility to about 3½ miles.

Excessive particulates from any source interact with emissions such as the sulfur dioxide from urban and industrial centers. Sulfur compounds in the air commonly come from pulpmills and from the burning of coal and oil. This interaction creates what are called synergistic effects which can be damaging to human health. Disastrous air pollution episodes occurring in Britain and the United States have begun when loadings exceeding 400 micrograms of particulate per cubic meter have been combined with the appropriate amounts of sulfur dioxide.

Remember that reliable data concerning human health are very difficult to accumulate. For example, the strong statistical link between cigarette smoke and lung cancer has yet to be clearly defined. Nevertheless, statistical evidence is good enough to convince most scientists in this field that serious health hazards exist whenever the atmosphere becomes overburdened as it sometimes does in the urban-industrial areas of Montana. The same hazards can exist for a person who spends too much time sitting near a campfire or puffing on a pipe.

Production and Dispersion of Smoke

In General: I mentioned earlier that fire scientists have sampled convection columns from prescribed fires in western Montana. We've also measured the particulate matter near the ground in areas downwind of these fires. Figure 4 illustrates a high-volume sampler and a tape sampler used to characterize the particulate content of the air during such studies. Figures 5 and 6 show the kind of aircraft and instrumentation used to sample convection columns from experimental burns.

Our purpose in monitoring convection columns from experimental fires was to confirm, in practice, the theoretical principles which influence the dispersion of forest fire smoke. Let's review a few of these principles briefly. Convection columns from forest fires vary greatly in the altitude they reach and the rate at which they move downwind and mix with the air. Convection-column behavior is determined by the fire's intensity and variations in air temperature and wind speed above the fire. Similarly, the rate of spread of the downwind plume depends upon wind speed, temperature, and certain other factors.

Smoke becomes part of the gaseous and particulate loading of the atmosphere. The air immediately above a fire is warmer than surrounding air. Therefore, it tends to rise and expand as it cools. Finally, this air reaches an altitude where its temperature and that of the air around it are approximately equal. The smoke then diffuses and moves with the air in which it is imbedded. Other things being equal, the hotter and larger the fire, the higher the smoke rises before it dissipates.

Inversions: A temperature inversion is a natural meteorological phenomenon in which, contrary to the normal arrangement, warm air overlies cooler air. In mountain valleys inversions occur almost daily, but they are usually short-lived. Occasionally, however, during the cooler months, they persist for several days. Then, the higher, warmer air traps and accumulates emissions from the urban and industrial sources within populated valleys.

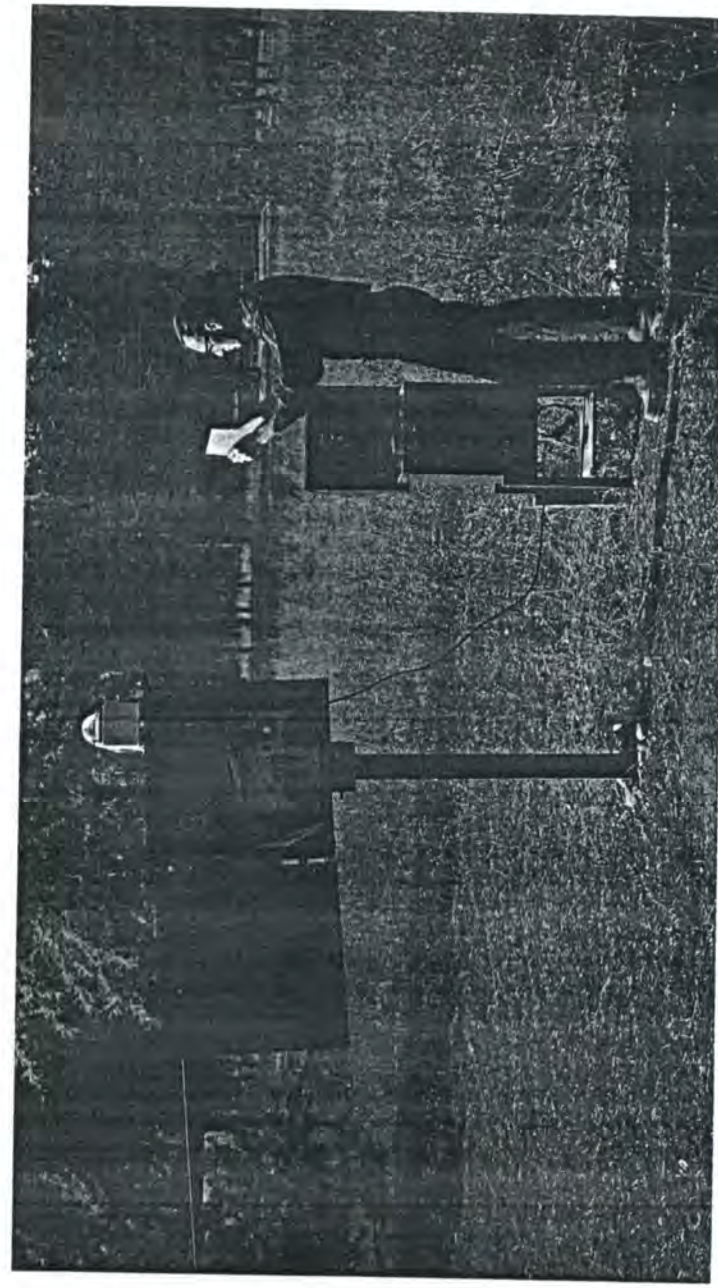

FIGURE 4. One of five sampling stations used to measure the quality of air downwind of experimental burning areas. Instrumentation includes high-volume and tape particulate samplers and an actinograph to measure sunlight *(U.S. Forest Service Photo).*

Because these emissions have low heat energy, they cannot overcome the stabilizing effects of the inversion. Thus, there is little mixing of the polluted valley air with the atmosphere above the valley.

Forest fires rarely occur in populated valley bottoms. Smoke from man-made or wild fires at high elevations encounters the same barriers to movement into valleys as does effluent from urban-industrial sources in dispersion out of these valleys. In other words, forest fire smoke may be visible in the sky above us, but need not descend into inhabited valleys. Moreover, the smoke from fires which are scheduled and managed can actually be directed into the atmospheric currents which will permit optimum dispersion, diffusion, and dilution. This is not true of unplanned wildfires which burn through the passage of several weather systems and over many days and nights. Under these circumstances downslope and downcanyon winds characteristic of mountain drainages can carry smoke from wildfires or poorly managed prescribed fires into inhabited valleys.

Atmospheric stability: Similarly, instability in the atmosphere

FIGURE 5. Aircraft employed in sampling convection column characteristics and plume dispersion *(U.S. Forest Service Photo).*

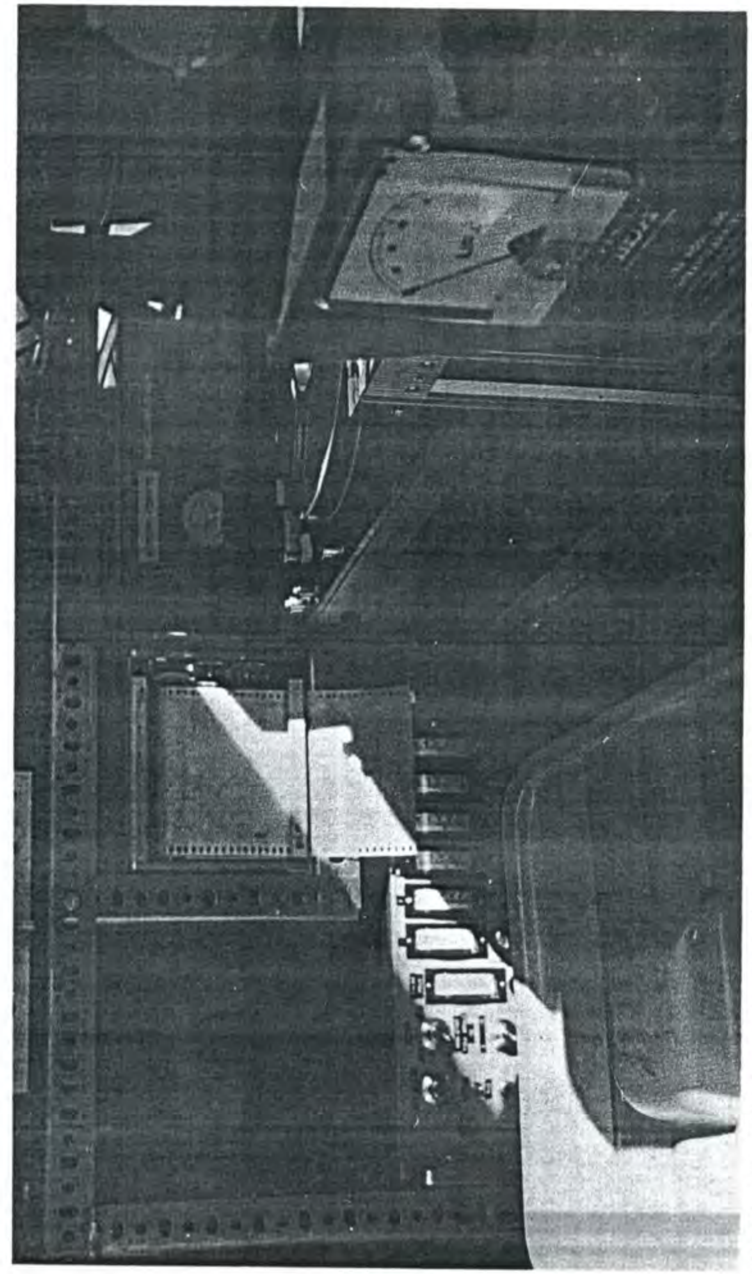

FIGURE 6. Interior instrumentation of the aircraft provides for continuous monitoring of position, visibility range, and oxides of carbon, sulphur, and nitrogen *(U.S. Forest Service Photo).*

FIGURE 7. Convection column from a test fire in the Coram Experimental Forest in western Montana. This smoke was vented into an atmosphere which dispersed it without affecting the air quality of inhabited valleys ***(U.S. Forest Service Photo).***

tends to increase the height of convection columns. What do we mean by "unstable air"? Briefly, air normally cools with increasing altitude. *Unstable* air cools very rapidly with an increase in altitude. This rapid cooling can cause convection columns to rise higher than the heated air alone would permit.

Occasionally, air cools more slowly than normal with increasing altitude. Vertical motion of air is then suppressed and a *stable* condition is said to exist. Stable air tends to dampen convection activity.

Intense fires burning large amounts of fuel cause convection columns to rise rapidly to a relatively high altitude (Figure 7). Actually, the altitude reached by forest fire smoke ranges from slightly above the ground, under stable atmospheric and slow burning conditions, to 40,000 feet above terrain under less stable and more vigorous burning conditions. The height of the convection column is analogous to the height of a smokestack above the surface of the earth in that it determines the altitude at which the bulk of the smoke will be vented. However, forest fire smoke is always contained within the troposphere—that portion of the atmosphere which is weather-active and therefore subject to regular cleansing.

Burning Efficiency: We should be aware that the particulate and gaseous emissions from inefficient fires are greater than those from efficient fires. The differences in emission are almost entirely a function of the rate of combusion. A good analogue of this phenomenon in industrial practice is a multistage incinerator whose effluent is markedly less than that of a single stage teepee burner (Feldstein et al., 1963). A wildfire or prescribed fire which burns intensely under favorable atmospheric conditions may produce only one-tenth the particulates and unburned byproducts of a fire which burns night and day and spans both favorable and unfavorable burning conditions. If we accept the inevitability of photosynthetic and oxidative processes in our forests, we must also accept their emissions and consider alternative ways of dealing with them.

Atmospheric Cleansing: The atmosphere of the earth is a remarkable envelope. Fortunately for animal life, it is self-cleansing within reasonable and predictable periods. Particulates, for example, are cleansed from the air when they become nuclei for condensing or freezing water and fall with the rain or snow.

Historically, the atmosphere has been capable of handling the particulates and gases from forest fires, sand storms, and volcanic eruptions. The life-supporting characteristics of the atmospheric envelope can be maintained as they have in the past if society controls the use of fossil fuels so as not to emit more combustion residues than the atmosphere can assimilate. Present rates of release in certain urban areas are sometimes in excess of this capacity.

Technological capabilities exist which, when applied to processes going on within factories, internal combustion engines, and generating plants, promise future relief from air pollution. Any time a process is contained within walls, cleansing treatment is possible—even though it may be very expensive. As a last resort, society can close down such sources of pollution. Unfortunately, the same cannot be said for more than 600 million acres of flammable forest land in this country, a significant portion of which is located in the Intermountain West. Here, photosynthetic activities proceed which man cannot manage in the same sense that he can manage his factories or his automobiles. What, then, are our resource management alternatives in respect to fire?

Resource Management Alternatives

Political-Social-Economic Decisions

Any rational discussion of resource management alternatives ultimately leads to consideration of who makes the management decisions. I submit that there are two kinds of decisions to be made: (1) those in the political-social-economic sphere, and (2) those requiring expert knowledge. The former are most appropriately made through the democratic process. The latter must be made by the scientists or professionals most familiar with biological principles.

As John Dewey recognized early in the century:

> Any scene of action which is social is also cosmic or physical . . . it is also biological. Hence the absolute impossibility of ruling out the physical and biological sciences from bearing upon ethical science.

Laymen cannot be expected to make decisions requiring expert knowledge; yet they have the responsibility for political and social decisions. For example, there are three basic decisions to be made regarding the management of public forest lands. First, we can decide to manage or not to manage given stands. Second, if we decide to manage these stands, we must determine the nature of goods and services to be derived from them. Finally, we have to decide what to do with the waste products of this utilization.

Of course, waste products are generated by stands in wilderness areas as well as by those which provide timber products, water, and wildlife production. Some of these waste products are natural and accumulate slowly, while the accumulation of others has been accelerated by the management process. The former

are exemplified by forest litter; the latter by logging slash. In either case, there must be commitment and plans for dealing with waste products.

Once it has made the political decision to manage a given forest, society can turn to experts for decisions on how to do so with the greatest efficiency. Often there is feedback between experts and those making political decisions. With this background, let's look at four different kinds of decisions which must be made concerning fire and smoke in Montana forests.

Decisions Requiring Expert Knowledge

The public should look first to its professionals for evaluation of fuel accumulation, wildfire hazard, wildfire control, and similar matters affecting public safety. These are not simple matters for decision makers. Forest scientists do not live as long as trees and, thus, must resort to historical records for data on which to base estimates of future fuel accumulation in northern forests. Earlier, I discussed evidence which suggests that fuel accumulation increases both wildfire hazards and control problems.

The next contribution experts can make is a clear definition of the biological and physical principles operating for and against the achievement of management goals selected by political processes. Certain segments of society require forest products for such essential commodities as housing, packaging, and reading material. Other groups require water of sufficient quality and quantity to support domestic, agricultural, and industrial needs. Still other segments of society seek amenities in and from forest communities such as are afforded by wildlife, wilderness experiences, and other recreational opportunities. None of these human needs can be met outside of the natural laws governing the maintenance, production, and regeneration of forest communities—all of which follow the energy pathways I outlined for you earlier.

An appreciation of the interdependence of site productivity, plants, and animals in these forest communities is the expert's stock-in-trade as he decides how to provide goods and services and dispose of waste products associated with management. Fortunately, with the public's discovery of ecology, forest biologists have been able to acquaint those making the political decisions with concepts of interdependence. Unfortunately, we lack good ways of expressing the interdependence of many of the natural processes which operate simultaneously. Consequently the public is often confused by what the forest biologist calls interactions and seeks over-simplified solutions to problems involving these relationships.

I know of two simplistic notions regarding the problem of forest fire smoke. They are (1) that we can "conquer fire" and (2) that "technology will out." The first of these premises is seriously challenged by the concept of fuel accumulation which I have described above. How can fires be conquered if there is no reasonable way of separating causative agents and an ever-increasing load of fuel? The possibility of a technological solution seems similarly remote in light of the fact that in 1970, with the most powerful mechanical resources ever marshalled to combat forest fires at a cost of millions of dollars, two fires larger than any recently recorded burned in southern California and in eastern Washington until rain finally permitted firefighters to move in and mop up.

Similar conflagrations in 1961 in southwestern Montana and in 1967 in northern Idaho pose the question, are serious fire seasons increasing in severity and occurrence? If so, why? Included among the causes has to be a 60-year-old fire control and prevention policy of extinguishing every wildfire as soon as feasible, only to set the stage for a more intense fire at a later date. Fire managers in public agencies now realize that inattention to accumulating natural fuels combines with any lag in slash treatment to create serious wildfire hazards. These potentials were clearly recognized as early as 1939 by Hornby and again by Lyman in 1945.

Fuels created by logging operations are not always reduced at the same rate that the timber is harvested. The safety of people and their property can be threatened by a status quo which includes a history of fire prevention, exclusion, and control. Also, in Montana and northern Idaho there are many areas where hazardous fuel accumulations associated with insect and disease attack and windthrow should be reduced.

Lest anyone misunderstand what I've just said, let me hasten to point out that natural and man-made accumulations of fuel in Montana forests have resulted from basically sound and effective management policies of the past. Forest fires had to be fought to protect human life and property. Forest land management of any kind requires a large measure of control over unscheduled destructive agents, including fire. The fact that fire is natural doesn't make it good or bad—it only makes it natural.

One of the major reasons for the present challenge in fuel management is the dedication and success of men in public agencies who responded to the need for control of wildfires. The quality of this success bodes well for solution of future problems in forest management.

By now you must realize that there are no easy solutions to the dilemma posed by the fire history of our Montana forests and the smoke resulting when they burn. The difference in trophic levels

has come home to roost like vultures in a thorn tree. The simplification of complex organic molecules to more elemental forms is an inevitable process.

An analogy that I frequently use is that of snow avalanches. Snow falling on mountaintops must ultimately descend to lower elevations, releasing energy as it does. This process may occur through either slow melting or rapid avalanching. Slow melting or evaporation is analogous to normal decomposition of organic matter.

When more snow accumulates than can be supported by mountain topography and vegetation, some event usually triggers an avalanche. If an avalanche hazard should arise where life and property are threatened, however, snow rangers purposely trigger it before the accumulation becomes potentially destructive. Similarly, forest land managers use prescribed burning to reduce accumulations of forest fuels which may cause damaging wildfires. In either case man intervenes as a colleague of nature to moderate the inexorable, natural process of energy level reduction.

I hope by now that you will join me in admitting that society must cope with the inevitable emission of smoke from the forests of Montana. It is time for a realistic appraisal of the possibilities for smoke management.

Smoke Management Possibilities

Smoke management and fuel management must become concurrent activities in what I prefer to call a public health approach to the prevention, control, and scheduling of forest fires. Today's public health officer recognizes that the plagues of mankind were controlled only through sanitation and immunization. We must recognize that successful fuel management requires that the forest be viewed as an energy storehouse with annual inputs and irregular withdrawals. We must learn to control our fuel inventories just as we learned to cope with plagues.

Many tools can be employed in fuel management practice: harvest operations; mechanical treatments such as chopping, grinding, and chipping; preventive or prescribed fires; and even wildfires. Preventive burning and wildfires may be the only methods applicable to wilderness areas.

However, when fire itself is used, the smoke need not be traded on a one-to-one basis for that from nature's fires. It is possible to manage smoke from prescribed fires so as to minimize its impact on downwind air quality. Fires can be scheduled at times when atmospheric conditions will vent smoke to high altitudes and when subsequent weather conditions will cleanse the atmosphere within a reasonable period. Thus, unlike the regular emissions from urban and industrial sources of pollution, smoke from prescribed fires can be controlled so as not to affect human populations directly.

Forest fire scientists have the foundation of knowledge for deciding when to schedule prescribed fires (Beaufait and Cramer, 1969; Norum, 1970). With real commitment on the part of fire managers, the dispersion of smoke from these fires can be predicted with the same reliability as that associated with normal weather forecasts.

None of the foregoing should be construed to suggest there are not technological opportunities to minimize the smoke from forest fires. Unfortunately, machines designed to reduce forest slash or accumulated natural fuels can also reduce the productivity of the land. The forest around us is the product of past fire, and the ecological effects of fire are reasonably well known. However, there is still a lag in understanding of the ecological effects of such alternatives to fire as chippers, crushers, and complete yarding of organic material. Serious attention must be given to the long-range consequences of removing all woody matter from the site or creating a woody pavement by compacting noncommercial residues.

The greatest dilemma faces land managers in the unmanaged forest where fuels cannot be freely manipulated at least once during a generation of trees. These stands usually are not harvested or subjected to cultural treatments of any kind—yet fire is sometimes past due. We have two choices in these legally or economically unmanageable stands. The first is to continue to protect them until Nature ultimately takes her course. The second is to combine the use of wildfires, preventive fires, and mechanical methods to reduce accumulated hazards. Subsequent maintenance of moderate fuel levels will help prevent destructive wildfires in the future.

Conclusions

Fuel-Management Program

Consideration of smoke-management and fuel-management alternatives leads inevitably to proposal of a full-scale fuel-management program in Montana forests. The dimensions of this program are still hazy, but it probably will include some use of fire underneath growing stands of timber before they reach maturity. Fire also has a role in wilderness areas where it provides the variety of environmental conditions and age classes necessary for complete wilderness resources. The program will probably involve the intelligent use of wildfires as well as prescribed fires —providing they are accomplishing preplanned management objectives (Figure 8). It undoubtedly will include greater utilization of forest products from those areas which have been harvested, but with caution to avoid overutilization of the site. Actually, an amalgam of all of these methods will be needed to achieve a full-scale forest fuel management program in the future.

The Alternative to Fuel Management

I would be a poor observer if I did not recognize the likelihood of legislative and administrative constraints being applied to open burning in the forests of the western United States within the next few years. As is sometimes the case, public pressures for essentials like clean air are directed against symptoms rather than causes. In other words, I expect a blanket reaction to forest fire smoke rather than a directed response to biological reality and recognition of circulation in energy systems.

Therefore, I would like to sketch briefly a scenario which could occur as early as next year, but more likely in another five or

FIGURE 8. The trees in this managed stand are the same age as the young man in the foreground. Their establishment was stimulated by a harvest cutting and controlled burn 13 years before the photo was taken *(U.S. Forest Service Photo).*

more years. It is now 1984, 10 years after a ban on forest burning. Fuel buildup has combined with increasing demand for forest resources to set the stage for a holocaust. Reduction in clearcutting and emphasis on partial cutting to maintain the aesthetic quality of western mountainsides have eliminated any remaining options for preventive fire on vast harvested areas. We have had a dry year without typical June rainfall. Now, during July and August, a series of dry mountain lightning storms scatter fire throughout the northern Rocky Mountains. These fires converge, as they frequently have in the past, overwhelming control forces and violently consuming the accumulated vegetable matter—up to 300 tons per acre—plus some animal matter which happens to be in the way. You see, by this time human beings have fled the congestion of urban centers for suburban retreats in Montana like those which existed in the California and Utah brushlands during the '70s. The resultant loss of human life and property and the devastation of huge tracts of forest land finally focus public attention on the absolute necessity of limiting forest fuel accumulations. Those living in the Intermountain West who survived the flames—and the weeks of dense smoke—are now soberly evaluating what fire prevention really means, and public health officials view the forest with new respect.

Our job as citizens concerned with natural resources should be to do our best to prevent fruition of that scenario. We must recognize the weaknesses in traditional concepts of forest succession when applied to western forests and contemplate the forests of John Muir who wrote of early fires in the Sierras:

> Even when swift winds are blowing, fires seldom or never sweep over the trees in broad all embracing sheets as they do in the dense Rocky Mountain woods and in those of the Cascade Mountains of Oregon and Washington. Here they creep from tree to tree with tranquil deliberation. . . .

Sierra fires are no longer tranquil due to the invasion of a dense understory following fire exclusion. However, sheets of flame need not be as common in the Rocky Mountain woods as in Muir's and our own time if we elect a public health approach to forest fire management.

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