PRESCRIBED BURNING SYMPOSIUM

Proceedings

April 14–16, 1971

CHARLESTON, SOUTH CAROLINA

Sponsored by

Southeastern Forest Experiment Station, USDA Forest Service
Duke University
Clemson University
The Belle W. Baruch Research Institute in Forestry, Wildlife Science, and Marine Biology of Clemson University

Printing provided by the Belle W. Baruch Research Institute

Citation:

USDA Forest Service
1971. Prescribed burning symposium proceedings. 160 pp. Asheville, N. C.: Southeastern Forest Experiment Station.

CONTENTS

FOREWORD 5
Stephen G. Boyce

KEYNOTE ADDRESS 7
E. M. Bacon

SESSION I

THE EARLY HISTORY OF WILDFIRES AND PRESCRIBED BURNING 11
Roland J. Riebold

CURRENT USE AND PLACE OF PRESCRIBED BURNING 21
Robert W. Cooper

COMMENTS 28

SESSION II

EFFECTS OF PRESCRIBED BURNING ON TIMBER SPECIES IN THE SOUTHEASTERN COASTAL PLAIN 34
O. Gordon Langdon

COMMENTS 45

EFFECTS OF FIRE ON WILDLIFE AND RANGE HABITATS 46
E. V. Komarek

COMMENTS 53

MANAGING FOREST LANDSCAPES: IS PRESCRIBED BURNING IN THE PICTURE? 54
George Meskimen

THE EFFECTS OF PRESCRIBED BURNING ON OUTDOOR RECREATION. 59
Carroll J. Perkins

PRESCRIBED BURNING FROM THE TOURISM POINT OF VIEW 64
Robert Papenfus

COMMENTS 66

SESSION III

EFFECTS OF PRESCRIBED BURNING ON PHYSICAL PROPERTIES OF SOIL 68
Charles W. Ralston and Glyndon E. Hatchell

COMMENTS 84

EFFECTS OF PRESCRIBED BURNING ON SOIL CHEMICAL PROPERTIES AND NUTRIENT AVAILABILITY 86
Carol G. Wells

COMMENTS 97

PRESCRIBED BURNING AND SOIL MESOFAUNA ON THE SANTEE EXPERIMENTAL FOREST 100
Louis J. Metz and Maurice H. Farrier

EFFECTS OF PRESCRIBED BURNING ON THE MICROBIAL CHARACTERISTICS OF SOIL 107
J. R. Jorgensen and C. S. Hodges, Jr.

COMMENTS 111

EFFECTS OF PRESCRIBED BURNING ON LONG-TERM PRODUCTIVITY OF COASTAL PLAIN SOILS 115
Earl L. Stone, Jr.

COMMENTS 127

SESSION IV

PUBLIC INFORMATION AND LEGAL ASPECTS OF PRESCRIBED BURNING 130
Leonard A. Kilian

COMMENTS 136

AIR QUALITY ASPECTS OF PRESCRIBED BURNING 139
John H. Dieterich

COMMENTS 151

EFFECTS OF PRESCRIBED BURNING ON THE ECOSYSTEM 152
Charles F. Cooper

COMMENTS 159

FOREWORD

Fire, whether accidentally started or deliberately set for some purpose, has been an important force in the ecology of the Southeastern Coastal Plain for thousands of years. For the past 20 years prescribed fire has been used as a management tool for fuel reduction, seedbed preparation, control of undesirable brush and tree species, improved cattle forage and wildlife habitat, tree disease control, and for other purposes. Now--throughout the 1960's and in 1970--about 2-1/3 million acres of forest land are prescribed burned each year. The 450 people attending this Prescribed Fire Symposium did so specifically to take stock of the impact of these burning practices on the total environment. Fire in the forest, prescribed or wild, introduces both immediate and delayed effects on the environment, and these most knowledgeable scientists and laymen of broad and varied training and experience from industry, universities, and state and federal agencies reviewed for two full days the state of our knowledge to date.

They did not meet as a prejudiced group to defend or to preserve the use of prescribed fire. They met as competent scientists, skilled land managers, and concerned environmentalists to evaluate the effects of using, or having used, and of continuing to use fire as one of the most readily and economically available forest management tools. Consensus was essentially unanimous that prescribed fire, when properly used in the South, is an almost indispensable management device having generally beneficial effects, certainly lacking in sustained deleterious effects on the crop trees, on the soils on which they grow, or on the flora and fauna of the area burned.

Still, the symposium did point out one area of growing concern where our knowledge and experience are weak and not yet adequate to support valid conclusions: WHAT IS THE IMPACT OF THE EFFLUENT FROM PRESCRIBED FIRE AND FROM WILDFIRES ON THE QUALITY OF OUR AIR? A number of relatively simple measures were discussed that could reduce, at least locally and momentarily, the more obvious effect of forest fire smoke on air quality. But to solve more basic problems, we must learn what combustion products are released into the atmosphere by both prescribed fires and wildfires, in what volume, for what period of time, where they go, and what are their significant effects on air quality. We must learn whether prescribed fires maintain a higher quality of air than the uncontrolled oxidation of accumulated fuels by wildfires. Intensified and speeded-up research is essential if we are to get these answers in the time that may still be available for decision making based on facts rather than fancy.

The cards are all laid out on the table, so to speak, in the papers and comments reproduced herewith in these Proceedings. Readers of these articles will be in possession of all the facts, as best they were known at this symposium, and hence in position to make reasonable and logical decisions about prescribed burning. The decisions reached could have determining influence on the management of Southern forests and the South's environment.

Many people contributed to this meeting. It is not possible for me to name every individual. I would like to recognize the members of the Planning Committee, who worked hard for more than a year to make this symposium a success:

O. Gordon Langdon, Planning Committee Chairman
Southeastern Forest Experiment Station, U.S.F.S.
Ralph C. Bryant, North Carolina State University
L. E. Chaiken, Duke University
Robert W. Cooper, Southeastern Forest Experiment Station, U.S.F.S.
David D. Devet, Francis Marion-Sumter National Forests, U.S.F.S.
Paul C. Guilkey, Southeastern Forest Experiment Station, U.S.F.S.
Barry F. Malac, Union Camp Corporation
John K. McDonald, Southeastern Forest Experiment Station, U.S.F.S.
Louis J. Metz, Southeastern Forest Experiment Station, U.S.F.S.
John R. Tiller, South Carolina Commission of Forestry
R. Scott Wallinger, Westvaco Corporation
Carol G. Wells, Southeastern Forest Experiment Station, U.S.F.S.

Stephen G. Boyce
General Chairman of the Symposium
Southeastern Forest Experiment Station, U.S.F.S.

KEYNOTE ADDRESS

E. M. Bacon
Forest Service
U. S. Department of Agriculture
Washington, D. C.

I consider it a distinct honor and I know it is a real pleasure to have been asked to give the keynote address to this distinguished group of concerned researchers and land managers. I consider it an honor because assembled in this room is undoubtedly the most knowledgeable group of people ever brought together to explore in depth each and every aspect of prescribed burning. I know it is a pleasure because fire in the forest, whether prescribed or wild, has an impact on many aspects of the environment, and, I am personally and officially very much concerned with both the present condition and the future prospects for the environment in which we live. By the same token, I am both personally and officially very much concerned with the present and future productivity of our forest-land resource. Here in the South, the two are almost inseparable.

The theme of this symposium is most appropriate and timely because of the growing public concern with all aspects of our environment. Webster defines environment as "the complex of climatic, edaphic, and biotic factors that act upon an organism or an ecological community and ultimately determine its form and survival." It is thus obvious that we can't possibly escape from our environment or evade responsibility because we are stuck with whatever environment we ourselves have been and still are instrumental in creating. For 300 years now, we have been altering the natural environment of the United States. Unfortunately, much of this alteration has not been for the better. The rate of environmental deterioration has accelerated most rapidly in recent years to the point where the "survival" part of the definition is beginning to be of significance even to man himself. As our population increases, and as we demand more and more of the materialistic "good" things from life, our environment seems to suffer disproportionately in the process.

It seems to me that we must plead guilty to those who charge that we have been slow to recognize impacts on environment and on people that have been the result of some of our activities. There are still those who harbor the secret hope that all this environmental concern will just go away sometime soon--that maybe it is just a fad, kept alive by the dreamers, the alarmists, and the spokesmen of the far left.

At least from the Washington vantage point, that hope seems faint indeed. Those voices have increasingly become the public's voice. And most of us have "gotten the message."

To bring this broad concern within the more narrow specifics, you will be discussing at this meeting I might interject a personal note. As a ranger and fire staff man in the West I took great pride in using weather information to accomplish effective and safe--at least usually safe--prescribed burns. What difference did it make that the mountain valleys and towns were smoked in for days or even weeks on end. Think what a wildfire would have done! Or as a parallel, wasn't it better in the South to obscure a southern highway with smoke from a prescribed fire when a wildfire would have been so much worse. Our purposes were noble and the related effects minimal.

Meetings such as this give clear evidence that while change may be slow in the absence of public pressure we respond positively when public concern does find expression.

It is inescapable that fire has an impact on each of the three aspects of the environment defined by Webster--the climatic, the edaphic, and biotic. Prescribed fire differs from wildfire in that we employ it only when and where we want it and in that we presume to control and manage it in such a way that its beneficial effects outweigh any of its detrimental effects. Questions arise, however, when different people attempt to evaluate these plus and minus effects. A prescribed burn that reduces the rough and thus "fireproofs" a stand for a number of years and thus prevents a possible "blowup" wildfire may rate a big PLUS from the forest manager. But the bird watcher may rate this same fire with an equally big MINUS. And the exasperated housewife whose laundry may have been soiled by particulates falling from the resultant smoke may be the first one to write her Congressman and say, "This burning has got to stop!"

So, I repeat that a meeting such as this one is most timely, perhaps even overdue, when we sit down together and objectively take a close look at both sides of the coin.

Fire can be friend or foe depending upon how we use it. Our first inclination is to think of all wildfires as bad and all prescribed fires as good, but this isn't necessarily so. The main difference between the two is often really but one of intent. Some ill-conceived and ill-managed prescribed burns do damage. And I'll be so bold as to say I think some wildfires do good--so much so that in some instances we might be well advised to spend our dollars to "guide" them rather than suppress them.

Fire of one type or another has always been a factor of the environment of coastal plain timber types. As a matter of fact, the pure pine stands of this region are a subclimax forest maintained largely by fires. Natural succession in the Southeastern United States is toward mixed hardwood forests. To maintain these pure pine stands which constitute the base for the present timber economy and provide the future hope of the "South's Third Forest," this natural successional trend must be upset. This probably could be induced by mechanical or even chemical means; to use fire is the simplest and most economical.

Prescribed burning seemingly had its origin in the South, it has certainly been an accepted management tool for a longer period of time in this region than anywhere else in the country. Research by the Forest Service and others during the last 20 or 30 years has led to the development of prescribed burning as an effective tool in the management of forests for timber production. But long before prescribed fire was employed, wildfires had their definitive place in forest ecology, i.e., they maintained these vast stands of pure pine.

Fortunately, reliable records have been kept in considerable detail for a number of years on the use and the various consequences of using fire as a management tool. Research has covered many phases of fire effects on the environment and ecology of forest communities. Foresters, soil scientists, ecologists, pathologists, entomologists, and other related disciplines are to be congratulated for their foresight in looking into the long-term effects of fire. Otherwise, we would not be able to gather here for this symposium and discuss these effects and pose the pertinent questions for discussion that still need to be answered. We can pretty well chart where we've been--now we need to consider where we are going, realizing that the gages we have been using for measuring fire effects and environmental impact may have to be recalibrated.

There is a wealth of operational background and capability in the use of prescribed fire under varying field and weather conditions available in the South. Many if not most of those here have had that experience. You have used fire for many purposes and feel a personal stake in its remaining an important tool available to forest managers.

We know something of the effects of prescribed fire on esthetic and recreational values, on the maintenance of wildlife habitat, on the physical, chemical, and biological properties of forest soils, and on the net growth of timber, and the reduction in numbers and intensity of wildfires.

But we don't know much about forest fire effects on air quality!

In recent years there properly has been a growing concern about all forms of atmospheric contamination. To most people smoke is a form of air pollution, and smoke is smoke whether it belches forth from an industrial smokestack, spews from an auto exhaust, or billows up from a forest fire, wild or prescribed. We are now in a

spot where all the pluses foresters credit to prescribed fire must be weighed against all the minuses considered by the public and which we must now more fully consider. Where these concerns may not rest on fact we must marshal the facts and more importantly convince people of their validity. Unfortunately, we don't have all the facts, really only a few of them, but as you will learn from subsequent discussions, a concerted drive is underway to gather them.

We can all think of a number of relatively simple things that might be considered as ways to minimize the possible air pollution effects of prescribed fire short of eliminating it:

-- We can burn only when weather conditions are favorable for complete combustion and rapid dispersal and dilution of smoke.

-- We might burn smaller tracts at any one time to lessen the output of contaminants.

-- We might disburse our burns so the concentration of pollutants at any one place is held to a minimum, and

-- We might be able to extend our burning day or season to further dilute the production of questionable products over both time and space.

But, these are only palliatives at best and we still must learn what products, in what volume, and for what period of time we do release into the atmosphere when we prescribe burn. Then these and all other known facts will be put on the scales, the pluses on one side; the minuses on the other, with John Q. Public watching to see which way they tip.

We must not wait until public sentiment builds to the point that prescribed fire might be banned or seriously restricted and then react defensively. We must design the constraints, mitigate the adverse impacts, and more than this, we must have ready or at least be exploring alternative means of accomplishing the same beneficial goals. These in turn may present problems for one of the most obvious choices might well be chemical treatment, and the use of chemicals is under even closer scrutiny than burning.

I think everyone here fully realizes it is high time we probe deeply into all aspects and known details of the effects of prescribed fire, both good and bad. If this were not true, this symposium would not have been organized.

Thank you, and have a fruitful session.

THE EARLY HISTORY OF WILDFIRES AND PRESCRIBED BURNING

Roland J. Riebold
USDA Forest Service (Retired)
Tallahassee, Florida

The custom of annual burning of the woods from Colonial times onward is a subject of more interest, perhaps, to ecologists and social scientists than it is to foresters. The important point to us is that it had become a well-settled folkway by the time large-scale lumbering began in the southern pineries about 1890. Before this lumbering began, the light annual fires brought fresh green grass in the early spring and surely did little harm to the stands of old-growth longleaf pine. Similarly, raking and burning in the turpentine woods did little harm and did save the faces from being burned by wildfires. However, when large-scale harvesting began, the annual fires no longer burned old-growth timber but cutover lands; and not even longleaf pine seedlings, and certainly not slash or loblolly pine seedlings can survive fire in their first year of life. Here was a significant change in a situation that had not changed much in a century. Fires killed seedlings on cutover land, and the areas of cutover land grew larger each year.

GENERAL HISTORY

The early history of prescribed burning can hardly be separated from the general history of forestry in the South. The acceptance of prescribed burning and the development of the proper tools and techniques had to take place in step with the other events which make the history of forestry. In 1881 the Division of Forestry was established in the U. S. Department of Agriculture. In 1886 Bernhard Fernow, a professional forester, became Chief of the Division of Forestry. In 1891 the Congress passed the Forest Reserve Act, which authorized the creation of Forest Reserves

from the public domain. In 1898 Fernow resigned and Gifford Pinchot was appointed Chief of the Bureau. To put forestry into the woods, Pinchot made arrangements for the foresters of the Bureau to be available for professional assistance to private timberland owners. In the first year, 123 owners of 1.5 million acres in 35 states requested assistance. Most of the requests were from the South.

Working plans were prepared for the properties and published as bulletins by the Bureau. Among others, there were bulletins by F. E. Olmstead in 1902 on lands in Arkansas, by F. W. Reed in 1905 on lands in Alabama, and by C. S. Chapman in 1905 on lands of the Burton Lumber Company in Berkeley County, South Carolina. The latter was published as Bulletin 56. The stand of loblolly pine now on the Santee Experimental Forest dates from the seed trees marked under Chapman's prescription.

Another forester, Max Rothkugel, was employed by the Burton Lumber Company to prevent and control fires. In 1907 he published an article in the Forestry Quarterly in which he prescribed the age or height at which loblolly pine reproduction should receive its first prescribed burn for fuel reduction.

In 1908, after 10 years, this form of assistance to forest landowners was discontinued because the results in forestry practiced were disappointing. In 1905 the Forest Reserves had been transferred from the Department of the Interior to the Department of Agriculture and renamed the National Forests. The Bureau of Forestry was renamed the Forest Service, which then of necessity became engaged for the next three decades mostly in the administration of the vast area of National Forests in the West.

During the early part of the era of harvesting the virgin pines, most of the lumber companies were without the services of professional foresters. With the taxes of the time, the custom of burning the woods, the free-ranging of cattle and hogs, and the attitude of most of the industry, the employment of foresters other than logging engineers was probably not worthwhile.

During the latter part of this period, there was a notable change in the attitude of the industry. The Urania Lumber Company of Henry Hardtner in Louisiana was a pioneer in 1912. The Great Southern Lumber Company at Bogalusa began reforestation in 1920. In 1926 the Superior Pine Products Company began with cutover land at Fargo, Georgia. There were other interested companies; but, even so, not many industrial foresters had the opportunity to acquire silvicultural experience, which might have included prescribed burning. Although papermakers came South almost as early as did the big sawmills, it was not until the late 1930's that the pulp companies came in numbers, acquired large forests, and employed many foresters.

FOUNDATIONS OF FORESTRY

In 1925, at the peak of large-scale harvesting, the industry and the people of all the Southern States began to lay the foundations of the new forestry business by passing laws prohibiting forest fires and by creating state forestry agencies. Louisiana passed legislation in 1910, Virginia in 1914, North Carolina and Texas in 1915, Alabama in 1923, Mississippi in 1926, and Florida and South Carolina in 1927. It is noteworthy that the states sought and found able and experienced professionals to become their first State Foresters. A notable feature of this legislation was that, unlike Pennsylvania, none of the Southern States provided for the acquisition of State Forests by purchase. Consequently, the State Foresters had no lands of their own on which to practice and to acquire experience as forest managers or, perhaps, as prescribed burners.

CREATION OF NATIONAL FORESTS

Not only were there very few industrial foresters or State Foresters during this period but there was also an absence of any substantial presence in the South of the U. S. Forest Service. In the Southern States, there were no large areas of unreserved public domain from which National Forests could be created as there were in the West. In 1908, about 100,000 acres of sand pine in central Florida and about 400,000 acres of longleaf pine-scrub oak in west Florida were proclaimed as the Ocala and Choctawhatchee National Forests. Areas of public domain in the Ouachita and Boston Mountains in Arkansas became the Ouachita and Ozark National Forests.

In Florida, however, the creation of the two National Forests resulted in only one professional forester, the Forest Supervisor, plus three non-technical rangers. The District Forester who had supervision of these new National Forests was headquartered in Albuquerque, New Mexico. Since about 1900, various groups of citizens had promoted the creation of a national park in the southern Appalachians and another in the White Mountains of New Hampshire. These efforts finally resulted in the Weeks Act of 1911. Purchase Units were subsequently established in the Appalachians--but not in the Coastal Plain--and these were staffed with six Forest Supervisors, a number of land examiners, and a score or so of non-technical forest rangers. In 1918, an Eastern District Office was established in Washington. In 1921 the Appalachian Forest Experiment Station, forerunner of the Southeastern Station, was established in Asheville, North Carolina, with a five-man staff. In 1923 the Southern Forest Experiment Station was established in New Orleans with a small staff, but several of its men were stationed at Starke, Florida, where they were engaged in research on gum naval stores.

The Weeks Act also provided the states with assistance in fire control, but its provisions were not very effective. The Act was amended in 1924 by the Clarke-McNary Act. The financial assistance under the latter act helped many state organizations to get started. To supervise work under the Act, two Forest Inspectors were assigned at Asheville and New Orleans; they worked under the Chief's office. The Clarke-McNary Act also provided

for the purchase of lands not only for the protection of the headwaters of navigable streams but also for timber growing.

About 1928 the Forest Service began acquisition of three new National Forests--Osceola in the naval stores belt in Florida, Kisatchie in the cutover longleaf pine lands in Louisiana, and Homochitto in the loblolly-shortleaf pine area in Mississippi. But these acquisitions resulted in only one more Forest Supervisor plus a professional assistant and two professional foresters in Florida, a Forest Supervisor and one professional ranger in Louisiana, and one professional ranger in Mississippi. The Forest Service still had no substantial presence in the Southern Coastal Plain.

During the period of heavy harvesting, 1890 to 1933, there were almost no federal, state, or industrial foresters who might have acquired skill in the silviculture of southern pines from experience as forest managers. The Southern States had State Foresters, but they had few assistant foresters, inadequate budgets, and little public support. Of 69 million acres of forested land in Florida, Georgia, Mississippi, and South Carolina in 1928, only 2,300,000 were under protection, about 3 percent.

In 1927 the American Forestry Association launched a 3-year fire-prevention project, "The Dixie Crusaders." Young foresters were sent to every rural school to make talks and show motion pictures on fire prevention.

By 1933, at the end of the period, most of the southern pine land had been cut over. The majority of it had not been restocked. Large areas were in old-field pine, worked-out stands of slash pine too small for sawtimber, and the culls and whips left from logging. Often, with a few years of fire exclusion, 10's of thousands of acres of longleaf pine land became restocked with slash or loblolly pines, sometimes with no obvious seed source. But most of the land was not under fire protection, most of it was still subject to annual burning and open-range grazing by other people's cattle and hogs, and much of it was tax delinquent.

RECOMMENDATIONS FOR CONTROLLED FIRE

As early as 1890, thoughtful persons had observed and pointed out that controlled fire might have a place and was possibly necessary in the silviculture of longleaf pine. Inman Eldredge, first Forest Supervisor on Choctawhatchee National Forest, proposed controlled burning for purposes of fuel reduction. Dr. Roland Harper, a botanist, proposed its use for understory hardwood control from 1911 on. Professor H. H. Chapman of Yale began in 1909 to urge the use of fire for preparation of longleaf pine seedbeds and for fuel reduction, and he continued to do so in many articles. Soon after its establishment, the Southern Station set up an experiment at McNeil, Mississippi, in cooperation with the Bureau of Animal Industry; its purpose was to study the merits of annual burning of lands devoted to grazing and timber growing.

At Bogalusa, Louisiana, the Great Southern Lumber Company had obtained large areas of longleaf pine reproduction; these lands had been annually burned until the time of seedfall in 1922 and were thereafter protected from fire. In a few years the effects of brown spot needle disease were observed there, and the Division of Forest Pathology of the Bureau of Plant Industry, USDA, promptly began studies of the infection.

The disease had been identified and described in 1876 by H. W. Ravenel of Aiken, South Carolina. Its damaging effects had probably not been realized until large areas of longleaf pine seedlings were protected from fire for several years after germination. In 1926 Professor Chapman published Bulletin 16, "Factors Determining Natural Reproduction of Longleaf Pine on Cutover Lands in La-Salle Parish, Louisiana." In 1931, S. W. Greene, who was in charge of animal husbandry at the McNeil experiment, published "The Forest That Fire Made" in American Forests. Also in 1931, Herbert Stoddard published "The Bobwhite Quail" in which he recommended the use of fire for quail management. In 1932, Paul Siggers, a pathologist stationed at the Southern Forest Experiment Station, published "The Brown-Spot Needle Blight of Longleaf Pine Seedlings", and in 1934 he published "Observations on the Influence of Fire on the Brown-Spot Needle Blight of Longleaf Pine Seedlings," both in the Journal of Forestry. In 1932 a 12,000-acre fire occurred on the Osceola National Forest. In 1934 a 17,000-acre fire occurred on the lands of Alec Sessoms at Cogdell, Georgia.

Thus, by 1933, there was sufficient evidence as to the need for prescribed burning in the silviculture of longleaf pine for preparation of seedbeds, control of brown spot, reduction of hazardous fuels, and management of wildlife. Although there were not many foresters practicing as forest managers, there was some response to this growing awareness of the place for controlled fire. Prescribed burns for fuel reduction were conducted on Choctawhatchee National Forest in 1927-1928. Trials of prescribed burning were made on Osceola National Forest in 1932. Extensive prescribed burns were conducted on the privately owned Suwanee Forest at Fargo in 1933.

However, the proper tools for prescribed burning were not yet at hand. Neither control of wildfires nor the proper execution of prescribed burning were possible in the Coastal Plain until tractor plows became available. Certainly, the practices of uncontrolled burning of the woods would not serve the needs of prescribed burning. Without tractor plows, it was impractical to plow firelines along property lines, to plow the crosslines which enabled several lines of fire to back into the wind at the same time, to control the breakovers, or to plow out the whole prescribed burn if weather conditions dictated.

INFLUENCE OF CCC

Among the measures for dealing with the Depression, the Roosevelt Administration created the Civilian Conservation Corps in 1933 and made money available for the acquisition of additional National Forest lands. In that year, the Forest Service examined, and the National Forest Reservation Commission created, 18 new Purchase Units in the Southern Coastal Plain--Croatan, Francis

Marion, Apalachicola, Conecuh, Leaf River, Chickasawhay, Biloxi, and those in Louisiana and Texas, with a gross area of about 13 million acres. New Forest Supervisors were stationed in Alabama, Mississippi, South Carolina, and Texas. In 1934, a Southern Regional Office was established in Atlanta. Foresters were assigned to Supervisors' staffs, to land acquisition, to CCC camps, and as district rangers on the new Purchase Units. As fast as lands were acquired, CCC camps were established. At the same time, State Foresters established CCC camps with foresters in the camps and on their headquarters staffs. At their peak, there were 311 forestry CCC camps in the South--186 under State Foresters and 125 on National Forests.

Now, for the first time, there was a substantial presence of the Forest Service in the southern pinery as forest managers; and now, for the first time, the State Foresters had the muscle and the money to build the lookout towers, telephone lines, roads, and other improvements needed and the manpower to fight the thousands of fires which occurred each year.

To burn or not to burn was not the sole, nor even the most pressing, concern of the Forest Supervisors and foresters on the new National Forests. They had hundreds of individual transactions for land purchase underway in all stages--from proposals through examination, appraisal, approval, negotiation, survey and title examination, and possession. They had the problem of creating work programs for CCC camps on lands they had just acquired, in areas with which they were not at all familiar, and without the maps they were in the process of making. They had the difficulties of patronage appointments of nontechnical supervisory personnel in the CCC and problems with the Army in the joint administration of the camps and in the training of the enrollees. They had public relations problems with local people and their elected officials, with whom they were not yet well-acquainted. The large number of young foresters from the North and the West had to become socially as well as silviculturally acclimated to the South.

The Forest Service established large nurseries in Louisiana and Mississippi, and, for the first time, it had to conduct large-scale planting of southern pines. There were thousands of fires to fight with back-pack pumps, swatters, small tank trucks, and CCC boys. The State Foresters had similar problems plus the problem of dealing with lands which other people owned.

The Southern Forest Experiment Station established three Experimental Forests to study fire problems--Harrison in Mississippi, Olustee in Florida, and Palustris in Louisiana. In the latter 1930's, both the Appalachian and Southern Forest Experiment Stations developed fire-danger meters which related the factors of wind, fuel moisture, and season or condition of vegetation to probable fire occurrence and probable rate of spread. These meters and the fire-weather forecasts of the U. S. Weather Bureau enabled foresters to anticipate suitable conditions for prescribed burning and to avoid unsuitable times.

In 1935, Forest Supervisors in Florida, Mississippi, and Louisiana were directed by the Regional Office to initiate large-scale prescribed burns for administrative studies and for experience in handling prescribed fire, but the resulting actions were less than had been desired. It was proposed in the Regional Office in 1937 that the Forest Service adopt a policy of conducting prescribed burns.

DIFFERING VIEWS ON PRESCRIBED BURNING

That foresters had differing viewpoints about prescribed burning at that time is well-known. Some, having spent a lifetime in working to prevent fires or in fighting them, were emotionally opposed to what seemed to them to be an abandonment of all they had worked for--fire protection--when much of the forest land was still endangered. Some felt that the evidence so far available was far from sufficient and preferred to wait and hope that the Southern Station would produce more substantial results from wider studies.

So far, the studies were on longleaf pine--not slash or loblolly pines. Some foresters on slash pine forests and on loblolly-shortleaf pine forests, which now had thousands of acres of seedlings and saplings, were concerned that any publicity about prescribed burning would hamper their fire-protection efforts. Some had fears about the damage that controlled burning might do, but there was little information about such damage, even on longleaf pine.

Many foresters were baffled by the problem of combining the use of prescribed fire with the then-prevalent practice of selective cutting at frequent intervals in order to obtain reproduction at each cutting. The Forest Service and the State Foresters were perplexed by the problem of choosing a policy for their fire-prevention programs. They were trying to guess what the public response would be to widespread publicity about prescribed burning at the same time that efforts were still being made to persuade people to reduce the occurrence of wildfires. It did not seem likely that prescribed burning and fire exclusion could be taught at the same time.

Of course, the proponents of prescribed burning said they opposed indiscriminate burning of the woods, but they did not have the responsibility held by the Forest Service and the State Foresters for conducting fire-prevention work--by personal and group contacts, speeches, radio broadcasts, posters, and publications. Nor did the advocates of prescribed burning--neither the botanists, practitioners of animal husbandry, estate managers, wildlife specialists, teachers of forestry, nor even the research foresters--have the legal or official responsibility of the State Foresters and Forest Supervisors for protecting the forests in their charge from damage by fire.

INFLUENCE OF WORLD WAR II

In 1941 war came to the United States. By mid-summer 1942, the CCC came to an end and so did the further acquisition of National Forest land. By that time, the Forest Service had acquired 4,176,000 acres of the 13 million gross acres in the new Purchase Units, but on most Units it was trying to protect the gross acreage. The end of CCC meant the loss of the manpower which had fought the thousands of fires. During the 9 years of CCC, neither the Forest Service nor the states had organized sufficiently the fire-warden system which had functioned so well in the Appalachians, and now military service and war industries took away much of the local manpower.

Although tractor-plows had been devised at several places in the South as early as 1930, they had not been produced in numbers; and neither plows, tractors, nor transport trucks were available in 1942 to replace the lost manpower. During and just after the war period, the Forest Service developed a variety of plows to suit the forest and soil types present. Consequently, enough tractors, plows, and transports became available on the National Forests to conduct all the prescribed burning when needed and to cope with the probable number of wildfires which could reasonably be expected at any one time. During the same period, the techniques of planning for prescribed burns were developed. With the aid of aerial photos, stand maps were prepared for whole blocks destined for prescribed burning. And on the basis of field examinations, prescriptions for burning were written, setting forth the reasons for burning, the time and intensity of fire to be used, the lines to be plowed, and the areas to be excluded from burning.

PIONEER PUBLICATIONS

In 1942 Professor Chapman published his "Management of Loblolly Pine in the Pine Hardwood Region of Arkansas and Louisiana West of the Mississippi River," Bulletin 49. In 1943 Bickford and Curry published as a Station Paper "The Use of Fire in the Protection of Longleaf and Slash Pine Forests." In 1943 the Chief of the Forest Service approved a policy of prescribed burning for longleaf and slash pines and authorized large-scale administrative tests of prescribed burning in loblolly pine forests. Thus, 10 years after the establishment of the Purchase Units, the Forest Service had accepted the ideas of prescribed burning and had developed much of the necessary technique. These developments occurred in spite of the overload of other problems on the foresters, who before 1933 had not had the opportunity to gain any experience in the southern pines.

In 1946 W. G. Wahlenberg published his monumental "Longleaf Pine" in which he set forth in calm professional language the place of prescribed fire in the management of longleaf pine. In 1950 on the Francis Marion National Forest in South Carolina--apparently for the first time on one of the new National Forests--prescribed burning was fitted into a management plan for longleaf and loblolly pines; this plan prescribed the use of fire for seedbed preparation, control of brown spot, fuel reduction, and control of understory

hardwoods. The system provided for even-aged stands of 100's of acres, thinnings, and natural regeneration by shelterwoods.

The State Foresters began about the same time to prepare and issue information to landowners on the uses of prescribed fire and techniques and precautions to be observed in applying fire. They also began to provide on-the-ground professional advice.

They were probably right in presenting the new approach to individual timberland owners before embarking on a campaign of educating the general public. That there might be grounds for their apprehensions that publicity on prescribed burning could adversely affect fire prevention may be borne out by the number of wildfires which occurred during the war years and the 5 subsequent years. From 1941 to 1950, the number of fires on state-protected lands in Region 8 averaged 42,772 each year. The peak of 48,780 occurred during the war year 1943. The lowest number, 27,225, occurred in 1945. During the next decade, 1951 to 1960, the annual average was 58,675 fires, with a peak of 91,938 in 1954, when 2,229,000 acres were burned by unwanted fires. Obviously, whether there was a causal relationship or not, elimination of wildfires had not yet been achieved. The tenor of the Southern Forest Fire Conference of 1956 in New Orleans was a recognition of this fact.

THE SECOND FOREST

In spite of the fires, several million acres of pines in the 20-year age-class now extend from the Carolinas to Texas because they were put there by the fire exclusionists during the period from 1930 to 1950 and kept there by the prescribed burners. The fire exclusionists were not only the foresters and the small crews of regular employees but also the lookouts, the project superintendents, the foremen, and the thousands of CCC boys who fought the intentionally set fires every day of the week including Saturdays, Sundays, Thanksgiving Day, Christmas Day, and Easter Sunday. Someone has aptly named this vast age-class and the old-field pines and the whips now grown to sawlog size as "The Second Forest."

The year 1960 seems to be a suitable stopping place in the history of prescribed burning. During the decade from 1950 to 1960, prescribed burns on the National Forests in the Coastal Plain averaged 250,000 acres annually. In 1960 prescribed burns were conducted on 281,000 acres, and the area burned in wildfires was 12,000 acres. In 1960 Wahlenberg published his "Loblolly Pine" in which he described in adequate detail the usage of prescribed fire in the silviculture of loblolly pine.

During the decade, the progress of tree improvement programs foreshadowed a silvicultural change. The Second Forest is now being clearcut rapidly and efficiently by machines. On the corporate forests, especially, it is being replaced by machine planting of slash pine, increasingly with genetically superior seedlings in even-aged stands of thousands of acres. These plantings are being called "The Third Forest."

CONCLUSION

May I say that I hope forest historians will prepare a thorough history of our profession and business of forestry during the past hundred years in the South--which of course this short sketch does not pretend to do--and that this is done before all of the source material disappears. I believe we owe it to our professional successors to give them a fair and perceptive account of the events of that time, the circumstances surrounding those events, and some insight into the personalities of those who were most instrumental in making things happen.

CURRENT USE AND PLACE OF PRESCRIBED BURNING

Robert W. Cooper
Southeastern Forest Experiment Station
Asheville, North Carolina

Some 2 million acres of forest land in the South are subjected annually to some form of prescription burning. Costs may range from a low of about 10 cents an acre to several dollars or more. The principal prescription is that of hazard reduction--an economical and expedient means of reducing fuel accumulations to a level where high-intensity wildfires are virtually impossible. Other demands met by prescribed fire treatments include (A) control of undesirable understory species, (B) improvement and maintenance of wildlife habitat, (C) seedbed and site preparation, (D) grazing enhancement, (E) control of brown spot on longleaf pine and certain other forest tree diseases, as well as myriad incidental uses. Finally, we have learned that fire (suppression firing) may be the best weapon at our disposal for combatting the large, high-intensity wildfires that defy normal control action.

APPLICATION

Fuel buildups, inherently part of the forest, are composed of vegetative growth and litter accumulations, and they require some measure of control if eventual damage from wildfire is to be minimized. Under most circumstances, prescribed fire offers the most practical and economical means of solving this dilemma for the majority of pine flatlands in the South. Hazard reduction burns are generally carried out during the dormant season when temperatures are low, upper litter moisture is relatively low (8 to 12 percent), lower litter moisture is moderately high (20 percent or more), and winds are steady--conditions that permit us to manipulate and control fire spread and behavior (2). Backfiring (forcing

the fire to spread against the wind) is the most common technique used in hazard reduction burning, although strip, spot, or flank firing may be appropriate in special situations.

Some years ago, we attempted to evaluate the effectiveness of a prescribed burning program in reducing the number, size, and intensity of wildfires in the Southern Coastal Plains (7). Although a higher rate of wildfire occurrence was indicated for "roughs" 3 years old or older, the differences were not great. On the other hand, differences in burned acreage and intensity between the youngest and oldest roughs were extreme. Annual burns ranged from 0.03 percent in the youngest roughs to 0.14 percent in the 5-year-old roughs and to an unexpected 7.00 percent in the roughs to which prescribed fire had never been applied. In addition, all of the project-sized wildfires that occurred in the study area during the 4-year period of observation originated and burned primarily in the oldest roughs. Height of bark char, an indication of intensity, averaged about 2 feet in young roughs, compared with about 20 feet in the older fuels.

As a general rule, most of the pine sites in the South tend to revert to climax types (oak-hickory-gum) with the absence of fire. If these species are permitted to invade and compete with the overstory pine, production is impaired, subsequent regeneration of pine is difficult, and the chances of destructive wildfires remain high. Research trials have repeatedly shown that prescription fires are capable of keeping undesirable vegetation in check while actually enhancing the wildlife habitat--in a single operation. Summer fires, timed to coincide with favorable burning conditions, often can kill back at least half of the invading hardwoods 3 inches d.b.h. and smaller (1). The competition is curtailed while the sprouting vegetation and fruit production increase the food supply available for wildlife populations.

Herbaceous game-food plants are often 10 times as abundant on burned areas as on unburned ones. Legumes, one of the more important plants, are commonly about five times as abundant after burning as before (5). In heavily timbered areas, it is often desirable to create wildlife openings to increase the quantity and availability of game food. This practice, followed by a "hot" prescribed fire, increases seed production by 300 percent and plant abundance by 100 percent (6). This increase, accompanied by the improved availability as a result of litter reduction, makes these openings particularly attractive to quail, turkey, and dove.

The chances of successful germination of pine seed and establishment of seedlings are improved considerably after prescribed burning and the resulting exposure of mineral soil. During heavy seed years, seedbed preparation of any sort may not be necessary in the Coastal Plains and Piedmont pine sites. But when seedfall is only moderate or poor, a situation encountered in 4 out of 5 years, some form of preparation is needed. Fire appears to be the most dependable and economical of all the known treatments for seedbed preparation. It also achieves several management objectives with one application. A recent research trial in Georgia's Piedmont loblolly pine belt showed that twice as many seed were required

to establish a seedling on unburned sites as were required on burned areas (13). Evidence indicates that the beneficial effects of fire treatments persist for at least 1 year. The same story can be told for most of the Coastal Plain pine belt as well.

Cattlemen in the South have known for years that fire is essential if they expect to grow beef on native range. Wiregrasses and principal herbaceous plants of the pine-wiregrass type green up after burning, and cattle are attracted to the fresh food supply. New growth begins soon after burning, averaging about a ton of forage production per acre in 1 year. Levels of crude protein, phosphorus, and calcium are highest in the 3- to 5-month period after burning (9). Winter burning is preferred, as a general rule, in order to increase the availability and usefulness of the early-growing wiregrasses before other species have made substantial growth.

In the absence of fire, total herbaceous cover declines after 6 to 8 years, and the range becomes less desirable for animal use. Although the trend is away from year-round grazing of forest range to the use of improved pasture during the summer and fall, data from studies on the Alapaha range in south Georgia show that cattle seek out burned ranges for supplemental grazing and achieve their best weight gains when access to both improved pasture and forest range is available.

Considerable speculation remains concerning the role of prescribed fire in the control of forest tree diseases, or what we commonly refer to as "sanitation burning." For years, fire has been recognized as the most practical means of controlling brown spot disease (*Scirrhia acicola*) of longleaf pine seedlings. Brown spot is a fungal infection that generally defoliates young plants, saps their vitality, prevents height growth, and eventually kills. Winter burns are recommended at 3-year intervals until the seedlings are about head high (16). Strip headfires are often appropriate. Fire temperatures should be hot enough to scorch all infected needles. This scorching reduces the number of spores that might infect the seedlings the following spring, thereby permitting the development of a full crown with healthy needles.

It is possible that *Fomes annosus* root rot may be kept in check by the judicious use of fire. From all indications, heavy infestations of the rot are commonly found where dense accumulations of litter prevail. Further research is in progress to assess this potential role of fire.

On occasion, fire is still used to enhance logging chances by improving accessibility, to fireproof stands before initiating naval stores operations, for type conversion, or for opening closed cones to release entrapped seed.

Burning as a site preparation hardly seems necessary when mechanical disturbance is achieved with heavy equipment. Nevertheless, the potential role of prescribed fire in the management of pine plantations cannot be overlooked. If mechanical site preparation is complete and thorough, fuel accumulations during the early years of plantation development normally consist of only

grasses and herbs. As the crowns form, needlefall increases, litter buildup begins, and sometime during the plantation's life a hazardous fire condition generally develops (15). Without adequate site preparation, plantations become vulnerable to fire kill and damage almost from the day of establishment. When large, continuous areas of plantations are created, the probability of blowups increases. Cutting operations generally aggravate the situation. Prescribed burning may provide an expedient and economical solution to the problem by building "fuel-free" strips or "checkerboard" blocks of protection (11). In addition, it should enhance the wildlife habitat beneath the crown canopies.

Modern-day technology has failed to come up with a guaranteed scheme of wildfire suppression capable of subduing the blowup. Usually, a change in weather or fuel occurs before positive control action is possible. Man's actions are, for the most part, futile. Yet, we have learned by research trial and experience alike that we have at our disposal one of the most potent forces ever discovered by man--fire itself. Known as suppression firing, this intentional application of fire to speed or strengthen control action on free-burning wildfires may consist of counter firing, burning out, or mopup burning (3). Unfortunately, we have not taken full advantage of this force. We have not become proficient in its use and application. It could, nevertheless, prove to be the most versatile weapon in our arsenal, if we only recognize this fact and develop techniques to exploit its full potential.

DISCUSSION

In brief, then I have attempted to paint a picture of the current use and place of prescribed burning in the South. We might leave it at that. But current use is only part of the picture.

In the few minutes that remain, I would like to address myself to the problems we face in using prescribed fire today. We have learned to define and recognize the symptoms of a forest condition requiring a fire prescription. We have determined the weather and fuel conditions that are needed for a successful treatment. We have developed firing techniques and practices that produce required intensities and behavior (8). We can predict the effects and responses from various burning operations (10). We are learning more and more about the possibilities of using fire as a means of wildfire suppression. Yet, we find that new and troublesome considerations plague us.

Take the case of air quality. As foresters, we are as much concerned about the environment as any other professionals--more so, I hope. The principal products of forest fuel combustion are CO_2, H_2O, CO, and certain hydrocarbons. Most of what we actually see is water vapor. Oxidation processes in the upper atmosphere, which receives short-wave ultraviolet radiation from the sun, convert carbon monoxide to the dioxide with time (17). Most evidence indicates that nearly all of the particulates and many of the gases adsorbed on their surface are washed out by precipitation. Consequently, it is reasonable to assume that most effluents of prescribed

fire that remain suspended in the lower atmosphere are short-lived. They may, in fact, actually be responsible for the washout. Smoke particles act as condensation nuclei that initiate precipitation; soluble gases are dissolved in rainfall and in the oceans; particulates are washed out or fall out as a result of wind and gravity (4). Indeed, the air has a great capacity for cleansing itself. The point I want to make is this: there is, to my knowledge, no evidence to indicate that air quality is permanently impaired in areas where prescribed burning is practiced extensively.

Prescribed fires have been responsible for reduced visibility, dangerous traffic situations on highways and expressways, and the aggravation of existing pollution in centers of population. We must learn to fulfill the objectives of a sound fire prescription without creating associated smoke problems. If we do not, we will be in trouble.

How about other undesirable side effects? Crown scorch and consumption will, of course, result in some growth reduction for a 2-year period. However, the well-conceived and performed prescribed fire will have little effect on the growth of most southern pines. Soil movement is negligible after fire applications on moderate slopes in Piedmont pine stands. In the Coastal Plains, evidence indicates that no serious damage to the soil is encountered as a result of any prescribed burning treatments (12). Mineral elements, nitrogen, and organic matter tend to increase in the surface 4 inches after annual and periodic fires over a 10-year period. No detrimental effect on the physical properties of bulk density, porosity, or percolation rate has been noted (14).

Prescription burning is being applied to some 2 million acres of forest land in the South each year. There may be, in my opinion, another 10 million acres or so in need of burning each year. Why is it not being burned? For a number of reasons, I am sure, but the greatest single one is weather. Many foresters will claim that there just are not enough good burning days each year to get the job done. It has been my experience that generally there are enough such days each year. We simply are not aware of when they exist; predictions of their occurrence are not reliable; or other activities intervene on those days.

Our weather forecasters are doing their best, but apparently their best is not good enough. As a general rule, the elements that concern us most are the ones that are most difficult to predict with any degree of reliability. Wind velocity, persistence, and duration are particularly troublesome. Nothing can botch up a prescribed burn more than a miscalculated estimate of wind. Fire behavior and performance can be diametrically opposite to that desired; chances of escape rise drastically; costs climb rapidly. We often lose more than we gain.

Fuel moisture and relative humidity are also especially troublesome. Local factors can apparently exert enough influence to make broad predictions unreliable. Relationships between fuel moisture and relative humidity are not exact; understory vegetation, aspect, slope, and timber type all have confounding effects.

Improved forecasts are essential if we are to master the problems of smoke management. If nighttime burning is to achieve its potential, reliable predictions of wind and humidity must become a reality. It is not enough to know that we can expect five nights suitable for burning during the season: we must know in advance exactly which nights they will be. We need to know at least 24 hours ahead, not at 6:00 p.m. of the night in question.

I challenge the weather forecasters to tackle this problem. It is not a matter of passing the buck. Rather, I believe its solution can do more to advance the science of prescribed burning than any other single contribution I can think of.

A FINAL WORD

Prescribed fire is not a cure-all. It is simply a tool for correcting some ailments of the forest.

Circumstances exist in which fire is neither desirable nor needed. We burn many acres that do not need treatment in the first place; an even greater acreage, however, goes untreated because we fail to face up to the need or the means of accomplishing the job.

There are, of course, alternative treatments. For the most part, however, they are generally more costly, incur more undesirable side effects, and seldom exhibit the diversity and multiple-purpose achievements of prescribed fire. We cannot afford to overlook good possibilities; neither can we afford to raise management costs far above what they already are today.

Can we afford not to burn? I contend that we cannot, at least as far as the South is concerned. Prescribed burning does have a place in the management of southern woodlands--one of importance and proven need.

LITERATURE CITED

1. Brender, Ernst V., and Cooper, Robert W. 1968. Prescribed burning in Georgia's Piedmont loblolly pine stands. J. Forest. 66: 31-36

2. Cooper, Robert W. 1963. Knowing when to burn. Second Annu. Tall Timbers Fire Ecol. Conf. Proc. 1963: 31-34.

3. _____ 1969. Preliminary guidelines for using suppression fires to control wildfires in the Southeast. Southeast. Forest Exp. Sta., USDA Forest Serv. Res. Note SE-102, 2 pp.

4. Cramer, O. P. 1969. Disposal of logging residues without damage to air quality. U. S. Dep. Com. Weather Bur. Tech. Mem. WR-37, 8 pp.

5. Cushwa, Charles T., Brender, Ernst V., and Cooper, Robert W. 1966. The response of herbaceous vegetation to prescribed burning. Southeast. Forest Exp. Sta., USDA Forest Serv. Res. Note SE-53, 2 pp.

6. Cushwa, C. T., Czuhai, Eugene, Cooper, R. W., and Julian, W. H. 1969. Burning clearcut openings in loblolly pine to improve wildlife habitat. Ga. Forest Res. Counc. Res. Pap. 61, 5 pp.

7. Davis, Lawrence S., and Cooper, Robert W. 1963. How prescribed burning affects wildfire occurrence. J. Forest. 61: 915-917.

8. Dixon, Merlin J. 1965. A guide to fire by prescription. USDA Forest Serv. South. Reg., 32 pp.

9. Hilmon, J. B., and Hughes, R. H. 1965. Fire and forage in the wiregrass type. J. Range Manage. 18: 251-254.

10. Hough, W. A. 1968. Fuel consumption and fire behavior of hazard reduction burns. Southeast. Forest Exp. Sta., USDA Forest Serv. Res. Pap. SE-36, 7 pp.

11. Johansen, R. W. 1968. Fire control considerations in pine plantations. 7th Auburn Forest. Forum Proc. 1968: 14-19.

12. Lotti, Thomas, Klawitter, R. A., and LeGrande, W. P. 1960. Prescribed burning for understory control in loblolly pine stands of the Coastal Plain. U. S. Forest Serv. Southeast. Forest Exp. Sta. Pap. 116, 19 pp.

13. McNab, W. H., and Ach, E. E. 1967. Prescribed burning improves Piedmont loblolly pine seedbeds. Southeast. Forest Exp. Sta., USDA Forest Serv. Res. Note SE-76, 2 pp.

14. Metz, L. J., Lotti, Thomas, and Klawitter, R. A. 1961. Some effects of prescribed burning on Coastal Plain forest soil. USDA Forest Serv. Southeast. Forest Exp. Sta. Pap. 133, 10 pp.

15. Sackett, Stephen S. 1968. Prescription burning in pine plantations. 7th Auburn Forest. Forum Proc. 1968: 19-29.

16. Siggers, P. V. 1934. Observations on the influence of fire on the brown spot needle blight of longleaf pine seedlings. J. Forest. 32: 556-562.

17. Stern, A. C. 1968. Air pollution and its effects. 694 pp. New York-London: Acad. Press.

COMMENTS

The purpose of this first session is to provide an overview of the history and use of prescribed burning in forestry. I will have to admit that I fit more comfortably in the overview category, as I much prefer to speak in generalities than in specifics which might expose the limits of my technical knowledge.

I believe both papers have served the purpose intended--that of setting the stage. My comments will be brief in order to emphasize certain statements and to reorient some of them from the viewpoint of industrial forestry--particularly that of the company for which I work.

I believe we are in serious trouble in regard to our use of prescribed burning. At a recent meeting of an American Plywood Association Ad Hoc Committee on environmental quality, the members attempted to set priorities as far as threats to certain tools and practices of forest management are concerned. Prescribed burning headed the list. We have already seen several southern states move toward legislative regulations on the use of fire, particularly as regards time and place. However, I believe the situation can be saved, and I think this conference holds promise of being extremely helpful in the saving. I have no doubts, however, that we will soon see regulatory legislation to control those who use fire indiscriminantly, without thought to the safety, comfort, and property of others. This symposium can lead to the establishment of the thesis that the benefits of wise use of fire outweigh the benefits of not using it at all.

One cause of our current problem is, of course, ourselves. Of those here who have done much prescribed burning, I doubt that there are many who have not been guilty of accidentally trespassing on another's rights, property, or comfort. Such incidents, which have been given higher visibility by the current spotlight on environmental quality, put us on the defensive. Times have changed. People are no longer as tolerant of accidents and mistakes as they once were, and they are no longer as respectful of institutions and expert opinion.

Let me turn now to Mr. Riebold's paper. As you might expect, I heartily endorse his view of prescribed burning as a useful tool. In fact, it is as important a tool of forestry as are the tools for suppressing wildfires. We should always bear in mind that there would be no southern pine forest if it were not for the rather cataclysmic interruption of a natural sequence of events by either man or nature. And, if we had not used fire as a tool, we would have in some instances suffered intolerable losses of young pine stands to wildfire. Some years ago my company acquired a large tract of land in north Florida. This tract was understocked and barren of reproduction, having been burned for many years during the winter and spring to provide grazing. Our first efforts were directed toward planting and fire control. These efforts proved futile until we conferred with the local residents and set up a system of prescribed burning which provided the desired fresh forage and, at the same time, gave us the option of time and place of burning.

Mr. Riebold has mentioned that with the exclusion of fire in the early 1930's, 10's of thousands of acres of longleaf pine land became restocked with slash or loblolly pines, often with no obvious seed source. After this period, we came to a period when nature was not so generous. Shortly after World War II, mechanical site preparation was introduced to cope with difficult conditions. It has since become routine with many companies after final harvest cuts. Burning was and is an integral part of this site preparation. Whereas the prescribed fire used for other purposes was a rather gentle tool, the fire prescribed as a part of site preparation is often quite the opposite. The aim being to destroy as completely as possible any residual logging slash or vegetation which might interfere with preparation and planting, these fires are, if they achieve the desired end, not gentle. I believe the use of fire for this purpose is a major event in the history of prescribed burning. I might add here that Mr. Riebold's comment concerning the planting of improved slash pine should be expanded to include loblolly pine.

Let me turn now to Dr. Cooper's paper, first to his ordering of the uses of prescribed fire by importance. From the point of view of my company, the principal use is as a part of site preparation prior to planting. I would take exception with his statement that it hardly seems necessary to burn when mechanical disturbance is achieved with heavy equipment. The second most important use is in hazard reduction. Although this ordering of importance may not be true for all, I expect it is true for those who practice the intensive management characteristic of the pulp and paper industry. Burning for hazard reduction can be delayed, but site preparation as a part of a silvicultural system in conjunction with nursery production cannot.

As a part of the prescription for site preparation, fire is not irreplaceable. To achieve approximately the same results, we would, however, have to substitute an additional mechanical treatment. This treatment would cost from $8 to $15 per acre whereas burning in 1970 cost us $0.75 to $1.50 per acre. Although economics may be unimportant to some, cost differences of this magnitude are important to a company planting 35,000 acres a year and to an industry regenerating over a half million acres a year. In the trying times that the wood-using industries have suffered the past year or so, this added cost might make the difference between having a regeneration program and not having one.

In devoting our limited resources more to site preparation than to hazard reduction, we recognize that we are making a trade and accepting a risk. We do try to burn for fuel reduction when tracts of land are in particularly hazardous areas or in a particularly vulnerable condition. We place particular emphasis on lands under lease or when a prior agreement to cut has limited us as to time and the investment is high. Although we do little burning primarily to improve game habitat, we recognize and appreciate this valuable byproduct of prescribed fire.

My last comment has to do with the use of fire in fighting fire. The truest statement made thus far at this Symposium is that modernday technology has failed to come up with a guaranteed scheme

of suppressing blowup wildfires. We still depend largely on nature to bring a change of weather. Since the 1950's, we have not had an extended period of conditions conducive to blowup fires over a wide geographic area. During the last such period, many fledgling foresters had to learn to fight fires the hard way before they became at all effective in suppressing them. In fact, one of their most difficult learning experiences was in using fire to fight fire. Some of the worst fires resulted from well-intentioned backfiring. Thus, to the other benefits of prescribed fire, I would add its use as a training tool. The younger generation of foresters who are in the woods now, and who will be the frontline troops during the next blowup period, will be much better equipped by virtue of the experience they acquire in working with fire under controlled conditions.

J. O. Cantrell
Woodlands Department
Continental Can Company, Inc.
Savannah, Georgia

For more than 300 years, the flatwoods of the Southeastern Coastal Plain were subjected to annual burning. The settlers used fire to clear the ground for farming or to provide better pasture for livestock. How long this period of annual burning persisted is not known, but it probably equalled the tenure of the earliest settlers. Migrating pioneers also carried this custom into the Piedmont and the more mountainous terrain of the West. Lawson in 1714, Catesby in 1722, Bartram in 1773, and Michaux in 1802 made observations on the practice of burning by the Indians and settlers.

Among the first to report on the regeneration of longleaf pine as a result of fire was the English geologist Charles Lyell in 1849 near Tuscaloosa, Alabama. In an early publication, he states: "These hills were covered with longleafed pine, and the large proportion they bear to hardwoods is said to have been increased by the Indian practice of burning the grass; the bark of the oaks and other hardwoods being more combustible, and more easily injured by fire, than most of the pine."

A comment on the possible results of fire exclusion was made in 1889 by a Mrs. Ellen Long, who in an early writing states:

> The annual burning of the wooded regions of the south is the prime cause and preserver of the grand forests of Pinus palustris (longleaf pine) to be found there; that but for the effects of the burnings-----the maritime pine belt would soon disappear and give place to a jungle of hardwood and deciduous trees---the statute books of almost every southern state contain enactments prohibiting the setting of fire to the woods and severe penalties are attached to the violation of the law. There may be sound

reason for such legislation since great loss of property often results from burning forests and buildings. But viewed from a forestry standpoint, we believe the total abolition of forest fire in the south would have meant the annihilation of the great pineries.

The ability of the southern pines, especially longleaf, to regenerate themselves after a fire was recognized by a number of the early foresters. Among these were Charles Mohr in 1906 and D. F. Schwarz and Thornton T. Munger in 1907. Others were H. H. Chapman of Yale University and W. W. Ashe, the Forest Service Dendrologist, the latter espousing the use of fire for the silviculture of loblolly pine. On the other hand, there was strong opposition to any general program of prescribed fire in the forests of the South. For a period of 50 years or more, little progress was made in advancing the cause of prescribed burning.

H. H. Chapman stood out during this period as the primary exponent of prescribed fire. However, many individuals and groups were active in the development of prescribed burning, including public, private, State, and Federal agencies. Although none has a clearcut claim to leadership over the many years involved, there are many who claim Chapman as deserving of the major credit. Since his death, there is no single individual who has led the way. Under the circumstances, a cooperative, coordinated program of prescribed burning appears most desirable, possibly on a regional basis.

There is a great need to standardize terminology. Much of the misunderstanding among individuals (professionals and nonprofessionals alike) appears to revolve around this problem of labels--extending even to the term prescribed burn. With the tremendous national and worldwide interest in the subject of pollution, we must develop clear and meaningful terminology if we are to maintain our position in this highly controversial field.

A solid definition of prescribed burning is: The skillful application of fire to natural fuels under conditions of weather, fuel moisture, and soil moisture that will attain confinement of the fire to a predetermined area and, at the same time 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, or hazard reduction. A basic objective of such burning is to employ fire scientifically in order to realize maximum net benefits at minimum damage and acceptable cost.

The earliest research I know of concerning the burning of loblolly pine was initiated by personnel of the Southern Forest Experiment Station at Lanes, South Carolina, in 1924. This area lies in Williamsburg County north of the Santee River. The program included some research on longleaf pine as well as annual or periodic burns in loblolly pine. A. L. MacKinney published five articles on the results of burning longleaf pine, but inconclusive results on the loblolly pine plots resulted in their eventual abandonment.

Next came the well-known research initiated by the Southeastern Station on the Santee Experimental Forest in Berkeley

County, South Carolina. This program centered around the control of the hardwood understory in loblolly pine stands. When the study began in 1946, the planning and installation were carried out by L. E. Chaiken, K. F. Wenger, Norman Hawley, and W. P. LeGrande under my leadership. Many other people have contributed to the study during the subsequent 25 years. Many of those named above are present at this Symposium, and much of the research that will be described in the following papers has stemmed from this study.

For many years, researchers have studied the use of fire in the southern pines. Thus, present practices are largely supported by research findings. Further modifications or wider application of prescribed fire will assuredly follow, and these will continue to be based on solid research.

Thomas Lotti
USDA Forest Service (Retired)
Arlington, Virginia

I wish to comment briefly on International Paper Company's involvement in the history and use of prescribed burning. My remarks will be in reference to my company's Georgetown region, which includes our lands in east Georgia and North and South Carolina. This land base of more than 900,000 acres was acquired in the early 1940's and the early 1950's during the time, as Mr. Riebold pointed out, when burning of the woods was a common practice in the South. During this period, my company was also increasing its staff of professional foresters.

In retrospect, it is understandable why the logic of the fire exclusionists prevailed over the growing realization that prescribed burning was necessary. Furthermore, during this period the prevailing philosophy was that the land should serve as a giant storehouse to draw from when needed. This philosophy was predicated on the system of natural regeneration, and, perhaps, it accounts for International Paper Company's long delay before beginning its program of prescribed burning. In the early 1960's our philosophy concerning forest land changed. It changed because we realized that our lands must be managed if they are to furnish us with wood and with income on a regular and predictable basis.

Prescribed burning became an integral part of this change. For instance, our prescribed burning in 1964 in this region totalled 24,000 acres. By 1970 this total increased to 60,000 acres, and in 1971 we have scheduled 100,000 acres for such burns. We employ prescribed burning to reduce the hazards of seedbed preparation, to reduce rough and logging areas, to reduce or eliminate unwanted species, for wildlife management, and for many other reasons. We find that, aside from the seemingly heavy schedule of other management activities, many factors hinder us during what seems to be the most desirable period for prescribed burning. It seems to us that two

of the most difficult aspects are, perhaps, the legal liability involved and the impact upon the environment.

Hopefully, this Symposium will provide us with insights which will allow us to surmount these and the many other obstacles that stand in the way of our using this very necessary tool of forest management.

W. C. Sullivan
International Paper Company
Georgetown, South Carolina

EFFECTS OF PRESCRIBED BURNING ON TIMBER SPECIES IN THE SOUTHEASTERN COASTAL PLAIN

O. Gordon Langdon
Southeastern Forest Experiment Station
Charleston, South Carolina

Prescribed fire is a powerful silvicultural tool for controlling composition of vegetation in many of the pine timber types of the Southeastern Coastal Plain. The basic principle involved in this use, at least in this region, is that preferred pine species on their upland sites are fire-dependent at given times in their life cycles and, in effect, are subclimax on the succession scale. On the other hand, many if not most of their competitors are not fire-dependent.

In considering the effect of fire on a particular species, we must look at the direct effect on the tree at different ages or sizes. We also should examine the indirect effect as it creates either beneficial or detrimental conditions for growth or regeneration. Time does not permit our going into very much detail about these indirect effects. My discussion is limited to upland pine sites because, on the basis of present knowledge, prescribed burning does not seem to have a place as a practice in bottomland hardwood sites of the Southeast.

The term "prescribed burning" is often given to fires that clean up the logging residue and nonmerchantable trees remaining after a harvest cut. Because these fires generally are of high intensity and are not intended to be selective in their control of species, I have chosen to exclude them from my talk. I will restrict my discussion to those burns prescribed for timber stands after their regeneration and before their harvest cutting.

In the literature I reviewed for this talk I detected a subtle change in the philosophy of writers before 1941, when the term "prescribed burning" was introduced by Ray Conarro (11), and

of those writing subsequently. Perhaps I have read something into the various writings which was not intended. But it seems to me that the catastrophic fires that occurred early in this century in the Lake States and West led many foresters and other concerned people into thinking that:

> Fires kill. Forest fires kill trees, destroy homes, and take human lives. Therefore, all fires are evil and destructive and they must be prevented at all costs.

Thus, the campaign was on to exclude all fires from all our forests.

But then there were also keenly observant people--botanists, foresters, and others like Mrs. Ellen Call Long, Miss Andrews (1), Max Rothkugel (39), Roland Harper (24), Herbert Stoddard (44), W. W. Ashe (2, 3), and H. H. Chapman (9)--who noted that many fires in the longleaf and loblolly pine types did not cause much damage and that different species were affected differently. In fact, Mrs. Long proposed as early as 1888 that perhaps longleaf pine required fire in its life cycle--a ridiculous idea to many. The editor of Journal of Forestry in 1913 (25), in reviewing Harper's (24) monograph on Alabama's forests, suggested that revival of that theory was an interesting psychological study! Nevertheless, the prescribed use of fire under specified fuel and weather conditions began to be practiced as our knowledge on effects of fire on vegetation began to accumulate.

When we talk about effects of fire we must put the vegetative association into an ecological perspective. Wells (51) pointed out that the Coastal Plain is a remarkable mosaic of plant communities, both successional and climax. Succession would simplify this mosaic were it not for fire, but simplification is probably neither possible nor desirable. Robert Mutch (36) has recently proposed: Many plant species may have not only selected survival mechanisms that are fire-dependent but also inherent inflammable properties that contribute to the perpetuation of these fire-dependent plant communities. He proposes an hypothesis: "Fire-dependent plant communities burn more readily than non-fire-dependent communities because natural selection has favored development of characteristics that make them more flammable".

Many of you are familiar with the characteristic inflammability of longleaf-bluestem types in Mississippi, Louisiana, and east Texas and of longleaf pine-slash pine-wiregrass-sawpalmetto types of southeast Georgia and Florida. This inflammability is true also of the loblolly-shortleaf pine types, of the pond pine types in the Carolinas and Virginia, and of the pitch-shortleaf types in New Jersey. In fact, those recommending prescribed burning in loblolly pine-hardwood types (30, 42) have recognized that to get a prescribed fire to carry and burn cleanly there must be a fairly uniform pine overstory to provide sufficient fuel for a fire to burn. Or, said another way, if hardwoods dominate a loblolly pine-hardwood stand it is difficult and at times impossible to burn except under very droughty and dry conditions. These observations seem to support Mutch's hypothesis. Flammability of fuel is probably also one of the main reasons why prescribed burning as a practice in the southeast is limited to pine types.

This leads us to another question: If pines are more resistant to fire than their hardwood associates, why is this so? Fire kills vegetation by raising temperatures in the living tissue to a lethal level, generally assumed to be about 140° F. (6). Fire may partially or completely kill various parts of a tree--its leaves, buds, branches, roots, or stem cambium (22). Thus, damage can vary, depending on the tissues that are killed. In addition to these direct effects, there may be physiological effects manifested as loss in growth.

Species differ in their reaction to fire because of inherent differences in structure; e.g., bark of different species may vary in both thickness and insulating efficiency. Hare (23) found that, with bark thickness constant, longleaf and slash pines withstood up to twice as much heat as sweetgum, cherry, and holly. He divided the species he tested into five groups in descending order of the fire resistance:

1. Longleaf, slash
2. Loblolly, baldcypress
3. Magnolia, sweetbay
4. Red maple, water oak, dogwood, tupelo gum, river birch
5. Sweetgum, cherry, holly.

EFFECTS OF FIRE ON SOUTHERN PINES

Let us look specifically at the effects of fire on pine. The size of a tree is a factor greatly influencing the damage that a fire of given intensity will do; however, it is by no means the only factor. Other characteristics of the various species are also very important.

Effects in Seedling Stage

Longleaf pine seedlings in their cotyledon stage and during their first year of growth, and to a lesser extent during their second year, can be killed by even a light fire. But, after the second year and while the seedling is still in the "grass" stage, longleaf is highly resistant. Once it starts height growth and when it is between 1 foot and 3 feet tall, however, longleaf is again more vulnerable and may be killed by fire (10, 35).

A high percentage of loblolly and slash pine seedlings are killed by light fire when they are less than 5 feet tall (3, 12). It is considered inadvisable to burn in loblolly and slash stands until they are at least 10 to 12 feet tall (12, 20). Although prescribed burns have been made with only 8 percent mortality in 4-year-old slash plantations that averaged 6 feet in height, such burns are risky (34).

We must distinguish between typical slash pine of north Florida and Georgia and the much more fire-resistant South Florida variety. In a 2-year-old study, an accidental fire burned in plots planted with both varieties. It was found that 23 percent of the South Florida slash survived in the headfires and 56 percent survived in backfires, but less than 1 percent of the typical variety survived either fire. South Florida slash pine sprouts from

dormant buds along the stem and at or near the root collar, especially if the terminal bud has been fire-killed (26). Species that sprout from base of stem can have their tops killed by a fire, and yet the plant may not be completely killed. This is a characteristic of many fire-resistant species.

Longleaf has this capacity to sprout (45). The large buds with their bud-scales and sheaf of needles also provide a high degree of protection to longleaf from all but the most intense fires (6).

Shortleaf and pitch pine seedlings, although easily topkilled by fire, also sprout from dormant buds (45). In a New Jersey study (28), 70 percent of the shade-grown seedlings of both these species sprouted after a prescribed burn if they were vigorous, had well-developed basal crooks, or were more than 3/16 inch in diameter at the root collar. Sprouts from seedlings of shortleaf and pitch pines are fully as desirable as seedlings in both growth and form (28, 37). Bole sprouts are also quite common for both species. In contrast, Virginia and loblolly pines do not sprout from the bole and are much more susceptible to injury or mortality by crown scorch (28, 37). Pond pine seedlings react much like shortleaf and pitch pine in that they sprout prolifically after a light fire. Older pond pine also sprout from the bole and, because of this characteristic, will survive wet-season but not dry-season fires (52).

Prescribed fire indirectly benefits longleaf pine in its grass stage. Siggers (40) first presented data on the damaging effects of brown spot needle blight in retarding height growth of longleaf pine. He later showed (41) that prescribed burning at age 3 and at three-season intervals, or until height growth begins, was beneficial in reducing brown spot infection. Wakeley and Muntz (50) demonstrated the practicability of using prescribed fire in longleaf plantations and the resulting superiority in height.

The effects of fire on pine seedlings up to 5 feet in height may be summarized as follows:

1. Loblolly and the typical variety of slash pines are usually killed outright.

2. Shortleaf, pond, and pitch pines are topkilled, but may sprout from dormant buds.

3. South Florida slash can withstand a light fire and will also sprout at base from dormant buds.

4. Longleaf seedlings, the most fire-resistant of the southern pines, are usually not topkilled; prescribed fire is beneficial by destroying the brown spot needle blight fungus.

Effects on Saplings and Larger Sizes

The more dramatic effects of fire on saplings and larger pines are char or bleeding of the bark, needle scorch and needle consumption. An increasing amount of any of these represents increasing

severity of damage. In fact, needle scorch after a prescribed burn is good evidence that either poor burning techniques were used or weather and fuel conditions were not favorable (29). Ordinarily there should be no crown scorch if all precautions are followed in a prescribed burn. The amount of crown scorch or bark char is related to tree size; i. e., the larger the tree the less the crown scorch and the lower the mortality (14).

How does a fire kill a tree but consume only a small portion of the tree? Does it kill the cambium of the main stem, or is the kill the result of bud damage and needle scorch or consumption? Cooper and Altobellis (13), in an exploratory study with loblolly pine, protected boles of one-third of the trees with asbestos wrap to 6 feet, protected another third with asbestos sheets at base of crown, and left a third unprotected. The authors found that crown damage was apparently more responsible than bole damage for tree kill. Mann and Gunter (33) reached similar conclusions by estimating needle scorch and cambium kill at ground line in a study of 11 areas burned by wildfires in Louisiana. They found that mortality was more closely related to needle scorch than to the extent of cambium kill at ground surface. Ferguson (14) gathered data on wildfires in east Texas which showed that relative crown scorch was as good an indicator of subsequent mortality as was basal damage, but the latter tended to be more subjective.

Summer burns usually have been found more lethal than winter burns (14). Although physiological factors may also be involved, this lethality seems to be related to ambient air temperatures (46). Initial vegetation temperature, which is regulated by air temperature, controls whether a given fire will raise the vegetation temperature to its lethal level (7). Summer burns are usually not recommended as first burns in heavy litter (29).

If a tree survives after its needles are scorched or consumed by a fire, growth loss inevitably follows. Such growth loss is highly correlated with the amount of defoliation (32). Because scorch and needle consumption are related to tree size, more growth loss is usually sustained by smaller trees. A single fire that caused heavy defoliation in longleaf resulted, over about 3 years, in height-growth loss equivalent to 1 year's growth (49). Repeated burns which defoliate would cause additional growth loss.

McCulley's (32) results in a slash pine winter burning study showed after 3 years that height growth was slightly more sensitive to needle scorch than was diameter growth. For example, 3-inch trees with needle scorch of 30 percent or less suffered no diameter-growth loss but had between 15 and 25 percent height-growth loss; a 100-percent scorch of 3-inch trees resulted in a 50-percent growth loss in both diameter and height. Gruschow (21) reported on this study after 5 years and concluded that the diameter and height-growth losses of trees 12 feet and taller were related to whether a backfire or headfire was used. The headfires in litter fuels which resulted in 73 percent crown scorch showed a 20 percent height-growth loss over the unburned plots; trees on the backfire plots with only a 6 percent crown scorch showed no growth loss. Diameter-growth loss was 19 percent for headfire plots and no loss on backfire plots.

Most prescribed burning in older pine stands has shown no growth losses, even under frequent burning, provided there is little or no needle scorch. This has been the case for shortleaf (17), longleaf (49), loblolly (29, 31), and pitch pines (43).

If there are no growth losses, the next question is: Does burning indirectly benefit the overstory pine growth by reducing competition from the understory vegetation? There are conflicting answers. In the Southeastern Coastal Plain, where the growing season rainfall is usually adequate, the reduction of the hardwood understory by prescribed burning in 45-to-60-year-old loblolly pine did not significantly improve the overstory growth (27, 31). In Arkansas and Missouri, where growing season rainfall is often inadequate, increased pine growth resulted after removal of understory hardwoods by herbicides. This suggests that overstory pine would also be benefited by prescribed burning (5, 18, 38, 53).

In loblolly pine at 8 years, Trousdell[1/] showed growth response over a 6-year period that amounted to a 15-percent increase in basal area following the removal of understory hardwoods. The reasons for responses in young and not in older loblolly is not clear, but physical competition between crowns of hardwoods and pine at young ages may be one of the factors involved.

The effects of prescribed fire on saplings and larger pines may be summarized:

1. For a fire of given intensity, the larger trees will have less needle scorch than smaller ones. Prescribed burning in stands less than 12 feet in height is risky.

2. Summer burns are more lethal than winter burns. Headfires will cause more damage to pines than backfires under similar weather and fuel conditions, thus winter backfires are preferred. Also, a winter burn should precede a summer burn.

3. Crown scorch usually results in both diameter- and height-growth losses.

4. Controlling understory vegetation by prescribed burning is not detrimental to overstory pine growth and may at times result in increased pine growth, especially if soil moisture is critical and provided there is no crown scorch.

[1/] Trousdell, K. B. A study of the effect of understory hardwoods on the growth of loblolly pine. Office Rep., Southeast. Forest Exp. Sta., Charleston, S. C. 1966.

EFFECTS OF PRESCRIBED BURNING ON HARDWOODS

As I mentioned earlier, one of the primary reasons for using prescribed fire in upland pines is to favor the pine over understory hardwoods. How are we able to do this? First, the bark of most southern pines has inherently greater heat resistance than hardwood bark. Second, pines have a tendency to outgrow hardwoods on upland sites and can be burned and not damaged while the hardwoods are still small enough to be topkilled. Damage to hardwoods by fire is also highly correlated with tree size, i.e., the larger the tree the less the damage by a fire of given intensity (4, 16). In prescribed burning for hardwood control the objective must be to use fire under such weather and fuel conditions that it will do little or no damage to the pine. The thrust of most work in prescribed burning in the South has been toward finding the type of fire and conditions which will do the least damage to pine and the most damage to the understory hardwoods.

Let's look at some effects of the type (headfire vs. backfire), season, and frequency of burns (annual, biennial, and periodic) on understory hardwood vegetation.

Topkill of Hardwoods

Headfires, because of their greater intensity, generally will topkill more stems of all species than will backfires; summer fires, because of higher air temperatures, also topkill more stems than winter fires; small stems are more easily topkilled than larger stems (4, 15, 30). Stems smaller than 1½ inches usually suffer 80-100 percent topkill in a single winter fire; the topkill drops to between 10-30 percent for 4-inch sizes. Sweetgum is consistently more susceptible than oaks in all diameter classes (4, 15, 16). Sweetgum and oaks also tend to show a difference in topkill between seasons, with summer burns having the highest rate, but the topkill of oaks may be more variable and in some cases not significant (15). Except for a few stems which may be completely killed, most hardwoods will sprout at the base after a winter fire (15).

Complete Kill of Hardwood

Periodic winter prescribed burns--although they topkill hardwoods in diameter classes up to about 4 inches--completely kill only a relatively small number of rootstocks (3, 16, 29). Neither do single summer burns completely kill large numbers of hardwood stems. In studies in South Carolina (30) and Arkansas (19), a single summer burn killed less than 10 percent of bayberry, blackgum, sweetgum, and a mixture of oaks; in east Texas the complete kill of oaks from a single summer burn was similar, but the complete kill of sweetgum was about 40 percent.

Now the question arises: What about effects of repeated annual burns, both summer and winter? In a South Carolina study, four annual summer burns eliminated 50 percent more small hardwood stems and 66 percent more shrubs than did four annual winter burns (8). In another study in South Carolina, 100 percent of bayberry, and 65 percent of the blackgum were completely killed after seven annual summer burns. Two biennial summer burns killed about half

as many of the same species as four annual burns when these frequencies were compared (30). In a similar comparison in south Arkansas, Grano (19) found that biennial summer fires were effective in killing rootstocks of oaks but not of gums or other species. Presumably, repeated summer burning, when food reserves in the root are lowest, gradually reduce vigor and kill the plant (8, 42).

How long lasting is the effect of a prescribed burn or burns on hardwoods? Evidence indicates that hardwood vegetation recovers to its previous state from a single summer or winter burn in 5 to 7 years. In a Virginia coastal plain study, the recovery of hardwood and shrubby vegetation was measured 2, 4, and 6 years after a winter burn was followed by either one, two, or three annual summer burns, all of which preceded a harvest cut of loblolly pine. The shrubby vegetation recovered after 4 years (47), but differences in hardwood vegetation were still apparent after 6 years (48). What seemed to have happened was that pine reproduction captured the space formerly occupied by the hardwoods because total mass of vegetation produced was about equal after 6 years (48).

CONCLUSIONS

I have reviewed the effects of prescribed burning on timber species growing in the pine types of the Southeastern Coastal Plain.

Prescribed burning, if used properly, can effectively influence the amount and size of the hardwood component in pine stands. Prescribed burning also has a place in controlling brown spot needle blight on longleaf pine in its seedling stage. Little damage or loss in growth results from a prescribed burn in pine if needle scorch does not occur. Except for longleaf pine and to a lesser extent shortleaf and pitch pines, the earliest a prescribed burn can be used without a great deal of risk or damage is after the stand is 12 or more feet tall or about 8 years of age (less on better sites). In pine stands where hardwoods are a problem, winter prescribed burns at 5-to-8-year intervals will usually keep the hardwoods small during the rotation. Just prior to harvesting the stand, a series of two or three annual summer burns will further reduce the vigor, size, and amount of hardwood component, thereby preparing the area for the next rotation.

LITERATURE CITED

1. Andrews, E. F. 1917. Agency of fire in propagation of longleaf pine. Bot. Gaz. 64: 497-508.

2. Ashe, W. W. 1910. Management of loblolly and shortleaf pines. Soc. Amer. Forest. Proc. 5: 84-100.

3. _____ 1915. Loblolly or North Carolina pine. N. C. Geol. & Econ. Surv. Bull. 24.

4. Brender, E. V., and Cooper, R. W. 1968. Prescribed burning in Georgia's piedmont loblolly pine stands. J. Forest. 66: 31-36.

5. Bower, D. R., and Ferguson, E. R. 1968. Understory removal improves shortleaf pine growth. J. Forest. 66: 421-422.

6. Byram, G. M. 1948. Vegetation temperatures and fire damage in the southern pines. USDA Forest Serv. Fire Contr. Notes 9(4): 34-37.

7. _____ 1958. Some basic thermal processes controlling the effect of fire on living vegetation. USDA Forest Serv. Southeast. Forest Exp. Sta. Res. Notes 114, 2 pp.

8. Chaiken, L. E. 1952. Annual summer fires kill hardwood root stocks. USDA Forest Serv. Southeast. Forest Exp. Sta. Res. Notes 19, 1 p.

9. Chapman, H. H. 1926. Factors determining natural reproduction of longleaf pine on cutover lands in LaSalle Parish, Louisiana. Yale Univ. Forest. Sch. Bull. 16, 44 pp.

10. _____ 1947. Results of a prescribed fire at Urania, Louisiana on longleaf pine land. J. Forest. 45: 121-123.

11. Conarro, R. M. 1942. The place of fire in southern forestry. J. Forest. 40: 129-131.

12. Cooper, R. W. 1965. Prescribed burning and control of fire, pp. 131-137. In A guide to loblolly and slash pine plantation management in Southeastern USA. Ga. Forest Res. Counc. Rep. 14.

13. _____, and Altobellis, A. T. 1969. Fire kill in young loblolly pine. USDA Forest Serv. Fire Contr. Notes 30(4): 14-15.

14. Ferguson, E. R. 1955. Fire-scorched trees--will they live or die? La. State Univ. Sch. Forest. 4th Annu. Forest Symp. Proc. 1955: 102-113.

15. _____ 1957. Stem-kill and sprouting following prescribed fires in a pine-hardwood stand in Texas. J. Forest. 55: 426-429.

16. _____ 1961. Effects of prescribed fire on understory stems in pine-hardwood stands of Texas. J. Forest. 59: 356-359.

17. Garin, G. I. 1965. Frequent winter fires do not damage large pines. Auburn Univ. Agr. Exp. Sta. Highlights Agr. Res. 12(1): 14.

18. Grano, C. X. 1970a. Small hardwoods reduce growth of pine overstory. South. Forest Exp. Sta., USDA Forest Serv. Res. Pap. SO-55, 9 pp.

19. _____ 1970b. Eradicating understory hardwoods by repeated prescribed burns. South. Forest. Exp. Sta., USDA Forest Serv. Res. Pap. SO-56, 11 pp.

20. Gruschow, G. F. 1951. Effect of winter burning on slash pine growth. South. Lumberman 183(2297): 260, 262, 264.

21. _____ 1952. Effects of winter burning on growth of slash pine in the flatwoods. J. Forest. 50: 515-517.

22. Hare, R. C. 1961. Heat effects on living plants. USDA Forest Serv. South. Forest Exp. Sta. Occas. Pap. 183, 32 pp.

23. Hare, R. C. 1965. Contribution of bark to fire resistance of southern trees. J. Forest. 63: 248-251.

24. Harper, R. M. 1913. Geographical report on forests. Geol. Surv. Ala. Monogr. 8, Econ. Bot. Ala. Part I, 222 pp.

25. Howe, C. D. 1913. Review of R. M. Harper: Geographical report on forests. J. Forest. 11: 540-546.

26. Ketcham, D. E., and Bethune, J. E. 1963. Fire resistance of South Florida slash pine. J. Forest. 61: 529-530.

27. Klawitter, R. A. 1966. Diameter growth of mature loblolly pine unaffected by under-story control. South. Lumberman 213(2656): 154-155.

28. Little, S., and Somes, H. A. 1956. Buds enable pitch and shortleaf pines to recover from injury. USDA Forest Serv. Northeast. Forest Exp. Sta. Pap. 81, 14 pp.

29. Lotti, T. 1960. The use of fire in the management of coastal plain loblolly pine. Soc. Amer. Forest. Proc. 1959: 18-20.

30. _____, Klawitter, R. A., and LeGrande, W. P., Jr. 1960. Prescribed burning for understory control. USDA Forest Serv. Southeast. Forest Exp. Sta. Pap. 116, 19 pp.

31. McClay, T. A. 1955. Loblolly pine growth as affected by removal of understory hardwoods and shrubs. USDA Forest Serv. Southeast. Forest Exp. Sta. Res. Notes 73, 2 pp.

32. McCulley, R. D. 1950. Management of natural slash pine stands in the flatwoods of south Georgia and north Florida. U. S. Dep. Agr. Circ. 845, 57 pp.

33. Mann, W. F., Jr., and Gunter, R. 1960. Predicting the fate of fire damaged pines. Forests & People 10(1): 26-27, 43.

34. _____, and Rhame, T. 1955. Prescribed burning planted slash pine. USDA Forest Serv. South. Forest Exp. Sta. Res. Notes 96, 2 pp.

35. Maple, W. R. 1969. Prescribed burning in longleaf forests. Ala. Forest Prod. 12(7): 67, 69.

36. Mutch, Robert W. 1970. Wildland fires and ecosystems--a hypothesis. Ecology 51: 1046-1051.

37. Perry, G. S. 1942. Recovery of shortleaf and Virginia pines after forest fire. Tenn. Val. Auth., Dep. Forest Rela. Tech. Note 3, 2 pp.

38. Rogers, N. F., and Brinkman, K. A. 1965. Shortleaf pine in Missouri: Understory hardwoods retard growth. Cent. States Forest Exp. Sta., USDA Forest Serv. Res. Pap. CS-15, 9 pp.

39. Rothkugel, Max. 1907. Forest management in southern pines. Forest Quart. 5: 1-10.

40. Siggers, P. V. 1932. The brown spot needle blight of longleaf pine seedlings. J. Forest. 30: 579-593.

41. _____ 1934. Observations on the influence of fire on the brown spot needle blight on longleaf pine seedlings. J. Forest. 32: 556-562.

42. Silker, T. H. 1961. Prescribed burning to control desirable hardwoods in southern pine stands. Tex. Forest Serv. Bull. 51, 44 pp.

43. Somes, H. A., and Moorhead, G. R. 1950. Prescribed burning does not reduce yield from oak-pine stands of southern New Jersey. USDA Forest Serv. Northeast. Forest Exp. Sta. Res. Pap. 36, 19 pp.

44. Stoddard, H. L. 1935. Use of controlled fire in southeastern upland game management. J. Forest. 33: 346-351.

45. Stone, E. L., Jr., and Stone, M. H. 1954. Root collar sprouts in pine. J. Forest. 52: 487-491.

46. Storey, T. G., and Merkel, E. P. 1960. Mortality in a longleaf-slash pine stand following winter wildfire. J. Forest. 58: 206-210.

47. Trousdell, K. B., and Langdon, O. G. 1967. Disking and prescribed burning for loblolly pine regeneration. J. Forest. 65: 548-551.

48. _____, 1970. Disking and prescribed burning: Sixth-year residual effects on loblolly pine and competing vegetation. Southeast. Forest Exp. Sta., USDA Forest Serv. Res. Note SE-133, 6 pp.

49. Wahlenberg, W. G. 1946. Longleaf pine. Charles Lathrop Pack Foundation, Washington, D. C. 429 pp., illus.

50. Wakeley, P. C., and Muntz, H. H. 1947. Effects of prescribed burning on height growth of longleaf pine. J. Forest. 45: 503-508.

51. Wells, B. W. 1942. Ecological problems of the southeastern United States coastal plain. Bot. Rev. 8: 533-561.

52. Wenger, K. F. 1965. Pond pine (Pinus serotina Michx.), pp. 411-416. In Silvics of forest trees of the United States. USDA Agr. Handbook 271.

53. Zahner, R. 1958. Hardwood understory depletes soil water in pine stands. Forest Sci. 4: 178-184.

COMMENTS

I think it is worth noting Mr. Langdon's point about summer fires being more effective than winter fires because of higher ambient air temperature as well as the physiological activity of the tree. But also, we find in a number of studies that vegetation temperature in the summertime may be significantly higher than that of the ambient air temperature due to solar radiation. On very hot days in the Southeast this vegetation temperature may be just a few degrees below the lethal temperature of 140 degrees. You can see that it doesn't take much heat to raise the vegetation temperature to the lethal point, and this is why summertime burning kills a lot of trees.

Also, I think an obvious point in prescription burning should be noted--a steady wind is necessary. It is not only the direction of the wind that is essential, but its speed also is essential--probably not less than 3 miles an hour. To dissipate the convection so it won't rise vertically and scorch the needles of pine trees and perhaps kill them, the burning should not be done on a calm day.

I think we should further note that damage to overstory pines is always quite severe where a headfire meets a backfire. If a headfire is being used at all, the firebreak should be burned out completely with the backfire before the headfire ever reaches that point. Some of you may have seen such fires meeting, and the convection energy is terrific and will scorch the crowns and kill them.

I must also mention some observations made by Tom Lotti some years ago. When he was conducting summer burns in mature loblolly pine trees, he found cambial kill just at the ground level and below. This is where the thick bark on older pine trees decreases to almost nothing at the ground line and the roots. In mature stands there is usually a buildup of debris at the bottom of the tree, due to bark sloughing and accumulation of litter, and fire will be held at the base long enough to give considerable cambial kill to large trees, particularly in summer fires.

To say that an average winter fire will kill hardwood trees an inch and a half in diameter is quite misleading, but we use it as a guide. But this depends upon the amount of fuel, wind conditions, and weather conditions. So I think that future work on this particular subject--the effect of fire on vegetation--should get into the area of quantitative measurements; i.e., the energy output. Such knowledge related to the fuel moisture and quality and atmospheric conditions will give a better guide in determining how we can prescribe burn without killing the trees we want to save and kill those that we want to kill.

L. E. Chaiken
School of Forestry
Duke University
Durham, North Carolina

EFFECTS OF FIRE ON WILDLIFE AND RANGE HABITATS

E. V. Komarek
Tall Timbers Research Station
Tallahassee, Florida

There is abundant evidence, both experimental and observational, that fire is essential in the management of wildlife, game, range animals, and plants in the southeastern pine forests, grasslands, and adjacent wetlands. Ecologically, fire has been a natural force affecting these communities long before man appeared on the scene. All living things respond to certain biological and ecological laws or principles that involve the need for change, continuity, evolution, companionship, diversity, succession, competition, and the recycling of natural waste. The relationship of fire to these laws must be recognized and understood if we are to interpret and evaluate the effects of fire on wildlife and range habitat.

The fire ecology and fire management of the habitat of bobwhite quail (Colinus virginianus) will be discussed in relation to these laws as an example of how and why fire affects wildlife and range habitats in the southeastern forest and grassland communities. Although emphasis will be on the bobwhite, the discussion will relate to the ecology of the entire forest-grassland complex that once covered the Coastal Plain from Virginia to east Texas.

A great deal is known about the bobwhite, its habits and management. The classic studies of Herbert L. Stoddard reported in "Bobwhite Quail, Its Habits, Preservation, and Increase," (10) and in the report on the cooperative quail study association (11) led the way. Since that time, many investigators have added to our knowledge about this foremost game bird (9).

All these studies emphasize that the habitat of the bobwhite is formed by the grasses, forbs, herbs, legumes, and bushes. Although trees do furnish food at times, they are not really necessary, and quail can live without the pine overstory. The key to the survival of the bobwhite is the grassland--not the forest. If properly managed, however, the pine forest can be economically and aesthetically valuable in quail programs. In fact, some of the finest quail hunting is found where the pine forest and quail grassland have been closely integrated in a management program that benefits both. Fine quail hunting has been developed to the point where 30 to 35 coveys per shooting day can be found with regularity throughout the season. This is true, however, only where controlled burning is regularly conducted.

The type of wildlife management first suggested by Stoddard consists of manipulating the habitat, with emphasis on the habitat rather than on the wildlife. This type of management benefits a great many animals and plants. Stoddard recognized that the bobwhite did not live alone, and that it was but one of many animals that lived in close association.

Our forest-grassland community must be recycled, kept open or park-like, otherwise plant succession would soon eliminate the park-like effect of southern pine forests. They would quickly develop into brush-choked jungles and eventually into hardwood forests. In the process, the grassland would be lost and the bobwhite eliminated. In some regions, such as the Thomasville-Tallahassee redhill country, this successional change can occur so rapidly on good soils that the grassland and its inhabitants can disappear or be replaced in from 3 to 6 years of fire exclusion. Fire prevents this change, it renews the grassland, cleans up waste and refuse, keeps bushes pruned, eliminates dense shade, and recycles the minerals. Through burning, the pine-grassland is kept in a youthful stage of plant succession productive of quail and other wildlife.

The southeastern pine forest-grassland has been described by Wells (13), Stoddard (10, 11), and others. The relationship of these grasslands and fire has also been well discussed by many investigators in the past ten Tall Timbers Annual Fire Ecology Conferences. Some 140 speakers have discussed the relationship of fire to various plant and animal communities in many parts of the world. Without exception they have pointed out that grasslands cannot compete successfully unless the dead grasses are removed, the bushes pruned, and shade is limited, except in very rare instances.

The bobwhite, like all living things, must have a regular and properly balanced food supply. Such nutritional requirements as protein, calcium, phosphate, carbohydrates, and fats must be available in varying amounts throughout the year. The food must be of such size, shape, and structure that it can be utilized by the quail. Quail and other grassland birds are weak scratchers, so food must not be covered up by accumulations of dead grass and other litter. These are all obvious food requirements, but I emphasize them for their importance is too often disregarded by

both sportsmen and wildlife managers. The bobwhite cannot successfully live and reproduce properly without a great variety of food; thus, even diet is regulated by the basic rule of diversity.

The most critical times in the quail's life are during mating and egg-laying periods and during the first few weeks as chicks. It is particularly important that the birds have a diet high in protein calcium, and phosphate during these periods, and that they have variety and abundance. The pine-grassland, if properly managed with fire, produces such requirements for the bobwhite and associated wildlife. If fire is excluded, conditions may change very rapidly, within only 3 or 4 years in some places, and the conditions become such that the quail cannot live and reproduce successfully in any appreciable numbers.

Stoddard's study showed that quail fed on more than 300 different kinds of seeds in the Tallahassee-Thomasville region alone. Further studies have added considerably more species. These seeds are predominantly of grasses, and such associates as sedges, forbs, herbs, and the annual and perennial legumes. These are mainly fire-adapted plants in that they cannot live under heavy accumulations of dead grass, pine-needle litter, hardwood leaves, etc., and this must be removed or they eventually die. They are also sun-seeking plants and they cannot live in dense shade. Fire removes this litter and lets in the sunlight.

Thus, the most obvious effect of fire on the bobwhite habitat is the interruption of the plant succession so that the grassland remains a grassland, not a bush-land or hardwood jungle or forest. There are many complex and important changes that take place when such a habitat is burned. The old accumulation and waste is oxidized by fire into fertilizer rich in calcium, phosphate, potash, and other necessary minerals. At the same time, the burning literally cleanses the habitat of potential disease and insect pests. Fire is used for both of these sanitation purposes in the commercial production of many grassland seeds. Fire also stimulates some of these plants to greater seed production and over 20 percent higher yields of seed have been reported from the proper use of fire in commercial production of certain grass seeds (7).

Fire prepares the mineral seedbed that is needed for proper germination and growth of annuals, biennials, and perennials of most of the multitude of species that occur in these pine-grasslands The burning removes the litter and permits the seeds to come in contact with mineral soil. The germinating and juvenile plants must have freedom from competition of older individuals, and they must have sunlight. With some seeds, the heat from the fire assists in germination by cracking the seed coat. In others, the rainfall percolating through the ash dissolves the inhibitors on some seeds so that they can germinate.

Although seeds are an important part of a quail's diet, the insect and other invertebrate life in these fire-adapted grasslands is even more important. The adult quails must have diets high in protein and such minerals as calcium and phosphate during the breeding period. Generally a diet of over 20 percent protein is

necessary for quail to lay productive eggs. The chicks must have diets exceedingly high in protein, calcium, and phosphate. Stoddard's investigations showed that the hen quail diet is high in insects during the breeding period, and that for the first 2 or 3 weeks the chick's diet is practically all insects and other invertebrates. Stoddard listed more than 465 species of insects in the diet of the bobwhite in the summer months.

Studies now being conducted at the Tall Timbers Research Station show that the effect of fire on the quail habitat is important for the production of desirable insect and other invertebrate life that form the basic protein foods of the bobwhite at the breeding period. These studies may well prove that the insect and associated invertebrate animals which live in these fire-grasslands are even more important to the bobwhite than the plants and seeds on which the quail feeds. Grasshoppers are extremely important in the diet of quail and many other animals, such as the grey fox. If the grassland is not maintained, the numbers as well as the variety of species of grasshoppers decrease. Certainly there are few grasshoppers in dense hardwood thickets or forests. The proper use of controlled burning produces an environment conducive to the production of this desirable group of insects.

Although the foregoing discussion has dealt largely with the effect of fire on the quail habitat, I re-emphasize that this habitat is not only utilized, but is also necessary for a large variety of other animals and plants. Among them are such varied birds as the pine-woods sparrow (Aimophila aesivalis), a grassland inhabitant. The endangered species, the Red-cockaded Woodpecker (Dendrocopos borealis) is primarily an inhabitant of park-like forests, not jungle. The variety and beauty of the many flowering plants of this forest-grassland community is great. They range from many species of native orchids, such as the yellow-fringed orchid (Habenaria ciliaris) which, with proper fire management, literally carpets the floor of the pine forest, to such bog-growing plants as the pitcher plants (Sarracenia sps.).

The fire-maintained grassland is also the natural habitat of many of our most beautiful butterflies. Most of our native earthworms (Diplocardia sps.) require a fire-maintained grassland. A million dollar industry of one such species (D. mississipiensis) is based on the proper use of fire in the Apalachicola National Forest in Florida. Studies now being conducted at Tall Timbers Research Station are showing that many desirable species of invertebrates are inhabitants of fire-adapted environments. Many of our insect problems in both forest and farm management may have been caused or at least encouraged by past policies of fire exclusion.

The beneficial effect of fire on range habitats for wild herbivores as well as domestic livestock has been amply documented. The Indians of the South used fire to attract animals to the new growth on a "green burn." The early cattleman, recognizing the preference of cattle for the green flush of young and tender grass, used fire literally as a fence on the open range. Sections were burned at periodic intervals and the cattle moved from one burn to another of their own volition.

In their report on burning and grazing in the Coastal Plain forests (3), Halls, Southwell, and Knox showed that cattle spent 85 percent of their grazing time in spring and summer on areas that had been recently burned. They also showed, as Biswell (1) had previously, that protein content of burned range in the spring was double that of unburned range, and that cattle on burned ranges gained two to three times more than those grazing on unburned range.

Experiments at the McNeill Experiment Station in southern Mississippi also showed that cows gained more on burned range than on unburned range (12). Hilmon and Hughes (4) reported that annual forage production on burned plots was double that on unburned plots, that protein, phosphorus, and calcium were higher in spring forage on burned plots. Cushwa, Hopkins, and McGinnes have shown that legumes benefited from burning (2).

In a report on fire ecology of canebrakes, Hughes (5) showed that, with periodic fire and carefully regulated grazing, cane is one of the most productive grazing types in the United States.

In more recent studies in Texas, it was also found that burning increased the production of and cattle preference for weeping lovegrass (6).

Lemon (8) has reported on the similarity of the effects of fire on range habitat in the southeastern United States and Central Africa, and he found richer flora and improved nitrogen cycling in both areas when light burning and moderate grazing were practiced.

The response of grasslands to fire is not limited to the southeast; it is a world-wide phenomenon. I have personally observed the effect of fire on the tension zones between grasslands, bush-lands, and forest from southern Mexico to Alaska and the Yukon, from Nova Scotia to British Columbia, in east and southern Africa, and in Australia. The effect is essentially the same--fire, when properly applied, favors grasslands over bush or forest. Likewise, when the burn flushes or greens up with new vegetation, it has a very strong attraction for many species of animals, ranging from small rodents to elephants, from small passerines to ostriches.

There are, of course, certain environments where natural fire plays a very little part, for example, the tropical evergreen forests and the northern tundra. The southeastern pine forests, however, are one of the world's best examples of a fire-adapted community of plant and animal life. Furthermore, the use of prescribed fire in the southeastern forests is an outstanding example of how fire management benefits the natural wildlife and range complex and improves management of the forests so that timber products can be harvested practically and economically. When properly managed, the southern pine forests are the best examples of man working with nature and with fundamental ecological principles to obtain what he needs from his natural environment.

If man interferes in the fire environments through fire exclusion it would be followed by a successional elimination of

many valuable species of wildlife, plants, and trees. This could include the pine forest itself, which might be eliminated by disastrous wildfires.

The disappearance of the heath hen (Tympanuchus C. cupido) is a good example of species elimination through fire exclusion. In the early 1900's, the last of the population was literally starved out of existence by a rigid policy of total fire exclusion in Martha's Vineyard, Massachusetts. The grassland habitat of the heath hen had been destroyed by invasion of bushes and trees when fire was excluded. Without the grasslands, the food supply, both plant and insect disappeared, and the birds starved to death. Ironically, the last few survivors were said to have been killed by a disastrous wildfire. The major damage, however, had already occurred.

Much of southeastern wildlife, including the quail, could suffer similar fates on our forested lands, if we excluded fire completely.

SUMMARY

1. The major game and wildlife habitats and the natural range for livestock in the South are grasslands and the early stages of bushland. These plant communities or habitats have evolved in direct response to lightning fires before man. They must have various frequencies and intensities of fire to exist.

2. These habitats can be maintained by controlled burning. This kind of fire management has been successfully demonstrated on many thousands of acres of southern lands. This man-directed recycling of the grassland and associated elements is in tune with nature. This management of a natural phenomena is within those natural ecological "laws" mentioned earlier; change, continuity, diversity, evolution succession, competition and the recycling of waste or the refuse after death.

3. Properly managed fire will keep the bush-land from encroaching upon the grassland. Pines, such as longleaf, slash, and loblolly, are all adapted to various frequencies of fire by nature.

4. The recycling with fire of the grassland maintains a high diversity of flora, particularly in the legume family.

5. The forage or browse on burned areas is high in protein and phosphorus during the spring of the year when these elements are most needed by both wildlife and range animals.

6. Burning maintains a high population of those species of insects that are needed by such birds as the bobwhite during the breeding period of the quail. Insects have a very high analysis in protein, calcium, phosphorus, and many other minerals.

7. Without proper fire management and the use of controlled burning, our southern pine forest-grassland complex of trees,

grasses, legumes, wildflowers, game, and desirable wildlife cannot exist. There is no substitute for fire in environments that have evolved ecologically in the course of thousands of years where fire was a natural component of the environment.

LITERATURE CITED

1. Biswell, H. H., Shepherd, W. O., Southwell, B. L., and Boggs, T. S., Jr. 1943. Native forage plants of cutover forest lands in the Coastal Plain. Ga. Coastal Plain Exp. Sta. Bull. 37, 43 pp.

2. Cushwa, C. T., Hopkins, M., and McGinnes, B. S. 1970. Response of legumes to prescribed burns in loblolly pine stands of the South Carolina Piedmont. Southeast. Forest Exp. Sta., USDA Forest Serv. Res. Note SE-140, 6 pp.

3. Halls, L. K., Southwell, B. L., and Knox, F. E. 1952. Burning and grazing in Coastal Plain forests. Ga. Coastal Plain Exp. Sta. Bull. 51, 33 pp.

4. Hilmon, J. B., and Hughes, R. H. 1965. Forest Service research on the use of fire in livestock management in the South. Fourth Annu. Tall Timbers Fire Ecol. Conf. Proc. 1965: 260-275.

5. Hughes, R. H. 1966. Fire ecology of canebrakes. Fifth Annu. Tall Timbers Fire Ecol. Conf. Proc. 1966: 149-158.

6. Klett, W. E., Hollingsworth, D., and Schuster, J. L. 1971. Increasing utilization of weeping lovegrass by burning. J. Range Mgmt. 24(1): 22-24.

7. Komarek, E. V. 1965. Fire ecology--grasslands and Man. Fourth Annu. Tall Timbers Fire Ecol. Conf. Proc. 1965: 169-220.

8. Lemon, P. C. 1967. Effects of fire on herbs of the southeastern United States and central Africa. Sixth Annu. Tall Timbers Fire Ecol. Conf. Proc. 1967: 113-127.

9. Rosene, W. 1969. The Bobwhite Quail, its life and management. Rutgers Univ. Press, New Brunswick, N. J. 418 pp.

10. Stoddard, H. L. 1931. The Bobwhite Quail, its habits, preservation, and increase. Charles Scribner's Sons, N. Y. 559 pp.

11. _____, Beadel, H. L., and Komarek, E. V. 1961. The cooperative quail study association. Tall Timbers Res. Sta. Tallahassee, Fla. 500 pp.

12. Wahlenberg, W. G., Greene, S. W., and Reed, H. R. 1939. Effects of fire and cattle grazing on longleaf pine lands as studied at McNeill, Miss. U. S. Dept. of Agric. Tech. Bull. 683, 52 pp.

13. Wells, B. W. 1932. The natural gardens of North Carolina, Chapel Hill. Univ. of North Carolina Press. 457 pp.

COMMENTS

Mr. Komarek did a very fine job of laying out some of the relationships between pineland management, pineland ecology, fire, and grazing. He pointed out that, when skillfully done, grazing in a pine community can actually enhance the production of benefits from grasslands both from wildlife and from cattle and at the same time not be detrimental to the production of pine. What he's talking about, of course, is a synergistic effect in a positive way. What we lose when we talk about a single product is any opportunity to capitalize on positive synergisms.

I think that before this afternoon is out and certainly, before tomorrow is out there will be some discussion of the alternatives to management or control of pine communities with fire. I think it is very important that this conference address itself to these questions.

In the matter of quail, and I'm speaking here from the wildlife standpoint, they are but one species and the question of mast does not really come out. I know that many biologists over the years have been concerned about maintaining a hardwood component for mast production purposes. When you talk about quail management only lack of mast may not be a problem but if you bring in turkeys, squirrels, and other species, then you've got quite a different complex to consider.

Thomas H. Ripley
Tennessee Valley Authority
Knoxville, Tennessee

MANAGING FOREST LANDSCAPES:

IS PRESCRIBED BURNING IN THE PICTURE?

George Meskimen
Southeastern Forest Experiment Station
Forest Resources Laboratory
Lehigh Acres, Florida

What does prescribed burning do to the quality of forest landscapes? Well first, you may logically ask, what is quality in a forest landscape? I can only answer that it's a lot like love--we can't define it or measure it, but we sure know when we've got it and we get more of it by mastering a few basic principles which amateurs apply as successfully as professionals.

Therefore, supported only by the fact that I have the floor, I'll declare that land managers can become landscape managers merel by utilizing four simple concepts: Create variety by arranging vegetation types so their edges form naturalistic patterns.

Peace! Don't turn off yet. I agree with you that variety seems as abstruse as perception theory; and there are as many vegetation types as there are ecologists; and edge effect is something mystic that wildlifers talk about; and naturalistic patterns sound suspiciously like consulting fees for landscape architects.

Sorry, but I can't make it that heavy. Howard Orr boils it down to just two words--nature faking. And it's so intuitive that chair swivelers and stump stompers alike can be instant experts--programming the scenic impact of every land manipulation, includin prescribed burning.

VARIETY--THE "CHARACTER" IN THE CHARACTERISTIC LANDSCAPE

Let's tackle that first concept, variety, as I've been able to parasitize from Howard Orr. If you came to this symposium from another region, you've probably already attuned to the flat terrai

and expansive vegetation types that characterize the Southeastern Coastal Plain. Despite your short exposure you could easily point out views that strike you as better or worse than the average view in the Coastal Plain. All regions have characteristic landscapes to which viewers attune, and all are vast mosaics--chunks of plus scenery and minus scenery scattered among a lot of ordinary scenery.

Plus scenery usually has the quality of variety--contrasting landforms or life forms arranged in patterns that impress us as pretty or at least interesting. Conversely, minus landscapes lack variety: perhaps not enough different landforms or life forms to show contrast; or forms too disordered to make patterns; or patterns displeasing in shape or size.

Between the extremes of landscapes so empty that no contrast exists, or so cluttered that no patterns emerge, there is an almost infinite spectrum of desirable variety. This broad range of variety offers unlimited opportunity to intensively manage our multiple resources. And we'll be scenically compatible as long as we imitate shapes and sizes from the characteristic landscape. That's nature faking.

VEGETATION TYPES--ONLY THREE

To manage landscapes instead of just land, we need to know what clay we're molding. Vegetation types are the building blocks of forest landscapes, and Warren G. Kenfield, an irascible New Englander, has made them as easy as one, two, three--meadow, shrub thicket, forest stand. That's right, for our landscape purposes there are only three vegetation types.

It doesn't matter that your meadows are bluestem and mine wiregrass; or that your shrub thickets are rhododendron and mine palmetto; or that your forest stands are hardwood and mine conifer. For our respective characteristic landscapes, they function visually as the same building blocks--meadow, shrub thicket, or forest stand.

Where all three vegetation types are present, landscape design is deciding what to take out to emphasize contrast, and landscape installation is deciding how to take it out to delineate patterns akin to the characteristic landscape.

EDGES--THE LINES WE READ BETWEEN

The concept of edge is equally simple in our landscape context. Where different landforms and life forms come together, their contrasting surfaces make outlines, or interfaces, or ecotones, or tension zones, or your choice of jargon. I call it edge--as between water and rock, pond and meadow, meadow and forest, forest and shrub thicket, or--hemline and thigh, bosom and blouse. The point is that our eyes seek and follow edges; it's how we read landscapes and girl shapes. Landscape designers,

and designing women, arrange edges to direct our gaze toward things they want noticed and away from things they don't want noticed.

Our friends in outdoor advertising also get the edge on us by managing edge. A well-maintained billboard has as its foreground a mowed triangle which starts many yards in front of the sign and flares on a 20- to 30 degree angle to the outside corner of the billboard. The object is not to free your view--the sign is elevated above the brush--the object is to confine your view within that wall of mowed edge. An especially well-sited billboard may also feature a backdrop of trees to frame both the sign and your attention.

With no more instruction than this, land managers can begin managing edges to emphasize the plus facets of their working landscapes while toning down--or better, rehabilitating--minus aspects.

NATURALISTIC PATTERNS--MIDDLE GROUND BETWEEN MONOCULTURE AND WILDERNESS

If natural beauty were the land's only resource we could leave landscape management to natural forces. But scenery is not an isolated value; we impact it--plus or minus--with every manipulation of our production systems. We may harvest goods and services--wood, water, meat, game, recreation--but we manage landforms and life forms--soils, streams, lakes, meadows, shrub thickets, and forests. Therefore we are not just land managers, we are landscape managers, for better or worse, trained or untrained, if we choose it or not.

It is economically desirable and socially urgent that we fulfill our scenic stewardship as a by-product of normal production management. Fortunately it is also technologically feasible. When we plant or harvest forests, sow pastures, burn range, or clear fuel breaks we are arranging vegetation types and delineating edges. We're playing with the three building blocks. If our pastures and clearcuts are huge rectilinear voids we sew boring patches of minus scenery on our landscape fabric. And plantations that grow into humdrum rows of visual barriers are another kind of minus scenery that tunnels the traveler's view for mile after tedious mile.

On the other hand, if plantation margins undulate and scallop the edges of free-form pastures--if fuel breaks meander like lazy streams between banks of mast-producing shrubs--if clearcuts writhe through hunting groves and coil around leave islands--then we actually create variety and fling plus chips into the mosaic of our characteristic landscape. Our mechanized implements all turn around at the end of a straight row; make them turn all along the row; make them carve naturalistic patterns; make them create variety.

Nonproductive wilderness or geometric monoculture are not our only options. We are easily capable of intensively managing

our multiple resources in naturalistic, integrated patterns that actually enhance scenic quality.

PRESCRIBED BURNING--KEEN CHISEL OR SMUDGY ERASER?

Now that we've attached some of Orr's and Kenfield's handles to forest landscapes, let's rephrase that original question about prescribed burning and landscape quality: For example, what can fire do to vegetation types? to edges between types? and to patterns formed by edges? In each case there are three obvious answers: destroy, create, or maintain. Fire can create a meadow, destroy a hardwood stand, or maintain a pine forest. Similarly, if fire always stops at the same place, an edge will form there. But if fires burn sometimes this far and sometimes that far, then edges will be erased and patterns blurred.

In the Coastal Plain's characteristic landscape many plus scenes feature hardwood hammocks, cabbage palm islands, or rank shrub thickets that the vagaries of wildfire have spared for many years. Yet fire has also sculptured the serpentine meadow or park-like pinery through which we view those diverse broadleaf types.

Assuredly, wildfire can be a master landscaper--occasionally. But occasionally or even usually will not suffice for prescribed burning or for our responsibility as scenic stewards. The effectiveness of prescribed burning as a landscaping tool depends on our ability to stop fires precisely and consistently where we want them to stop.

And this is where I must stop, for I have neither training nor experience in prescribed burning. I look forward to an unorthodox but stimulating discussion period as the speaker queries his knowledgeable audience. For openers: What techniques can you use to turn a fire off along that sharp, serpentine edge between vegetation types? What fire strategy do you employ where the naturalistic patterns writhe and meander, and what you started as a backfire must necessarily flank or head relative to types that must remain unburned?

I respect your commitment to landscape quality and I admire your expertise with man's ancient tool, fire. I hope we have passed along some practical guides to help you put the two together. For scenic stewardship is simply the will and skill to apply our land manipulations in naturalistic patterns reminiscent of our region's landscape heritage.

SELECTED BIBLIOGRAPHY

Burke, H. D., Lewis, G. H., and Orr, H. R. 1968. A method for classifying scenery from a roadway. U. S. Dep. Interior, Nat. Park Serv. Park Practice Development Guideline 3/68: 125-141.

Kenfield, W. G. 1966. The wild gardner in the wild landscape--the art of naturalistic landscaping. 232 pp. New York and London: Hafner Publishing Co.

Williamson, R. M., and Currier, W. F. 1971. Applied landscape management in plant control. J. Range Manage. 24: 2-6.

THE EFFECTS OF PRESCRIBED BURNING ON OUTDOOR RECREATION

Carroll J. Perkins
International Paper Company
Bainbridge, Georgia

The effects of prescribed burning on outdoor recreation in our southeastern forests cannot be properly evaluated unless we understand the role of fire in the evolution of this forest. The southern pine is generally considered to be a fire climax, however, it is seldom realized that the other plants, as well as the animals, of this forest community also evolved with fire as an integral part of the natural environment. Consequently, a change in any of the environmental factors, such as moisture, temperature, or frequency of fire, has had, and will continue to have a profound effect on the species composition of this ecosystem.

When primitive man first made his appearance on this continent, 20 to 40 thousand years ago, the southern pine forest community, as a result of periodic lightning-caused fires, was already well established. Meteorological data indicate that atmospheric conditions that create lightning fires occur primarily in the summer. Fires during this season will generally be lethal to hardwood stems of less than 4 inches in diameter, whereas winter fires will only kill the tops of these species, leaving the roots to sprout the following spring. Therefore, it may be assumed that our southern pine forests had a park-like appearance and were relatively free from underbrush when first seen by primitive man.

These pine barrens, as created by nature, were an extremely poor environment for all forms of wildlife. Likewise, it is thought that the vast hardwood bottomlands were also relatively poor wildlife habitat. These areas, as described by early writers such as DuPratz and Bartram, were made up of a few species of hardwoods with relatively clean understory or dense stands of switchcane.

None of this contributed to good wildlife populations. Therefore, the best wildlife habitat was probably to be found only in the intermediate zones located between the higher, drier pine sites that burned frequently and the moist bottomlands that burned only rarely.

During wet cycles these transition zones would escape burning for several years, permitting a buildup of fuel. Later, during extremely dry periods, the fuel would burn with a heat intense enough to kill many of the tree species. This type of burning led to a diversification of species of trees, shrubs, and vines, as well as herbaceous plants, most of which were favorable to good wildlife habitat.

Archaeologists tell us that the Indians probably burned the woods at every opportunity. It is believed that they used fires to facilitate travel, as an aid to their primitive farming, and probably for game management purposes. It is logical to assume that most of this burning was done in the wintertime after the first frost. Winter burning would have altered the plant composition of the understory in the pine forest, extending the limits of the intermediate zones, allowing the encroachment of hardwood species, as well as encouraging the establishment of annual grasses and forbs. Indians were never very numerous in the southeast, so it is doubtful that they had much effect on the forests except in the vicinity of Agrarian Tribes and along well-established travel routes.

The earliest white settlers, likewise, exerted little influence on the forest composition. As their numbers increased, however, this situation began to change. After the logging industry moved into the southeast, vast stands of virgin timber were clear-cut, and the farmers and cattlemen began to burn much of the cut-over land each winter. This was done to improve grazing, to kill ticks and snakes, and quite often, no doubt, "just to see it burn."

This common practice created a monumental problem for the early foresters in their attempts to re-establish the pine forests. So it is understandable that most foresters of that day could see no beneficial effects of any type fire in the forest. Consequently, they concentrated their efforts on fire suppression, which led to the establishment of pine forests throughout the southeast that did not have fire as a part of their environment. These forests often contained mixtures of hardwoods and shrubs that rarely occurred in natural forests on these sites. The exclusion of fire also altered the herbaceous flora. All this had a profound effect on wildlife because the exclusion of fire created a habitat less favorable for deer, quail, turkey, rabbit, and many songbirds. The encroachment of various species of hardwoods into the pine sites, however, produced a habitat favorable to squirrels.

The forest land manager's principal objective has always been timber harvest and fire protection, and outdoor recreation has been of little concern. However, this situation is changing. He must now produce more forest products on less land and at the same time fulfill the ever increasing demands for recreation by an affluent society. Economics dictate the planting of genetically

improved species of pine and hardwoods. These trees are being planted in rows and spaced to take best advantage of moisture, nutrients, and sunlight. Eventually these plantations may be cultivated and fertilized much like farm row crops, and certainly they will be harvested with machinery. Such pine plantations can easily become biological deserts.

It is taxing the ingenuity of the land manager to incorporate outdoor recreation into this intensive forest management program.

Today, hunters are concerned with the effect of intensive forest management on wildlife habitat. Therefore, the forester must find ways in which he can incorporate game management into his existing forest management practices. Prescribed burning has proved to be an inexpensive and effective aid in his endeavors.

As stated earlier, fire was part of the natural environment and the plants and animals of the pine forest community are oriented toward burning; therefore, let us consider some ways that the use of fire can help create a habitat favorable to game in the managed forest.

WHITETAILED DEER

By using winter fires, vines, shrubs, and hardwood seedlings, which often grow out of reach of the deer, can be reduced to sprouts. These provide excellent deer food. The removal of litter on the forest floor by fire encourages the growth of annual grasses, forbs, and certain mushrooms, which all improve the habitat for the whitetailed deer.

TURKEY

Turkey depend upon keen eyesight for survival, and they prefer open, park-like conditions in the forest. This requirement can best be fulfilled by prescribed burning in the winter, which will also provide the diversification of flora necessary for good turkey habitat.

BOBWHITE QUAIL

A habitat favorable for the bobwhite quail includes food and feeding cover in association with areas suitable for roosting, nesting, and escape. These conditions can best be met by prescribed burning in late winter or early spring.

OTHER GAME SPECIES

The same prescription that benefits deer, turkey, and quail will also improve conditions for rabbits, because it provides succulent plants for food. It will also provide a readily available source of weed seeds for doves and mushrooms and weed seeds for fat squirrels.

With the use of prescribed burning, the land manager can provide good game habitat. Managing the land just to please the hunter will no longer suffice, however, because the percentage of the public that hunts is decreasing, while the percentage that participates in other forms of outdoor recreation is on the increase. Fortunately, prescribed fire can also be beneficial to many of the other outdoor activities that are gaining in popularity.

CAMPING, PICNICKING, HIKING, ETC.

Probably the greatest number of visitors to our forest today are interested in camping, picnicking, hiking, or just driving through the forest and enjoying the scenery. Prescribed burning benefits all these types of outdoor recreation. The proper prescription can maintain a park-like appearance in the forest and provide wildflowers and wildlife.

BIRDWATCHING

There are 8 to 10 million ardent bird watchers in the United States today, and it is estimated that by the year 2000, this number will increase to 20 million. This large group of conservationists is certainly interested in the effects of our forestry practices on the environment of birds. Most serious students of ornithology are aware of the use of fire in managing the habitat for the Kirtland's Warbler. This warbler will nest only in an open stand of young jack pines, 6 to 12 feet tall. It is so dependent upon recurring fires for the creation of this particular habitat that it is conceivable the species would become extinct if fire were suppressed within its limited range. However, the role of fire in providing suitable habitat for many other species of birds in the southeast is rarely considered. The proper prescription of controlled burning (that is burning the pinelands in the late winter) provides better feeding conditions during a very critical time of the year for many resident and migrant avian seed eaters. It also produces a more diversified herbaceous flora the following growing season. Likewise, this type of fire will provide good food and feeding conditions for those species of birds that are insectivorous, since insects and worms are also oriented to periodic burning.

OUTDOOR PHOTOGRAPHY

The sport of outdoor photography is gaining in popularity each year as the quality of cameras and film improve. Today it is estimated that one person out of every ten in the United States owns a camera. Scenic beauty is one of the most popular subjects being photographed. Our pine forests of the southeast, if manicured periodically with prescribed fire, will offer a profusion of wildflowers and a variety of wildlife in an attractive landscape that will be a joy to many a photographer.

OTHER FORMS OF OUTDOOR RECREATION

In addition to these more familiar forms of outdoor recreation, the land manager of our forest lands in the future will be requested to provide an environment conducive to many new types of sports. These may include: recording the sounds of the out of doors, butterfly watching and collecting, mushroom gathering, and many others. The land manager's successful compliance with the demands of these and all other groups seeking recreation in the forest will depend upon his ability to use prescribed fire in his manipulation of the forest environment. If the use of fire is restricted, visitors to our forests will no longer thrill to the sight of the whitetail deer bounding through the open woodland; no longer will they expect to flush a covey of bobwhite quail; no longer will they enjoy the spine tingling sound of the majestic turkey gobbler. Our pine plantations will have become a dull, uninteresting, sterile monoculture. Such a forest will be deserted and for the most part silent, except for the sighing of the winds in the pines.

PRESCRIBED BURNING FROM THE TOURISM POINT OF VIEW

Robert Papenfus
South Carolina Department of Parks, Recreation, and Tourism
Division of Parks and Recreation
Columbia, South Carolina

I was told that the underlying idea behind this symposium was to present an objective, in-depth evaluation of prescribed burning in the Southeastern Coastal Plain. I don't know how in-depth my evaluation will be, but I can assure you that it will be extremely objective, because no one in the tourism business in South Carolina has considered the effects of prescribed burning enough to have any subjective thoughts concerning the matter. Since the invitation to participate in this program came, I have been consulting not only people in our own Travel and Tourism Division but also individuals involved in the private tourism industry. Only a few had even heard of prescribed burning, and no one could give either the advantages or disadvantages of the practice.

This may sound strange to some of you who have devoted a lot of your working life to forest management, but maybe the following story about my wife will let you know why most tourist-oriented organizations have not concerned themselves with the effects of prescribed burning.

Several months ago we were traveling on Highway 15, south of Walterboro. I pulled over to the side of the road and asked her what she saw. Pine trees was her answer, and she was right, nothing but pine trees on both sides of the road. I asked her if she saw any difference between the trees on either side of the road and her answer was "no." Rolling the car ahead I stopped in front of a sign that read - DEMONSTRATION AREA - PRESCRIBED BURN - 1969. Her reply to that was typical - "What does it mean?" After a discussion of the uses of prescribed burning for fire-hazard

control her attitude changed to - "Oh!, well I guess the right side of the road is a little prettier. How much farther is it to Fripp Island?"

My wife is a typical tourist and I can only assume that hers was a typical response to your sign.

Last year, 18 million people toured South Carolina, and most of them headed for the coast. The average tourist thinks only of getting where he is going and not too much about what he sees along the way. In other words, he only gets an indirect impression of the landscape he sees enroute to his destination. With that idea, I think we can get to the crux of the matter concerning prescribed burning and tourism. If selected burning of the certain areas for forest management practices can also make these areas more aesthetically pleasing, then the prescribed burning has an indirect, but valuable effect on tourism. To put it in simpler terms, if an area has become aesthetically pleasing, it leaves a good impression on the tourist. If an area is scrubby looking, it leaves a bad impression on the tourist and he may take his money elsewhere.

There is, however, one drawback to be considered with selected burning and tourism. This drawback is, of course, the actual fire itself. Tourists like to see nice park-like areas, but they don't like to drive by and see the process by which this may be accomplished. Horrors strike their hearts and they are saddened by the fact that there is, before their eyes a forest fire. You see, most tourists, and most of us in general, are suffering from the Smokey Bear Syndrome. All fire is bad, it destroys woodlands, it ruins wildlife, and makes areas forever ugly. Well, we know that in the case of a selected burn this is not the case, but the impression left on the tourist is bad.

You may have gathered by now, that when I speak of tourism on a general level I am referring only to impressions. I would now like to refer to some impressions that could be created in some of the state parks. South Carolina's state parks play an important role in the tourism industry of this state, and they are probably the prime areas in which selected burning could have the greatest value as it relates to tourism.

Several of our parks have large areas of both planted and natural growths of young pine. Quite often these same areas surround the entire park and also the hardwood growths that are along stream beds and lakes. There is a tremendous amount of scrub oak and other ugly little plants coming up under the pine. It appears to me that the fire hazard in these small pines must be tremendously high 6 months out of the year. Here is a place where prescribed burning could be used, both for its main purpose, to reduce the fire hazard, and for a secondary benefit, to open up these pine stands and make them more aesthetically pleasing and sylvan in nature. To put it in other words, prescribed burning in some of our parks would make perimeter areas more pleasing to the tourist and also reduce the fire hazard in the main-use area of the park, which nine times out of ten is the area with the greatest natural assets.

We have one state park, located near Cheraw, where I would and have advocated prescribed burning for no other reason than aesthetics. Several years ago an ice storm literally tore the natural vegetation of this park apart. Tree tops and limbs were scattered waist deep over 7,000 acres of park land. In the past 2 years, natural decay has reduced this to knee-deep debris. I am sure the fire hazard is great with this much litter, but--more than that--the impression upon entering this park is one of extreme ugliness. What better way to make the park more appealing than quick eradication of the debris and removal of the scrub brush that is popping up.

In summation, let me say that anything which creates a favorable impression on travelers is good for tourism. If you, as foresters and management specialists, have a tool which is good for timber production, and also provides a pleasing and aesthetic landscape, you are encouraged to use it. We, as people concerned with tourism, will be watching and perhaps soon will be able to adapt some of your principles and practices to our land management programs in our park lands.

COMMENTS

Mr. Meskimen's straightforward, down-to-earth presentation was a joy to read. As a forester, I have answered in the affirmative the silvicultural question "to burn or not to burn." But as a Professor of Recreation, I have also wrestled with a conscience not quite convinced that prescribed burns are always conducted with the recreational public in mind.

Having simplified the problem by limiting the objective to a two-word statement, "nature faking," Meskimen proceeds to denude the variables and conceptualize a solution which is useful at operational levels. Looking back on duty tours in Arizona, New Mexico, Florida, Texas, and North Carolina, I sense the validity of the building-block triumvirate as applied to any landscape where variety is possible. Meskimen and his collaborators have made a significant contribution toward much-needed mitigation of the conflict between silvicultural and recreational objectives. For bridging a communication gap which has long frustrated foresters of good will, they deserve a vote of thanks.

I am decidedly uncomfortable with Mr. Papenfus' premise that the average tourist is largely insensitive to the landscape as he proceeds to his destination. The increasing prevalence of "minus scenery" may have a desensitizing effect, but we who have responsibility for stewardship of the land are writing our own ticket to professional oblivion when we become accessory to the progressive deterioration of the public's tolerance levels for "the ugly."

Papenfus' characterization of scrub oak and other growth occurring under the pine as "ugly little plants" smacks of sawdust-oriented subjective thinking, the likes of which does nothing to stem the rising tide of disenchantment with public land-management policy.

Gordon A. Hammon
School of Forest Resources
North Carolina State University at Raleigh
Raleigh, North Carolina

EFFECTS OF PRESCRIBED BURNING ON PHYSICAL PROPERTIES OF SOIL

Charles W. Ralston
School of Forestry
Duke University
Durham, North Carolina

Glyndon E. Hatchell
Southeastern Forest Experiment Station
Charleston, South Carolina

INTRODUCTION

One of my colleagues annually assigns a review of literature on effects of fire on soil properties to one of his unsuspecting forest management students. The normal and acceptable result--at least regarding soil physical properties--is a paper concluding that almost any position on fire effects can be documented by reports of reputable researchers. Experimental evidence can be cited to show that infiltration capacity, structural aggregates, macro and micro pore space, and incorporated organic matter are increased, decreased, or unaffected by burning forest, range, or woodland habitats.

Rational evaluation of such diverse effects of burning on physical properties of soil--and their implications in management--requires careful consideration of the kind of fire, the kind of soil, the kind of topography, and the other environmental conditions that produced the observed effects. Was it a prescribed fire or a wildfire? If prescribed, was it a light surface backfire or a heavy slash burn? Was the wildfire a surface headfire, or did it crown? Was the terrain flat and the soil sandy? Was it a silty soil on steep topography, an area with thick duff, or a peat soil? All of these questions, and others unasked, have a bearing on the degree of direct and immediate changes in soil properties at the time of burning and on subsequent, longer range, indirect effects of fire on physical characteristics of the ecosystem. If the literature

on fire effects is studied and interpreted with proper regard for the dominant variables in each instance, anomalous results can be understood, and an array of soil physical changes caused by burning can be provided for managerial value judgments.

IMMEDIATE EFFECTS OF FIRE

When a forest or range area burns, fuels are consumed, thereby heating the soil and producing alterations of surface ground covers. The magnitude of these effects largely depends on the oxygen supply during combustion and the amount and condition of the fuel supply.

Studies of Soil Temperatures During Burning

Intensities and durations of soil heating by prescribed fires for rough reduction are considerably less than those generated by slash burning or wildfires. Heyward (16) made comprehensive observations of soil temperature trends during 44 prescribed fires on longleaf pine flatwood sites near Olustee, Florida, and on well-drained upland longleaf types in southern Mississippi. Fires--both with and against the wind--in roughs up to 15 years old, seldom generated temperatures above 52° C. (125° F.) for more than 15 minutes at shallow (3-6 mm.) soil depths, and except for brief intervals (2-3 min.), maxima were below 121° C. (250° F.). The highest temperature observed 1 inch below the soil surface was 66° C. (150° F.). A typical temperature record of this study is shown in figure 1a.

Soil temperatures associated with slash fires have been the subject of several studies in Australia. The results of an experiment by Beadle (4) are given in figure 1b. Test fires ranged from a surface litter burn of 3/4-hour duration to a blaze fed by all of the shrubs and trees on the plot, stoked for 8 hours. The surface fire heated the soil to 50° C. (122° F.) at 1-inch depth, and the hottest fire, which approximated a land clearing operation or a severe wildfire, created temperatures near 223° C. (434° F.), 3 inches below the surface. Later measurements of temperatures under burning windrows of eucalypt slash and logs (9, 10, 18, 31) revealed peak temperatures from 666° C. (1231° F.) just below the soil surface to 112° C. (233° F.) at a depth of 8½ inches.

Effect of Soil Heating on Organic and Mineral Fractions

Once the range of heat intensities of various kinds of fires is recognized and approximate quantitative temperature limits are known, one may ask what happens to organic and mineral fractions of soils upon exposure to different heat levels.

Soil organic matter.--Progressive heat destruction of organic matter in four Australian soils, one from England, Merck's "humic" acid, and filter paper was observed by Hosking (17). Samples were heated in a muffle furnace at temperatures of 100° to 500° C.

for periods of 16 hours to 1 week. Major temperature-dependent stages of ignition were:

a. 100°-200° C.--nondestructive distillation of volatile organic compounds

b. 200°-300° C.--destructive distillation of up to 85 percent of organic substances

c. >300° C.--ignition of carbonaceous residues.

Overall conclusions were that heating at 450° C. for 2 hours or at 500° C. for ½ hour are required to remove 99 percent of the organic matter in the materials tested.

Now, if these results are compared with soil temperatures recorded for various prescribed burns, it is most unlikely that soil heating by prescribed fires for rough reduction causes major loss of incorporated organic matter. Some nondestructive distillation of volatile substances can be expected and abnormal drying of organic colloids will occur at shallow depths. Thus, light burning causes no detectable change in total amount of organic matter in the surface soils (14, 27), or slight increases have been noted and attributed to more rapid decomposition and incorporation of residual organic fragments on burned surfaces (26).

Temperatures recorded during prescribed burning of slash piles and in hot spots of wildfires are high enough to cause ignition losses of organic matter near the surface and substantial destructive distillation losses to depths of several inches. An example of organic matter depletion in severely burned spots during disposal of slash of a Douglas-fir logging operation in Oregon is given by Dyrness and Youngberg (14). The organic content of the surface 5 centimeters (2 inches) of soil was 4.2 percent in places where slash piles burned, whereas comparable surface layers in lightly burned or undisturbed timbered areas contained about 11 percent organic matter.

Mineral soil fractions.--Temperatures associated with light surface fires are insufficient to cause any appreciable change in properties of mineral soil particles, but the heat of more severe fires can cause irreversible changes in the structure of soil clays. Temperatures between 100°-200° C. drive off water that is strongly adsorbed between adjacent micelles of montmorillonite and illite clays; at 550° C., both of these groups--and the kaolin clays, as well--lose water derived from hydroxyl ions that are part of crystal structures of clay minerals (21). Loss of structural water permanently alters the shrinking and swelling properties of montmorillonite clays to the extent that heat-treated clay aggregates have soil moisture properties similar to sand or gravel.

Alteration of Ground Surface by Burning

In addition to heating the soil, fires remove part or all of the forest floor materials that buffer the soil from rapid changes in microclimate and from the churning action of falling

raindrops. Therefore, in judging effects of burning, it is important to recognize variations in forest floor removal by different kinds of fires.

Ordinarily, prescribed fires for rough reduction will not remove all of the forest floor. Sweeney and Biswell (37) found that 76 percent of litter (O_1) and 23 percent of duff (O_2) horizons were consumed by four test fires in ponderosa pine types in California, and that in all cases, remaining materials were sufficient to cover the soil. After 10 years of study of prescribed burning in sawtimber stands of loblolly pine in the South Carolina flatwoods, Metz, Lotti, and Klawitter (26) reported one instance in which a winter fire consumed about 4,000 of 17,000 pounds per acre of surface organic matter, and that after 10 annual fires (winter or summer) 4,000 to 5,000 pounds per acre of organic fragments remained on the ground prior to autumn leaf fall.

The exposure of post-burn surfaces of slash fires and wildfires is variable both in degree and extent. Relationships between soil temperatures during burning and post-fire seedbed conditions for California woodland ranges were evaluated by Bentley and Fenner (6). Their observations--summarized in table 1--give a good description of burned surfaces after a hot fire.

Table 1

Seed bed condition	Maximum temperature during fire	
	Surface	2.5-cm. 1 inch depth
Black ash (surface covered by charred litter fragments)	177° C. (350° F.)	71° C. (160° F.)
Bare (litter consumed; no ash accumulation)	400° C. (750° F.)	177° C. (350° F.)
White ash (litter and heavy fuels consumed; thick ash deposits)	>500° C. (>1000° F.)	288° C. (550° F.)

Areal estimates of surface conditions after logging and slash burning in mature Douglas-fir given by Dyrness and Youngberg (14) were: undisturbed (17 percent), disturbed by logging (30 percent), lightly burned (45 percent), severely burned (8 percent). Obviously, fires can effect greater reductions in surface cover--including complete removal--than those cited, but these examples illustrate the fact that the impact of burning on surface cover is variable and that some restraint is needed when interpreting effects of fire on soil properties and site disturbance.

SUBSEQUENT EFFECTS OF FIRE

While soil heating and surface cover removal are the immediate factors that effect varying degrees of change in soil properties, we are usually more concerned with longer lasting effects that may occur when burned areas interact with other physical factors of the environment over a period of time.

Considerable attention has been given to study of soil temperatures, changes in macro-pore space, and related properties (infiltration rates and air space), but the studies of major consequence are those that provide data on how fires affect surface runoff and soil erosion.

Soil Temperature Changes

Forest floor material acts as an insulator against soil temperature changes, reducing extremes and moderating rates of soil freezing and thawing. Temperature differentials between fully insolated, charred burns and shaded, undisturbed, forested sites can be appreciable (ca. 10° C. at 7.6-cm. depth), but this response is diminished considerably (ca. 2° C. at 7.6-cm. depth) if the burn also is shaded (5). When the objective of management is perpetuation of a number of subclimax tree species, the combined effects of temperature changes, reduction of weed competition, and soil exposure on burns is favorable for regeneration by natural or artificial seeding.

Macro-Pore Space, Infiltration Rates, and Aeration

Alterations in these related properties mostly depend on fire intensity and the amount of forest floor that remains after burning. When increases in these properties are reported, it is likely that intense heating has altered the crystalline structure of shrinking and swelling clays, thereby causing them to be more permeable to air and water movement (30, 34, 36).

If mineral soil is exposed, either by hot wildfires or by repeated moderate burning for long periods of time, as aggregates are dispersed by beating rain and pores become clogged with fine particles, decreases in macro-pore space, infiltration, and aeration can be expected (1, 2, 3, 5, 33, 41).

Singular reductions in percolation rates sometimes are observed after fires on sandy soils, and special mechanisms have been advanced to explain this phenomenon. Water repellent soils have been found beneath litter layers of unburned chaparral areas and at varying depths in soils of burned watersheds of this type (22). These layers resist wetting and impede downward infiltration of water and upward evaporation from lower soil horizons. Their existence is attributed to downward distillation and condensation of volatile hydrophobic constituents of litter materials (13). Excessive drying of organic colloids also may affect their rewetting capacity (the senior author has found that ovendried samples of A_1 horizons retain less water when remoistened than air-dry or fresh

samples). Furthermore, if peat soil fragments are air-dried in the laboratory, they will float on water for prolonged periods (weeks); however, if steamed or boiled, they rapidly become rewetted. This behavior suggests that pores of organic colloids in such soils have shrunk to sizes where capillary conductivity is exceedingly slow and that vapor pressure gradients at pore entries are too low to permit rapid rewetting at ordinary temperatures.

When surface organic horizons are not completely consumed by prescribed fires, changes in pore space and infiltration may be too small to be detected. Thus, Metz, Lotti, and Klawitter (26) reported no change in these properties after 10 annual burns on the Santee Experimental Forest.

Surface Runoff and Erosion

The main impact of fire on the physical environment is the extent to which it removes surface cover and thus alters the partitioning of incident precipitation into surface runoff and infiltration components, thereby increasing the potential for soil loss by erosion.

The importance of forest floors in regulating runoff and controlling erosion was the subject of elaborate experiments by Lowdermilk (24). His conclusions were: (1) forest litter greatly reduced runoff, especially in finer-textured soils; (2) destruction of litter and exposure of bare soil greatly increased soil erosion and reduced the water absorption rate; (3) sealing of pores by particles suspended in runoff accounted for marked differences in infiltration between bare and litter-covered soils; and (4) water absorption capacity of litter is insignificant in comparison with its role in protecting maximum percolating capacity of soils. These conclusions are confirmed by work of Rowe (32) in natural stands of ponderosa pine and by his lysimeter experiments.

However, in the sequence of things causing erosion, the crucial significance of vegetation lies in its effectiveness in preventing the dislodgment and suspension of soil particles--an event that must happen before erosion can take place. This truly profound characteristic of plant cover in preventing soil erosion--irrespective of high rainfall, steep topography, and soil type--is amply demonstrated by clear flows from mountain watersheds; but only when adequate cover of forest or grass is present. Further evidence of the role of vegetation in minimizing erosion is given by Langbein and Schumm (23) who postulate maximum rates of natural erosion for areas with annual rainfall between 25 and 35 cm. (10-15 inches), because increased vegetational cover causes a decrease in soil loss above 35 cm. and runoff is rare below 25 cm.

Since it is seldom possible to protect natural or managed forests indefinitely from disturbance by fire or other disruptive events of natural or manmade origin, further examination of studies on fire and erosion is warranted.

A post mortem analysis of conditions following a large wildfire in central Idaho (7) effectively illustrates the interactions of cover type, fire intensity, and slope gradient on incidence of accelerated erosion (figure 2). Greater fire intensities generated by heavy brush and slash fuels on cutover areas were believed to be the reason for a higher percentage of eroded plots (42 percent) on logged areas than were found on virgin forest land (28 percent). Also, needle cast from trees killed by severe ground fires gave a degree of protection to timbered areas that was absent on cutover terrain and in stands where crown fires occurred.

Although this study presents an excellent qualitative picture of interactions of fuel, fire, and environmental conditions producing the complex erosion patterns following a large wildfire, we must examine less drastic fire treatments on a quantitative basis, if we are to evaluate the soil loss from prescribed burning.

Some of our early records on this subject were initiated during the conservation wave of the 1930's, when conservation experiment stations were established at 10 locations representing major agricultural areas of the United States. Soil runoff and erosion were measured over a 10-year period from plots cropped both by conventional and conservative practices, with forest or sod plots serving as controls. Results of all stations were similar, and as shown in figure 3 (29), the essentially conservative nature of forest or grass crops is quite apparent.

Some of these experiments and later work present estimates of soil losses caused by woods burning (table 2). Although these erosion rates seem nominal when compared with those of agriculture, it is evident that annual burning does cause significant increase in soil loss, so the persistence of such effects after burning is discontinued, and levels of erosion considered acceptable as long-term loss rates are matters that deserve further inquiry.

Recovery Trends

It is reasonable to suppose that reduction in erosion rates after burning depends on how quickly surface cover is re-establishe(The scrub oak areas treated by Ursic (39, table 2) apparently had enough regrowth to be stabilized by the end of the third growing season. Ursic (38) also measured sediment production over a 3-year post-burn period on three old field watersheds with grass cover. On two burned catchments the maximum sediment yield was 2.9 tons ac.$^{-1}$ (44 cm. 1000 yr.$^{-1}$) during the first year after burning, 0.26 tons ac.$^{-1}$ after 2 years (4 cm. 1000 yr.$^{-1}$), and 0.023 tons ac.$^{-1}$ (0.35 cm. 1000 yr.$^{-1}$) in the final year of study.

After a 4,500-acre fire that killed a ponderosa pine forest near Deadwood, South Dakota, Orr (28) measured runoff and erosion from plots on two watersheds, helicopter-seeded to grasses and legumes on top of winter snow. Trends of soil loss and vegetation density during the recovery period (1960-64) appear in figure 4. The author postulates that total ground cover of native and seeded vegetation must equal or exceed 60 percent density for minimum tolerable control of runoff and erosion.

Table 2.--Soil losses from burned and protected woodlands

Investigator	Location	Forest cover	Years of record	Annual PPT. (In.)	Soil loss (Tons $ac.^{-1}yr.^{-1}$)	Erosion[1/] (Cm. 1000 $yr.^{-1}$)
Meginnis (25)	Holly Springs, Mississippi	Scrub oak, burned	2	63.8	0.33	5.0
		Oak forest, protected	2	67.1	0.025	0.4
Daniel et al. (11)	Guthrie, Oklahoma	Woodland burned annually	10	30.6	0.11	1.7
		Virgin woodland	10	30.6	0.01	0.15
Copley et al. (8)	Statesville, North Carolina	Hardwood, burned semi-annually	9	46.5	3.08	47.0
		Hardwood, protected	9	46.5	0.002	0.03
Pope et al. (29)	Tyler, Texas	Woodland, burned annually	9	40.9	0.36	5.5
		Woodland, protected	9	40.9	0.05	0.8
Ferguson (15)	East Texas	Shortleaf-loblolly, single burn	1.5	--	0.21	3.3
		Shortleaf-loblolly, protected	1.5	--	0.10	1.5
Ursic (39)	North Mississippi	Scrub oak, burned and deadened	1st	65.1	0.51	7.8
			2nd	40.5	0.20	3.1
			3rd	50.5	0.05	0.8
		Scrub oak, protected	1st	65.1	0.21	3.1
			2nd	40.5	0.09	1.4
			3rd	50.5	0.03	0.45

1/ Assuming 1 cm. of soil weighs 65.6 tons $ac.^{-1}$.

Conditions following a single prescribed fire in southern pine types probably are given by Ferguson's example (15), table 2). Although the aggregate soil loss was greater from burned areas, the net difference in loss rate (1.7 cm. 1000 yr.$^{-1}$) was fairly low for the 18-month period, and most of the erosion presumably took place prior to leaf fall.

Viewpoints on Tolerable Erosion

Establishing a standard for maximum allowable soil erosion is a worthy but complex objective. If the goal is a loss rate on a national level equivalent to normal geological erosion prior to man's disturbance of the landscape, the estimate can only be obtained by inference. Accepting a current national rate of 6 cm. 1000 yr.$^{-1}$ for solid and dissolved loads discharged by rivers of the United States (20), Judson (19) estimates that our nation was eroding at a rate of 3 cm. 1000 yr.$^{-1}$ "before man started tampering with the landscape on a large scale."

Smith and Stamey (35) also tackled the problem of determining the range of tolerable erosion. They found sediment yields from 36 forest or grass control plots of erosion studies at 12 locations to be of the order of 0.05 to 0.30 tons per acre. These values were doubled to correct for short slope lengths of experimental plots in arriving at normal erosion rates for land protected by full permanent cover of from 0.1 to 0.6 tons per acre (1.5-9.1 cm. 1000 yr.$^{-1}$). In reviewing the rationale of SCS conservation planning standards of 0.5 to 6.0 tons per acre (7.6-91.4 cm. 1000 yr.$^{-1}$), they point out that available reserve depth of favorable, permeable material is a most critical planning factor. Thus, if a planning period of 1000 years is reasonable, the 6-ton-per-acre standard might be sound for deep, permeable, loess soils in Iowa, but a 3-ton annual loss rate would be most unacceptable for 41 cm. (16 inches) of favorable materials over intractable claypan soils of Missouri.

In considering these viewpoints on erosion standards, it may be observed that endorsing Judson's 3 centimeter per 1000 year prehuman intervention loss rate would, indeed, be conservative, as it virtually coincides with geological estimates of rock weathering rates in the central United States; thus, an equilibrium between soil loss by erosion and formation of new soil by weathering.

If we allow erosion from common forest practices to be judged by SCS planning standards, data of Ursic and Dendy (40) and those from other sources (table 2) are helpful in assessing the effect of burning on soil loss rates (figure 5). It is evident that soil loss from woods burning is within current planning limits[1/] for fire practices that are strongly discouraged, e.g., annual and even more irrational semiannual burning treatments.

1/ SCS planning standards were reduced to 0.25 and 3.0 tons ac.$^{-1}$ yr.$^{-1}$ in preparing figure 5 to allow for small watershed and plot sizes.

If prescribed burning is used as recommended in southern pine management, periodic fires for understory control, hazard reduction, and site preparation at the time of regeneration are less likely to cause runoff and erosion problems than the mechanical methods of site preparation and wildfires that would replace them.

CONCLUDING REMARKS

It should be recognized by now that drastic changes in soil physical properties and removal of forest floor materials sufficient to cause significant increase in erosion rates can only be expected from severe fires or on sites where particular combinations of soil, topography, and rainfall confer high risk of damage. If recommended conditions for prescribed burning are observed, the danger of causing soil damage is negligible. Probably the most cogent summary of our topic is given by Davis (12) who notes:

> There is a tendency to overemphasize the unfavorable effects of fire on mineral soil by stressing extreme situations in frequency and intensity of burning. There should be no minimizing of the destructive and undesirable results of wildfires, and this applies both to occasional severe fires and to the cumulative deteriorating effect of frequent moderate fires. But it must also be recognized, and this is a point of large practical importance, that many fires have little total soil effect one way or another and some are beneficial. This fact permits a fairly wide range of choice in using fire in particular situations as a tool in forest management without risking significant soil damage.

There seems little reason to question this viewpoint at this time.

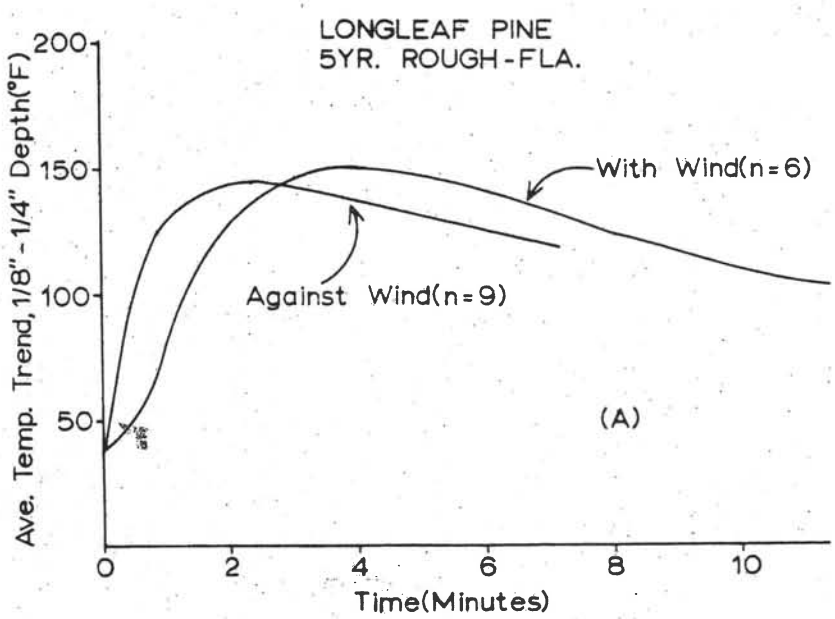

Figure 1A FROM: F. HEYWARD, 1938

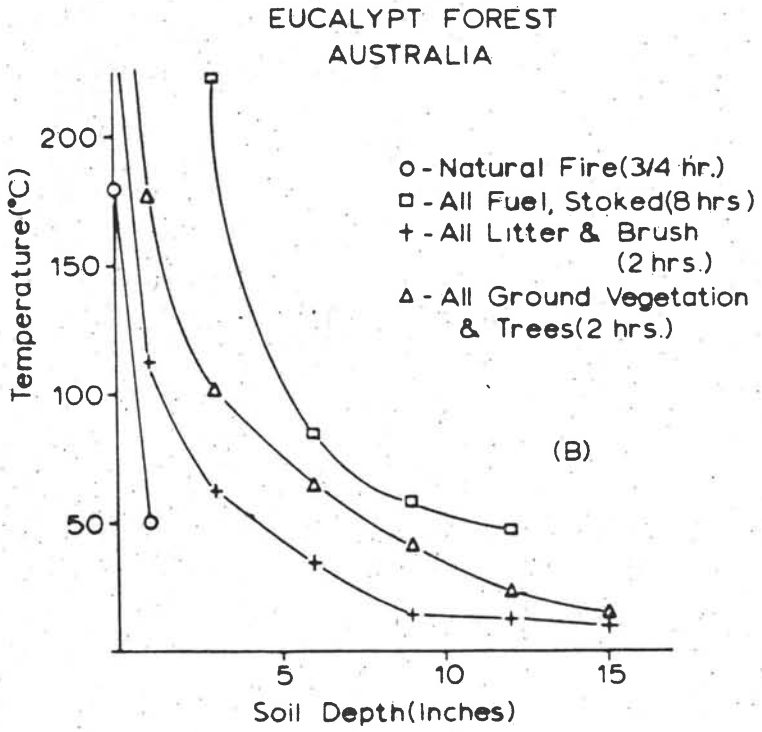

Figure 1B FROM: N.C.W. BEADLE, 1940

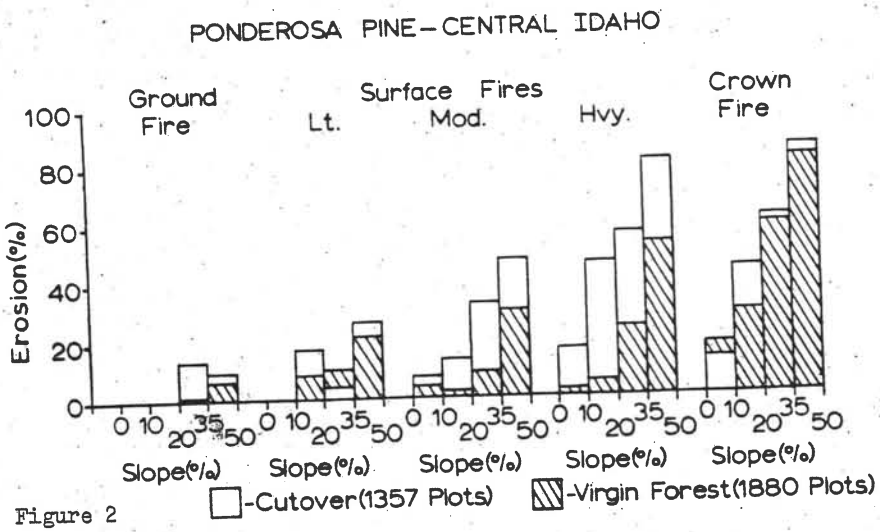

Figure 2

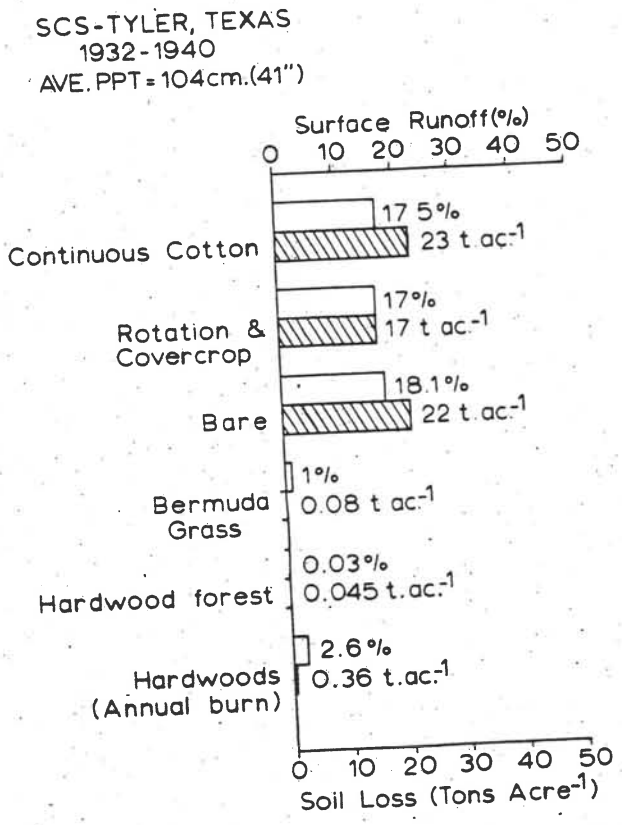

Figure 3

AFTER: POPE et al. 1946

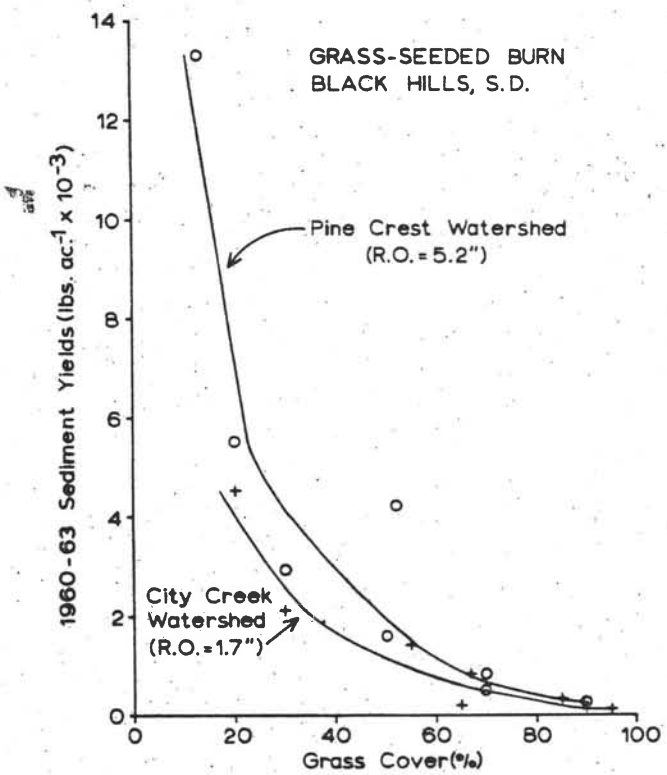

Figure 4 FROM: H.K. ORR, 1970

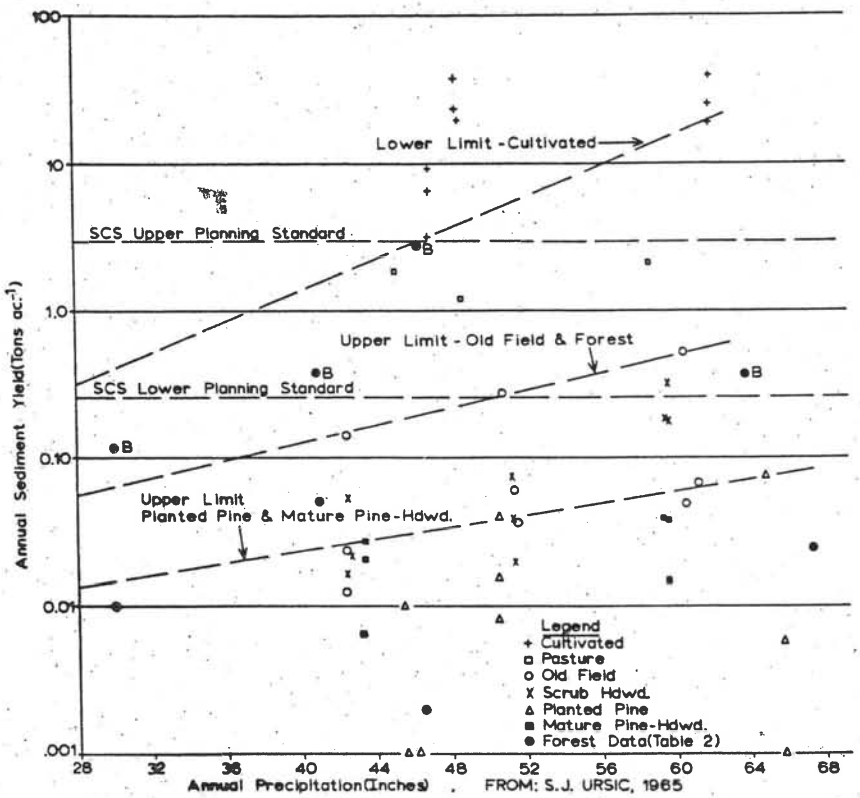
100
10
1.0
0.10
0.01
.001
Annual Sediment Yield(Tons ac.⁻¹)
Lower Limit - Cultivated
SCS Upper Planning Standard
Upper Limit - Old Field & Forest
SCS Lower Planning Standard
Upper Limit
Planted Pine & Mature Pine-Hdwd.
B
Legend
+ Cultivated
□ Pasture
○ Old Field
X Scrub Hdwd.
△ Planted Pine
■ Mature Pine-Hdwd.
● Forest Data(Table 2)
28
32
36
40
44
48
52
56
60
64
68
Annual Precipitation(Inches)
FROM: S.J. URSIC, 1965

Figure 5

LITERATURE CITED

1. Arend, J. L. 1941a. Infiltration as affected by the forest floor. Soil Sci. Soc. Amer. Proc. 6: 430-435.

2. _____ 1941b. Infiltration rates of forest soils in the Missouri Ozarks as affected by woods burning and litter removal. J. Forest. 39: 726-728.

3. Auten, J. T. 1934. The effect of forest burning and pasturing in the Ozarks on the water absorption of forest soils. USDA Forest Serv. Cent. States Forest Exp. Sta. Note 16, 5 pp.

4. Beadle, N. C. W. 1940. Soil temperatures during forest fires and their effect on the survival of vegetation. J. Ecol. 28: 180-192.

5. Beaton, J. D. 1959. The influence of burning on the soil in the timber range area of Lac le Jeune, British Columbia. I. Physical properties. Can. J. Soil Sci. 39: 1-5.

6. Bentley, J. R., and Fenner, R. L. 1958. Soil temperatures during burning related to postfire seedbeds on woodland range. J. Forest. 56: 737-740.

7. Connaughton, C. A. 1935. Forest fires and accelerated erosion. J. Forest. 33: 751-752.

8. Copley, T. L., Forrest, L. A., McCall, A. G., and Bell, F. G. 1944. Investigations in erosion control and reclamation of eroded land at the Central Piedmont Conservation Experiment Station, Statesville, N. C., 1930-40. USDA Soil Conserv. Serv. Tech. Bull. 873, 66 pp.

9. Cromer, R. N. 1967. The significance of the "ashbed effect" in Pinus radiata plantations. Appita 20(4): 104-112.

10. _____ and Vines, R. G. 1966. Soil temperatures under a burning windrow. Aust. Forest Res. 2(2): 29-34.

11. Daniel, H. A., Elwell, H. M., and Cox, M. B. 1943. Investigations in erosion control and the reclamation of eroded land at the Red Plains Conservation Experiment Station, Guthrie, Oklahoma, 1930-40. U. S. Dep. Agr. Tech. Bull. 837.

12. Davis, K. P. 1959. Forest fire: control and use. 584 pp. New York: McGraw-Hill Co., Inc.

13. DeBano, L. F., Mann, L. D., and Hamilton, D. A. 1970. Translocation of hydrophobic substances into soil by burning organic litter. Soil Sci. Soc. Amer. Proc. 34: 130-133.

14. Dyrness, C. T., and Youngberg, C. T. 1957. The effect of logging and slash-burning on soil structure. Soil Sci. Soc. Amer. Proc. 21: 444-447.

15. Ferguson, E. R. 1957. Prescribed burning in shortleaf-loblolly pine on rolling uplands in east Texas. USDA Forest Serv. Fire Contr. Notes 18: 130-132.

16. Heyward, F. 1938. Soil temperatures during forest fires in the longleaf pine region. J. Forest. 36: 478-491.

17. Hosking, J. S. 1938. The ignition at low temperatures of the organic matter in soils. J. Agr. Sci. 28: 393-400.

18. Humphreys, F. R., and Lambert, M. J. 1965. Soil temperature profiles under slash and log fires of various intensities. Aust. Forest Res. 1(4): 23-29.

19. Judson, S. 1968. Erosion of the land. Amer. Sci. 56(4): 356-374.

20. _____ and Ritter, D. F. 1964. Rates of regional denudation in the United States. J. Geophys. Res. 69: 3395-3401.

21. Kohnke, H. 1968. Soil physics. 224 pp. New York: McGraw-Hill Co., Inc.

22. Krammes, J. S., and DeBano, L. F. 1965. Soil wettability: a neglected factor in watershed management. Water Resources Res. 1: 283-286.

23. Langbein, W. B., and Schumm, S. R. 1958. Yield of sediment in relation to mean annual precipitation. Amer. Geophys. Union Trans. 39: 1076-1084.

24. Lowdermilk, W. C. 1930. Influence of forest litter on run-off, percolation, and erosion. J. Forest. 28: 474-491.

25. Meginnis, H. G. 1935. Effect of cover on surface run-off and erosion in the loessial uplands of Mississippi. U. S. Dep. Agr. Circ. 347, 15 pp.

26. Metz, L. J., Lotti, T., and Klawitter, R. A. 1961. Some effects of prescribed burning on Coastal Plain forest soil. USDA Forest Serv. Southeast. Forest Exp. Sta. Pap. 133, 10 pp.

27. Moehring, D. M., Grano, C. X, and Bassett, J. R. 1966. Properties of forested loess soils after repeated prescribed burns. South. Forest Exp. Sta., U. S. Forest Serv. Res. Note SO-40, 4 pp.

28. Orr, H. K. 1970. Runoff and erosion control by seeded and native vegetation on a forest burn. Rocky Mt. Forest & Range Exp. Sta., USDA Forest Serv. Res. Pap. RM-60, 12 pp.

29. Pope, J. B., Archer, J. C., Johnson, P. R., and others. 1946. Investigations in erosion control and reclamation of eroded sandy clay lands of Texas, Arkansas, and Louisiana, and the Conservation Experiment Station, Tyler, Texas, 1931-40. USDA Soil Conserv. Serv. Tech. Bull. 916, 76 pp.

30. Puri, A. N., and Asghar, H. G. 1940. Physical characteristics of soil. Vii. Effect of ignition. Soil Sci. 49: 369-378.

31. Roberts, W. B. 1965. Soil temperatures under a pile of burning logs. Aust. Forest. Res. 1(3):21-25.

32. Rowe, P. B. 1955. Effects of the forest floor on disposition of rainfall in pine stands. J. Forest. 53: 342-348.

33. Sampson, A. W. 1944. Effect of chaparral burning on soil erosion and on soil-moisture relations. Ecology 25: 171-191.

34. Scott, V. H., and Burgy, R. H. 1956. Effects of heat and brush burning on the physical properties of certain upland soils that influence infiltration. Soil Sci. 82: 63-70.

35. Smith, R. M., and Stamey, W. L. 1965. Determining the range of tolerable erosion. Soil Sci. 100: 414-424.

36. Sreenivasan, A., and Aurangabadkar, R. K. 1940. Effect of fire-heating on the properties of black cotton soil in comparison with those of grey and of humus-treated soils. Soil Sci. 50: 449-462.

37. Sweeney, J. R., and Biswell, H. H. 1961. Quantitative studies of the removal of litter and duff by fire under controlled conditions. Ecology 42: 572-575.

38. Ursic, S. J. 1969. Hydrologic effects of prescribed burning on abandoned fields in Northern Mississippi. South. Forest Exp. Sta., USDA Forest Serv. Res. Pap. SO-46, 20 pp.

39. _____ 1970. Hydrologic effects of prescribed burning and deadening upland hardwoods in northern Mississippi. South. Forest Exp. Sta., USDA Forest Serv. Res. Pap. SO-54, 15 pp.

40. _____ and Dendy, F. E. 1965. Sediment yields from small watersheds under various land uses and forest covers. Fed. Inter-Agency Sediment Conf. Proc. U. S. Dep. Agr. Misc. Pub. 970, pp. 47-52.

41. Vogl, R. J., and Ryder, C. 1969. Effects of slash burning on conifer reproduction in Montana's Mission Range. Northwest Sci. 43: 135-147.

COMMENTS

Fire has been a dominant, controlling factor in the development and maintenance of the southern pine forest. Its exclusion in modern times has resulted in significant and sometimes unwanted changes in species composition of the forest, even to the exclusion of fire-dependent species, such as longleaf pine, in some areas. I is significant, that at this time of environmental concern, this sy posium openly discusses the pros and cons of prescribed burning as management tool in southern forestry. Perhaps this will encourage an examination of other forest practices which are subject to publi criticism.

Current knowledge indicates that physical soil properties in the Coastal Plain are not noticeably damaged by repeated prescribed fires. This is due primarily to incomplete burning of the forest litter that leaves a charred but protective mat on the mineral soil surface. As Ralston and Hatchell point out, this mat reduces raindrop impact, minimizing soil splattering and plugging of soil macro pores. Wildfire, on the other hand, may consume the entire litter mat and expose the mineral soil to erosion forces of the atmosphere Thus, erosion is less likely to occur following prescribed fire tha wildfire.

Under what conditions might prescribed burning have a detrimental effect upon soils in the Coastal Plain? As already mentioned, soil damage is greatest when the mineral soil is completely exposed. This may occur as a result of 'hot fires' in heavy fuels or where annually prescribed fires are used. Fortunately, hot spots occupy only a small area in most prescribed burns and annual fires are not necessary nor recommended.

Where mineral soil is exposed, plugging of soil pores and reduced infiltration are more likely to occur on fine sandy and silt loam soils than on clay. Aggregation of soil particles and resistance to dispersion are usually greater in the heavier soils. In the lower Coastal Plain, soil damage consists primarily of reduced macropore volume, reduced infiltration, and increased bulk density in the surface horizon. Occasionally the damage may be severe enough to prevent seedling establishment. In the upper Coastal Plain, with its increased relief, accentuated runoff and erosion of exposed soils may occur, causing severe and sometimes permanent reduction in site productivity. Prescribed burning should be cautiously applied or avoided on soils with a history of erosion. Stabilization of exposed soils depends upon establishment of a protective cover. In most areas this occurs rapidly with natural succession. Correction of soil damage (especially on eroded sites), however, may require years.

At present, some benefits from prescribed burning in the pineywoods are: reduction of fuel hazards lessens the devastating impact of wildfires; increased seedling establishment; and reduced competition from understory species on droughty sites increases soil water availability to crop trees. Complete elimination of the understory, however, may not be desirable. Many of our understory plants are important in nutrient cycling, which may foster an active microbial population and good physical conditions in the surface soil. These plants also provide necessary cover and food for wildlife. A need exists for additional research in this area of soil productivity.

Alternative procedures to prescribed burning, e.g., intensive site preparation, usually disturb the soils' physical properties more severely than burning. Chemical control of competitive species, short of complete removal, may be less damaging than prescribed fire, but this practice is under attack due to other possible impacts upon the forest ecosystem. Properly applied, prescribed fires are less likely to impair the soil environment than are alternative forest practices, especially if done in accordance with well established procedures that have been developed over many years of research experience with burning.

David M. Moehring
Range Science Department
Texas A&M University
College Station, Texas

EFFECTS OF PRESCRIBED BURNING ON SOIL CHEMICAL PROPERTIES AND NUTRIENT AVAILABILITY

Carol G. Wells
Southeastern Forest Experiment Station
Forestry Sciences Laboratory
Research Triangle Park, North Carolina

Understanding the effects of prescribed burning on soil properties is important in forestry applications. If burning has no detrimental effect on soil, it can be used for fuel reduction and hardwood control. However, if burning does have an adverse influence on soils, that adversity could be a major consideration in not using fire. Of course, we should initially recognize that there is no one answer to the problem of the effects of burning on soil chemical properties, because the kind of soil, climate, vegetation, and intensity of burn will all have a bearing on the final decision.

Both burning and natural biological decomposition release mineral elements from organic matter to the soil. In biological decomposition, nutrient release is slow and steady, with most of the released nutrients taken up by plants on the site. In some instances, the annual release may be quite small; for example, a young pine stand still accumulating a forest floor. As a result of a burn, nutrients are released rapidly and much of the soluble mineral material and some fine organic residues may move down the profile.

After burning, the fate and movement of the released elements through the profile depend on the characteristics of the soils' organic and mineral layers and the nutrient uptake by plants on the site. When only the upper part of the forest floor is burned, the unburned residue has the capacity to adsorb or utilize biologically a portion of the soluble elements. Some materials may be lost by runoff, but most reach the mineral soil where they can accumulate near the surface, leach deeper into the profile, be used by plants, or, in soils with excessive drainage,

enter the ground water. The influence of burning on soil organic matter and nitrogen are of particular importance because these two factors have a strong influence on soil fertility and productivity.

A 20-year prescribed burn study in the Coastal Plain.--We have recently completed a report on a study of 20 years of prescribed burning in the South Carolina Coastal Plain.[1] Interim results after 10 years of burning were reported by Metz (9). The longest and most complete of any in the South, this study is the main source of information for this paper. Treatments were check or no burning, periodic winter burn, periodic summer burn, annual winter burn, and annual summer burn. There were four burns in 20 years for the periodic treatments. There were five replications, three on the Santee and two on the Westvaco Forest. Treatment effects on nutrient concentrations were tested by chemical analyses, and on nutrient uptake by growing loblolly pine seedlings in pots of soil.

The soils were mainly Coxville very fine sandy loam, but several other series were also found on the plots. All soils were poorly or very poorly drained, nearly level, and very acid. The humus type was a duff mull and the A horizon was about 6 inches thick. The soils in this study are common in the flatwoods of the lower Coastal Plain.

Organic matter.--The most obvious effect of burning on the soil is the reduction in the forest floor. Even in the annually burned plots, charred branches and needles covered the mineral soil. Where periodic fires had been used, except for the first year or two after burning, there was little visible change in the forest floor.

An accurate measure of the effect of burn severity on the forest floor is weight loss. Ranking the treatments on a weight-loss scale, from the most severe to the least severe, showed the annual summer burn the most severe, followed by annual winter, periodic summer, periodic winter, and check treatments (fig. 1). There was no statistically significant difference in the forest floor between the check and the periodic winter burn treatments, but all others differed significantly. After 20 years, annual summer and annual winter burns reduced the forest floor to 7,000 and 13,000 lb. per acre, respectively.

Forest floor samples collected immediately after a periodic winter burn showed a loss of 6,500 lb. of the 24,000 lb. per acre of the forest floor initially present. After 20 years and four burns of this type, however, the average forest floor, burned periodically in the winter, was reduced by only 2,000 lb. per acre. Periodic summer burns consumed more organic matter, yet after four such burns, the forest floor decreased by only 8,000 lb. per acre.

---

[1] Wells, Carol G., and Hatchell, Glyndon E. Some effects of prescribed burning on coastal plain forest soil. (In preparation for Forest Sci. Monogr.)

The loss for a single winter burn is comparable to the loss found by Brender and Cooper (1) who reported fuel consumption of 4,800 to 6,300 lb. per acre in a loblolly pine stand in the Georgia Piedmont.

Several studies across the South have given comparable results over a shorter span of time. In Arkansas (10), 10 annual burns decreased the forest floor from 11,000 to 4,000 lb. per acre. On a wet site in the Virginia Coastal Plain (11), four annual winter and three summer burns removed 14 of the 36 tons of forest floor. These reports and our study show that prescribed burning does not remove all of the forest floor, and that under some conditions, a single burn may remove only a small percentage of it.

Organic matter in the mineral soil in burned plots increased over the 20-year period. For the 0- to 2-inch depth, there was about 30 percent more organic matter in the annually burned plots than in the check plots, but there was no difference between treatments at the 2- to 4-inch depth.

A comparison of organic matter in the 0- to 2-inch depth at the end of the 10th and 20th years shows that most of the increase in organic matter occurred in the first 10 years. The increase in organic matter during the first 10 years was a result of burning the forest floor that had accumulated before the treatments began, whereas annual litterfall was the only fuel during the second 10 years and the established soil-organic matter level remained near the same. When the influence of fire on organic matter in both the forest floor and the 0 to 4 inches of mineral soil was taken into account, the principal effect of burning was the redistribution of the organic matter in the profile, and not in any reduction.

Nitrogen.--In the South Carolina study area, as in other regions, nitrogen is highly correlated with organic matter. When the forest floor was destroyed by burning, in all treatments except the periodic winter burn, nitrogen significantly decreased in the same order as burn severity increased. As nitrogen decreased in the forest floor, however, it was accumulated at about the same rate in the 0- to 2-inch layer of mineral soil. Again, as with the increase of organic matter in the 0- to 2-inch layer, most of the nitrogen was accumulated during the first 10 years of burning.

Sampling before and after a periodic winter burn showed that the single burn caused a loss of 100 lb. of nitrogen per acre. Four of these burns in 20 years would have volatilized 400 lb. of nitrogen. More severe burning over the 20-year study period would have destroyed a larger portion of the forest floor and produced even greater nitrogen losses; yet when total nitrogen was summed through the 4 inches of mineral soil, losses were not detectable.

Two annual burned plots showed nitrogen increases of 500 lb. and 900 lb. per acre during the second 10 years of the study. Investigation indicated greater nitrogen-fixing activity on annual burned plots than on control plots or unburned areas surrounding the plots (5). The plots with the greatest nitrogen accumulation were the wettest and this combination, together with the effects of

burning, could have stimulated nitrogen fixation by anaerobic, nonsymbiotic microorganisms. Other workers have also suggested increased nitrogen fixation after burning (8, 14).

Phosphorus, potassium, calcium, and magnesium.--At the end of 20 years of burning treatments, phosphorus was not significantly changed in the 0- to 2- or 2- to 4-inch depths; but when summed for the 0 to 4 inches, there was significantly more phosphorus in the annual winter burn plots than in the check plots (table 1). Potassium was not influenced by burning. Calcium and magnesium increased significantly in the 0- to 2-inch depth but not in the 2- to 4-inch depth..

Table 1.--Weight of phosphorus, potassium, calcium, and magnesium in the forest floor (F.F.), 0 to 2 and 2 to 4 inches of mineral soil

Layer	Annual summer	Annual winter	Periodic summer	Periodic winter	Check
			PHOSPHORUS[a]		
	- - - - - - - - - -		lb. per acre	- - - - - - - - - -	
F.F.	3.6	8.0	10.4	14.8	16.2
0 to 2	3.7	4.1	3.3	2.9	2.9
2 to 4	1.5	1.8	1.6	1.4	1.4
0 to 4	5.2	5.9	4.9	4.3	4.3
			POTASSIUM[a]		
F.F.	5.4	13.1	13.8	23.7	24.7
0 to 2	16.6	18.9	14.8	15.5	15.6
2 to 4	9.0	11.3	9.8	8.4	8.9
0 to 4	25.6	30.2	24.6	23.9	24.5
			CALCIUM[a]		
F.F.	40	77	124	134	140
0 to 2	142	74	101	51	29
2 to 4	55	27	72	23	16
0 to 4	197	101	173	74	45
			MAGNESIUM[a]		
F.F.	6.8	13.9	19.1	24.3	27.5
0 to 2	21.9	16.8	16.5	11.1	9.5
2 to 4	13.4	10.0	10.7	6.6	6.6
0 to 4	35.3	26.8	27.2	17.7	16.1

[a] Quantities are not comparable between forest floor and 4 inches of mineral soil because only extractable quantities were measured in the mineral soil and total analysis was made of the forest floor.

A comparison of the amount of phosphorus, potassium, calcium, and magnesium in the forest floor of burned and check plots shows that treatment produced relatively small differences. The most severe treatment, annual summer burning, moved only 13, 20, 100, and 21 lb. per acre of phosphorus, potassium, calcium, and magnesium, respectively, from the forest floor to the mineral soil over the 20-year period. These quantities had a very small effect on nutrients in the mineral soil when considered on an annual basis. Therefore, the soils are still low in exchangeable cations and available phosphorus.

At the end of 10 years, both annual treatments contained significantly more phosphorus in the 0- to 2-inch layer than the check and the periodic winter treatments, and the annual summer fire treatment was greater than the periodic summer fire treatment (9). There was significantly more magnesium in the 0- to 2-inch soil depth of the annual summer fire treatment than in the periodic treatment or check. Calcium showed an increase from burning, but the effect was statistically nonsignificant.

The effect of burning on mineral elements has, under some conditions, been too small to be significant (10, 12, 16). In general, burning has increased exchangeable calcium and magnesium (2, 3, 4, 7, 15).

The literature has not always shown the quantity and content of the burned material. For this reason, it is not now possible to quantitatively compare and develop methods to predict the results of a burning treatment. However, for mineral elements, basic principles can be applied to quantities of forest floor, soil chemical properties, texture, and drainage. For example, a study in Arkansas (10) may be compared with the one in South Carolina.

In Arkansas, in a loblolly-shortleaf pine stand with 11,000 lb. of forest floor per acre, 10 years of biennial and annual burning on imperfectly drained Grenada and Calloway silt loam had no effect on pH and nutrients in the 0- to 2- and 2- to 4-inch depths of mineral soil. In the South Carolina study, the soil was poorly to very poorly drained, had 16,000 lb. of forest floor per acre, and 10 years of burning increased the pH, phosphorus, calcium, and magnesium in the 0 to 2 inches of mineral soil. Annual burns decreased the forest floor to about the same amount in both studies. Differences in results could be attributed to soil chemical properties, drainage, and the amount of forest floor burned in the two studies. Exchangeable calcium and magnesium in the 0- to 2-inch depth of the Arkansas soil were 900 and 180 p.p.m. compared to 174 and 52 p.p.m. in the South Carolina soil. The amounts of these elements released by burning would be very small in comparison with the natural amounts in the Arkansas soil, but they would be important for the South Carolina soil. There was a greater possibility for leaching of elements through the surface 4 inches of the Arkansas soil, although leaching did not appear to be a factor.

Soil pH.--In this very acid, poorly drained soil, 20 years of burning decreased the acidity from pH 3.5 to 4.0 in the F and H horizons, and from 4.2 to 4.6 in the 0 to 2 inches of mineral soil.

There was no significant change in the 2 to 4 inches of mineral soil. Most of the change in pH occurred during the first 10 years of burning. The decrease in acidity of the surface layer was the result of ash residues which contained basic elements. The magnitude of change in pH depends on the amount of ash, the quantity of potassium, calcium, and magnesium in the ash, and the texture and organic-matter content of the soil. Ash produced by burning will increase pH more and to a greater depth in an organic-matter deficient sandy soil that has a low cation exchange capacity than it will in a soil with more organic matter and clay and a higher cation exchange capacity. In addition to the release of basic ions, destroying organic matter by burning reduces the formation of organic acids. These acids, formed during biological decomposition, are in part responsibile for soil acidity.

Nutrient availability by pot experiments.--Nutrient availability is often evaluated by pot experiments. The lack of knowledge about the form of nitrogen residues after burning makes this type of experiment particularly adaptable to nitrogen investigations. On ponderosa pine in the Coastal Range of northern California, Vlamis et al. (13) found burning treatments increased the nitrogen- and phosphorus-supplying power of the soil to indicator lettuce plants. The increase was considerably greater when tests were made 1 year after burning than it was after 2 years. In a second pot experiment, Vlamis and Gowans (14) found that brush burning increased the nitrogen, phosphorus, and sulfur supply to plants on soils acutely deficient in these elements. Wahlenberg (15) reported an increase in available nitrogen, exchangeable calcium, and organic matter after burning; and in greenhouse tests, slash pine grew better on the burned soil. Responses to the mineral elements released in burning are expected when supplies of the elements are limited. In contrast to this increased growth on the burned soil, spruce seedlings in pots of soils from repeatedly burned hardwood stands had poorer growth (6).

In South Carolina, two experiments to study seedling growth and nutrient uptake were conducted with soil from the burning treatment plots. For a test of seedling growth on undisturbed soil, cores 4½ inches in diameter and 5 inches deep were taken from the A horizon. The forest floor was left intact and the cores were placed in ½-gal. pots. In another study, six 1-gal. pots were filled with a mixed soil from the 0- to 2-inch mineral layer of each treatment on the Santee Forest. The soil of three pots was covered with a forest floor representative of that treatment, and the remaining three pots were covered with glass wool. After loblolly pine seedlings were grown in the pots for about 6 months, they were measured, removed from the pots, weighed, and analyzed for nutrient content.

Burning treatments had no effect on the growth of plants, but there was a tendency for fire to influence the uptake of some nutrients (table 2). Uptake of nitrogen by the seedlings had a similar pattern in both core and mixed soil pots. Although

plants grown in soil from annual summer burns took up 16 to 40 percent less nitrogen than plants grown in soil from periodic winter burn and check treatments, the burning treatment effect on nitrogen uptake was not significant.

Table 2.--Uptake of N and P by seedlings in the cores and mixed soil

Burning treatment	Cores	Mixed soils: Forest floor	Mixed soils: Glass wool
	NITROGEN		
	- - - - - - mg./pot - - - - - -		
Check	41	93	100
Periodic winter	44	103	109
Periodic summer	38	89	107
Annual winter	36	86	86
Annual summer	28	60	69
	PHOSPHORUS		
Check	2.8	5.3	4.2
Periodic winter	4.2	7.1	6.3
Periodic summer	3.1	6.8	7.3
Annual winter	3.5	7.8	8.2
Annual summer	2.7	6.3	7.2

Seedling weight and nutrient uptake was greater for the seedlings with glass wool mulch than for those having a forest floor cover. In a similar test of a Piedmont soil with 0.02 percent nitrogen, in contrast to an average of 0.15 percent nitrogen for the Coastal Plain soil, loblolly pine grew much larger with forest floor cover. In the test of Piedmont soil, the forest floor provided about 50 percent of the nitrogen, phosphorus, and potassium for the seedlings (17). Burning the forest floor of low nitrogen soil would affect seedlings much more than in more fertile soil.

Phosphorus and potassium uptake by seedlings grown in soil cores from burned plots was significantly greater than the uptake by seedlings grown in soil from the check, but there was no statistically significant difference due to burning in the mixed soil (table 2). Uptake of calcium, magnesium, zinc, and manganese was not significantly affected by burning. The uptake of nitrogen and phosphorus was highly correlated ($r = 0.70$); nitrogen uptake was affected by phosphorus uptake as indicated by phosphorus deficiency in some plots. To better test the effect of burning treatment on nitrogen uptake, a statistical analysis was made with phosphorus as covariant and nitrogen as the treatment variable. After this adjustment for phosphorus in the mixed soil experiment, the effect of burning treatment on nitrogen uptake was significant at the 10

percent level. The adjusted treatment means of nitrogen uptake followed fire severity with 116 and 66 mg of nitrogen uptake from check and annual summer burn, respectively (table 3).

Table 3.--Calculated uptake and availability percentage of nitrogen for seedlings in the 0 to 2 inches of mixed soil without forest floor

Burning treatment	Uptake	Available
	mg./pot	percent
Check	116	2.48
Periodic winter	111	2.92
Periodic summer	103	1.97
Annual winter	76	1.82
Annual summer	66	1.74

Expressing nitrogen uptake by plants as a percentage of total soil nitrogen is another approach to evaluate nitrogen availability. A comparison of treatments then shows whether burning has produced residual nitrogen which is resistant to biological mineralization. This approach was pursued to investigate nitrogen in the 0 to 2 inches of mineral soil of the mixed soil experiment.

Nitrogen availability percentage was computed as seedling nitrogen uptake per pot divided by total nitrogen in soil x 100. Nitrogen availability percentage was greatest in the periodic winter fire and least in the annual summer fire treatments (table 3). However, the burning treatment effect was not statistically significant.

SUMMARY AND CONCLUSIONS

Prescribed burning of mature southern pine stands normally leaves some of the forest floor, even when annual burns are applied. Generally, prescribed burning in these stands causes small increases in soil pH, organic matter, nitrogen, phosphorus, and exchangeable calcium and magnesium in the surface 2 or 4 inches of mineral soil. The effect of burning on the change in mineral element status in the soil is related to the amount and content of those elements in the burned organic matter.

In the 20-year South Carolina Coastal Plain study, a single winter burn volatilized 6,500 of the 25,000 lb. of forest floor per acre and 100 of the 300 lb. of nitrogen per acre. Under some conditions, burning may increase nitrogen fixation in the soil and thus compensate for nitrogen loss to the atmosphere.

Pot experiments with soils from burned forests in different locations have shown increased uptake of nitrogen and phosphorus after a single burn. In the 20-year burn study in South Carolina, seedlings grown in pots of soil from burned plots had a greater

uptake of phosphorus than did the controls. Annual burn treatments, however, showed tendencies for nitrogen uptake by seedlings to decrease. This suggests that nitrogen accumulated in the upper 2 inches of mineral soil as a result of repeated burning is less available to plants than nitrogen in soil from nonburned plots.

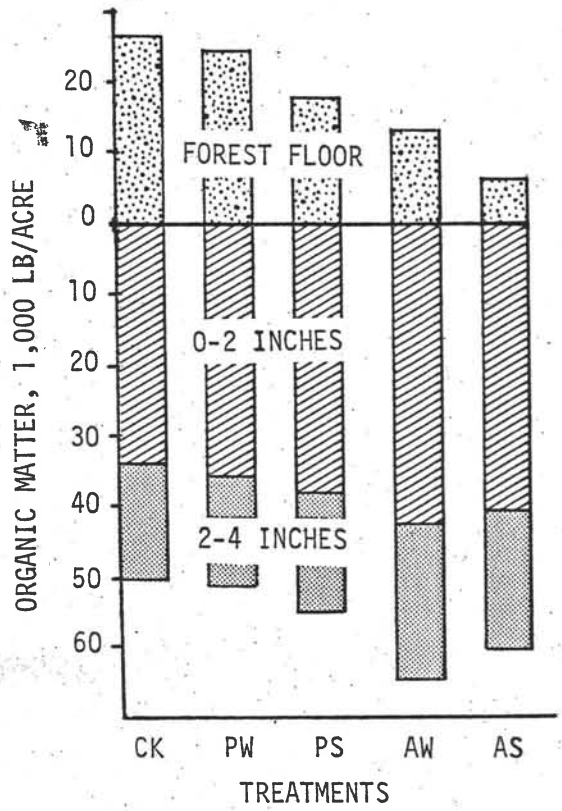

Figure 1.--Organic matter in the forest floor, 0-2, and 2-4 inches of mineral soil for check (CK), periodic winter (PW), periodic summer (PS), annual winter (AW), and annual summer (AS) treatments after 20 years.

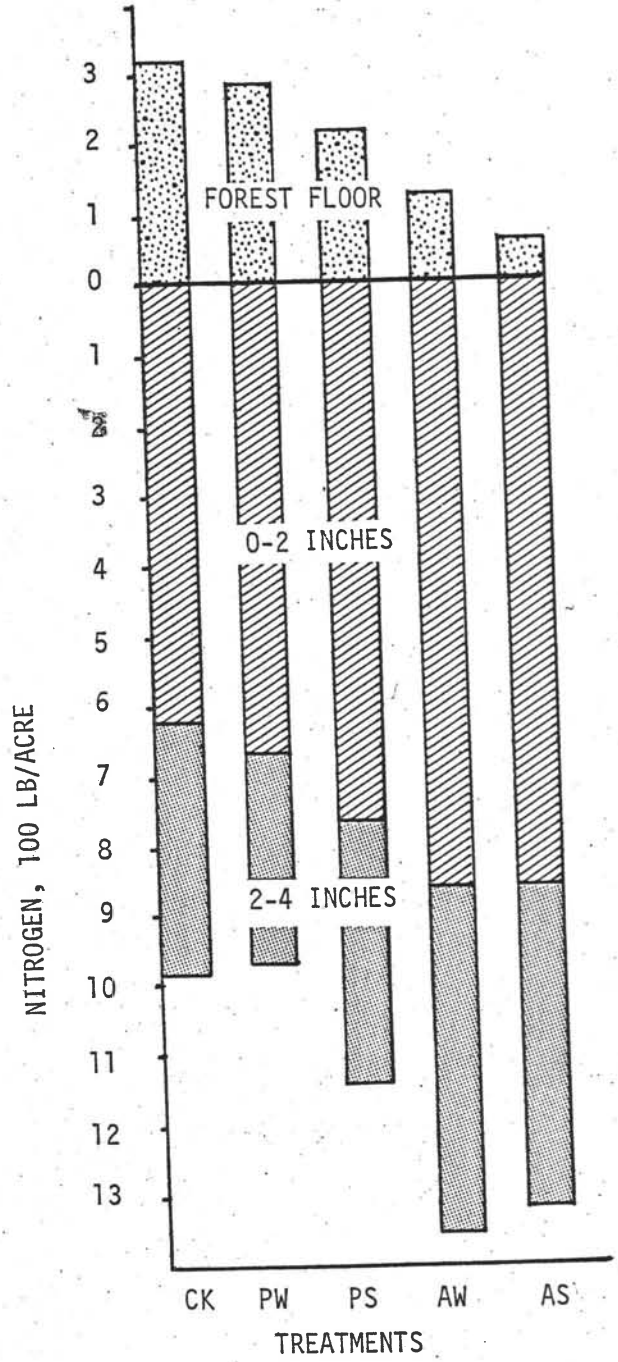

Figure 2.--Nitrogen in the forest floor, 0-2, and 2-4 inches of mineral soil for check (CK), periodic winter (PW), periodic summer (PS), annual winter (AW), and annual summer (AS) treatments after 20 years.

LITERATURE CITED

1. Brender, E. V., and Cooper, R. W. 1968. Prescribed burning in Georgia's Piedmont loblolly pine stands. J. Forest. 66: 31-36.

2. Burns, P. Y. 1952. Effect of fire on forest soils in the pine barren region of New Jersey. Yale Univ. Sch. Forest. Bull. 57, 50 pp.

3. Heyward, F. 1936. Soil changes associated with forest fires in the longleaf pine region of the South. Amer. Soil Surv. Assoc. Bull. 17: 41-42.

4. _____ and Barnette, R. M. 1934. Effect of frequent fires on chemical composition of forest soils in the longleaf pine region. Fla. Agr. Exp. Sta. Tech. Bull. 265.

5. Jorgensen, J. R., and Wells, C. G. (In press.) Apparent N fixation in soil influenced by prescribed burning. Soil Sci. Soc. Amer. Proc.

6. Lunt, Herbert A. 1941. A pot culture experiment with undisturbed forest soil. Soil Sci. Soc. Amer. Proc. 6: 403.

7. _____ 1950. Liming and twenty years of litter raking and burning under red (and white) pine. Soil Sci. Soc. Amer. Proc. 15: 381-390.

8. Lutz, H. J. 1956. Ecological effects of forest fires in the interior of Alaska. U. S. Dep. Agr. Tech. Bull. 1133, 121 pp.

9. Metz, L. J., Lotti, T., and Klawitter, R. A. 1961. Some effects of prescribed burning on coastal plain forest soil. USDA Forest Serv. Southeast. Forest Exp. Sta. Pap. 133, 10 pp.

10. Moehring, D. M., Grano, C. X, and Bassett, J. R. 1966. Properties of forested loess soils after repeated prescribed burns. South. Forest Exp. Sta., USDA Forest Serv. Res. Note SO-40, 4 pp.

11. Romancier, Robert M. 1960. Reduction of fuel accumulations with fire. USDA Forest Serv. Southeast. Forest Exp. Sta. Res. Notes 143, 2 pp.

12. Suman, R. F., and Carter, R. L. 1954. Burning and grazing have little effect on chemical properties of coastal plain forest soils. USDA Forest Serv. Southeast. Forest Exp. Sta. Res. Notes 56, 2 pp.

13. Vlamis, J., Biswell, H. H., and Schultz, A. M. 1955. Effects of prescribed burning on soil fertility in second growth ponderosa pine. J. Forest. 53: 905-909.

14. _____ and Gowans, K. D. 1961. Availability of nitrogen, phosphorus, and sulfur after brush burning. J. Range Manage. 14: 38-40.

15. Wahlenberg, W. G. 1935. Effect of fire and grazing on soil properties and the natural reproduction of longleaf pine. J. Forest. 33: 331-338.

16. Wahlenberg, W. G., Greene, S. W., and Reed, H. R. 1939. Effects of fire and cattle grazing on longleaf pine lands, as studies at McNeill, Mississippi. U. S. Dep. Agr. Tech. Bull. 683, 52 pp.

17. Wells, C. G., and Metz, L. J. (In press.) Nutrient availability in the soil of a loblolly pine stand. Soil Sci. Soc. Amer. Proc.

COMMENTS

This piece of work at the Santee Forest is a magnificient endeavor--one of very few where we have actually examined the effect of prescribed burning on the chemical properties of the soil. All too often, we neglect this part of the soil--the chemical features--and certainly we do need this sort of information.

This paper brings up two or three points that I would like to emphasize. The first is that the soil, as a natural body, has been formed over thousands of years--even here in the coastal plains, where the soil is relatively young geologically, it is more than 50 thousand years old. We have heard during these sessions over the last 2 days, particularly yesterday, that most of our soils were subjected to burning, perhaps even annual burning, by the Indians. What I'm trying to get at is this--that these soils have reached a state of equillibrium under conditions of frequent burning and it isn't too surprising that we haven't found great changes in soil properties due to controlled burning over a period of 20 years because these same areas have been burned before, literally for thousands of years. We don't make major changes in the soil over long periods of time without some very drastic action. We get short-time changes, not long-time changes.

Another point is that prescribed burning, if done correctly, does not actually affect the mineral soil very much--not directly. As Bill Ralston told you earlier, in a light burn the mineral soil is not heated to any great extent. So what we're talking about primarily is the forest floor--the burn as it affects the forest floor, not the mineral soil directly. There are two or three things to remember in this. One is that the forest floor itself is constantly being oxidized by microorganisms, as mentioned in Carol Wells' paper. Fire is a rapid method of oxidizing the organic material of the forest floor. During burning there is also a rapid release of calcium, magnesium, potassium, and sodium. This release, to be sure, also takes place from microbiological action, in a similar manner to burning, except that it takes place much more slowly. With a rapid release from burning, we get an increase of pH in the mineral soil, and although this may not be very great, 2 to 4 inches below the surface, as was shown in Wells' paper, certainly at the soil surface the pH can be quite high. These ash--or the bases which make up the ash--can raise the pH drastically at this interface and this, in turn, may have an influence on such things as the

production of legumes or, as suggested earlier, in nonsymbiotic fixation of nitrogen, either by anaerobic organisms, blue-green algae, or some other microorganisms.

When we speak of organic matter and nitrogen of the forest floor, there seems to be a contradiction. There is no question that nitrogen is lost by volatilization during burning. Wells estimated that perhaps as much as 20 pounds of nitrogen per acre per year was lost, on an average, from periodic burning, and 4 to 5 thousand pounds of organic matter per acre per year. So how do we account for a gain in organic matter and in nitrogen in the mineral soil? First, let us remember that we are talking about a gain in the mineral soil and not necessarily an overall gain in the ecosystem. It is even rather difficult to understand how we can come up with "no change" in nitrogen when we add the forest floor and the mineral soil together--and the organic matter comes out about the same. So, apparently what we are doing in rapid oxidation by burning is to burn that part of the forest floor that is most rapidly oxidized by microorganisms. This means that even without burning it, part of the organic matter will be fairly rapidly oxidized, but the part that is left after the burn does not oxidize, or does not decompose at a very rapid rate.

Yesterday Mr. Cooper mentioned that legumes were found five times more numerously in burned areas than in nonburned areas. There is the possibility, of course, that when we remove this litter layer by burning we encourage the growth of grasses and legumes--grass roots that contribute to an increase in organic matter and legumes that contribute to an increase in nitrogen as well as organic matter in this burned area. There is also a possibility of a movement of colloidal-size particles of charred material into the surface layer of these sandy soils. In other words, an apparent increase in organic matter in the mineral soil results simply by movement down of this material. A material--as suggested by Dr. Wells' paper--that does not decompose very rapidly. Dr. Viro in Finland has also reported that this charred material does not decompose very rapidly. So what we have then is a buildup of organic material in the surface of the mineral fraction of our soil--that is the A_1 horizon--with a staffe material.

Although we don't find that our soils are being enriched by burning, at least we should take some hope in the fact that they are not being destroyed. Over these thousands of years, burning hasn't changed the fertility of our soils greatly one way or the other. There are short-term losses of nitrogen and increases in the availability of bases, but the soil is buffered and soon reaches its equillibrium again.

This study points up the need to find out what happens to phosphorus and other nutrients after burning, particularly in the flatwoods soils. We must be sure that we're not getting a loss of these materials in the runoff or in leaching. I think it is not

good enough to assume that we're getting no loss of these elements. What we need in a study of this type, and this is a very good one, is to do some further, more complete, balance sheets on the nutrients in the soil and in the trees themselves.

William L. Pritchett
Soils Department
University of Florida
Gainesville, Florida

PRESCRIBED BURNING AND SOIL MESOFAUNA ON THE SANTEE EXPERIMENTAL FOREST

Louis J. Metz
Southeastern Forest Experiment Station
Forestry Sciences Laboratory
Raleigh, North Carolina

Maurice H. Farrier
North Carolina State University at Raleigh
Department of Entomology and Forestry
Raleigh, North Carolina

A prescribed burn will produce changes on a forest site. These changes may be slight or severe, temporary or permanent, beneficial or harmful. This report covers these effects on one small facet of the forest system, the mesofauna.

Animals of the forest vary in size from deer and bear to those which can be seen only through a microscope. Soil fauna includes those animals living in both the forest floor and the mineral soil. Some of these creatures live in the floor, some in the soil, and many move back and forth between these two strata. Animals included in the soil fauna may be divided into three groups, depending on size. The microfauna includes the very smallest, such as nematodes and protozoa; the mesofaunal group consists of mites, collembolans, and small insects; and the macrofauna refers to snails, earthworms, and other similar-sized animals. Vertebrates, such as mice and moles, are not included in this classification.

Why study the soil mesofauna? They are far outnumbered by the microfauna, and their size is exceeded by many other animals. Academically, they have generally been bypassed by zoologists and entomologists; but, practically, they play an important role in the decomposition process. Bacteria and fungi are often recognized as important decomposers, but the mesofauna have been overlooked. They play a big part in the process by breaking organic tissue into

smaller and smaller pieces. The smaller these particles become, the more susceptible they are to action by other organisms involved in decomposition. A Russian soil biologist placed naphthalene, which reduces the mesofaunal population but not the bacteria and fungi, on oak litter. During the 140-day experiment, the litter treated with naphthalene lost 9 percent of its original weight, while untreated litter lost 55 percent.

With this in mind, we decided to study the mesofauna on three types of plots of the Prescribed Fire Study conducted on the Santee Experimental Forest in Berkeley County, South Carolina: the control or nonburned plots; the annually burned plots; and the plots periodically burned in winter (these plots had not been burned for 38 to 46 months). The control is the benchmark to compare with other treatments; the annual burn is an example of an extreme treatment; and the winter periodic burn is an example of the usual practice on forest land.

Little work has been done to determine the effect of fire on soil fauna, and we found only one study in the United States concerned with prescribed burning. This study was conducted on the Duke Forest in Durham County, North Carolina. Because no microscopic work was done in the study, the only mites found were adult chiggers (Trombidium sp. and Microtrombidium sp.), and most were found on the nonburned area.

All other work in the United States, and there have been only a few such studies, concern the effect of wildfires on soil fauna. Work on the effect of fire on soil fauna in Europe has been done with both prescribed fires and wildfires. However, the prescribed fires were not comparable to those in the southeastern United States. For example, in the Scandanavian countries, forest stands are clearcut and then burned. In the southeastern United States, burns are made in forest stands and usually the only fuel is the surface part of the forest floor.

METHODS

To verify that the vertical distribution of soil fauna on the Santee Experimental Forest was comparable with previous reports, that is, that the majority of the soil fauna is in the floor and surface mineral soil, we sampled the forest floor and the mineral soil to a depth of 18 cm. For the four profiles sampled, 85 percent of the animals recovered were in the forest floor and surface 3 cm. of mineral soil. Accordingly, we decided to restrict our sampling to these depths.

On the control and periodically burned plots, the forest floor was subdivided into L, F, and H layers. On the annually burned plots, the F and H layers were combined because they were so thin they could not be separated for collection. The surface of the mineral soil was collected in 1-cm. layers to a depth of 3 cm.

Samples were collected on 10 sampling days, between February and November 1970, on three replicates of each of the three treatments. On June 15-16, 1970, samples were also collected a few hours before an annual summer burn and then again the day after the burn from the same plot.

For the L layer, samples collected were 225 sq. cm. in area; and, for the other layers of the floor and the mineral soil, the samples were 20 sq. cm. It is difficult to sample the L layer on a small area, and there are relatively few animals present in the layer; hence, the larger area was used. For comparative purposes, the number of animals collected in the L layer was converted to a 20-sq.-cm. basis. Samples of the soil and forest floor were placed on split Tullgren funnels, and animals were extracted into alcohol. After the extractions, the samples were ovendried to a constant weight at 60° C.

Animals carry mineral particles upward into the forest floor, and some mineral matter is scraped up when samples are collected. Thus, floor samples containing the same weights of organic material may weigh different amounts because of intermixed mineral matter. These differences are eliminated by burning the sample in a muffle furnace for 4 hours at 450° C. and determining the volatile matter content. These volatile matter values were used in calculating the number of animals per gram of forest floor.

The specimens collected in the alcohol were grouped with the aid of a stereoscopic microscope into mites, collembolans, and other animals. The latter category included insects, worms, etc. Individual species were not enumerated with respect to distribution in the profiles and treatment effects.

RESULTS AND DISCUSSION

Effect of Burning on Numbers of Mesofauna in the Forest Floor and Mineral Soil

On the three types of plots, comparisons were made of the number of animals found in the floor, the number found in the surface 3 cm. of mineral soil, and the number found in the floor plus the soil combined. The average number of animals found on the three treatments is shown in figure 1.

Comparisons between the control (not burned for 275 months) and periodically burned plots (not burned for 38 to 46 months) showed no significant differences by Duncan's multiple-range test in any animal group (mites, collembolans, other fauna) or in the total numbers of animals present in the forest floor, soil, or floor plus soil. The tests were made on an area basis and on the basis of mites per gram of substrate. There were usually more animals in the floor of the control plots, but in the soil there was no consistent trend.

When the numbers of animals in the forest floors of the control and annually burned plots were compared, significantly more were found in the control. There was no significant difference

between these two treatments in the number of animals present in the mineral soil, although there were consistently more on the annually burned plots. When the number of animals in the floor and soil combined was calculated, there were 2 to 3 times as many in the control for each animal group.

When animal groups were compared on the periodically and annually burned plots, there were significantly more mites and other fauna present in the floor in the periodic burn, but for collembolans there was no significant difference. No significant differences between treatments were detected in any animal group in the mineral soil, but in each instance the numbers in the annually burned soil were larger. For the complete profile, there were significant differences between the periodic and annual burns for mites, other fauna, and all animals combined.

Animals Present Before and After an Annual Summer Burn

To determine the immediate effect of the most severe burning treatment on the mesofauna, samples were collected immediately before and 24 hours after an annual summer burn on June 15-16, 1970 (fig. 2). Forty-four percent of the animals present in the whole profile before the fire were present after the fire. Forty-seven percent of the animals in the mineral soil remained, and 13 percent of those in the floor remained. The numbers of mites were reduced in both the soil and the floor. So few collembolans and other animals were present that any conclusions would be questionable.

Recovery Time on the Santee Burns

The immediate effect of fire has been highlighted by other workers, but the recovery time has not been determined. Recovery time may be defined as the period following a burn after which no significant difference can be detected between conditions on the burned and nearby unburned areas.

The precise recovery time in the present experiment could not be determined because the period of our observations was too short. However, because no significant differences could be detected between animal groups and the weights of the floor in the periodically burned and the control plots, we concluded that these plots did not differ with respect to these two factors. The periodically burned plots were sampled 38 to 46 months after burning. Thus, the recovery time for the periodic burn is 43 months or less (the average length of time since last burning for the 10 sampling days).

The periodic burns were conducted under carefully selected conditions such that usually only the L and part of the F layers were removed. The weights of 20-sq.-cm. samples of the periodically burned floor did not increase noticeably during the 10 months of observation.

On the other hand, there was a marked increase in the average weight of the annually burned floor when samples collected 3

months after a fire (1.46 grams) were compared with those collected 9, 10, and 11 months after a fire (2.50 grams). The rebuilding process was then halted by another fire.

When plots were burned under conditions such that the F and H layers were not consumed and when sufficient time elapsed between burns such that the L layer accumulated and decomposed into the F and H layers, resulting conditions were not greatly different from those on the nonburned control.

SUMMARY

This paper presents the first information on the effect on soil mesofauna of prescribed burning under defined conditions and frequency. Annual summer burning caused reduction of the soil mesofauna immediately after the burn. The immediate effect of prescribed fire on the periodically burned plots was not observed because they were not burned during the period of observation.

Although mesofaunal populations did not differ significantly, a smaller population was noted on the periodically burned plots (burned 38 to 46 months previously) than on the control plots. This differential suggests that the recovery period for this type of burn is less than the 43 months that elapsed since burning. Mineral soil in the annually burned plots consistently had higher populations of mesofauna than did the soil in the periodically burned and control plots, though not significantly so.

We strongly emphasize that the findings of this work are applicable only in the Southeasteastern Coastal Plain where the forest floor of pine stands and the burning techniques used are similar to those used in the Santee burns. Burning with a drier forest floor would probably produce different results. There is no evidence in the literature to indicate whether these data would be applicable to other forest types or burning regimes.

Acknowledgement

The authors wish to thank William P. LeGrande, Jr., and David S. Priester for their assistance in collecting samples.

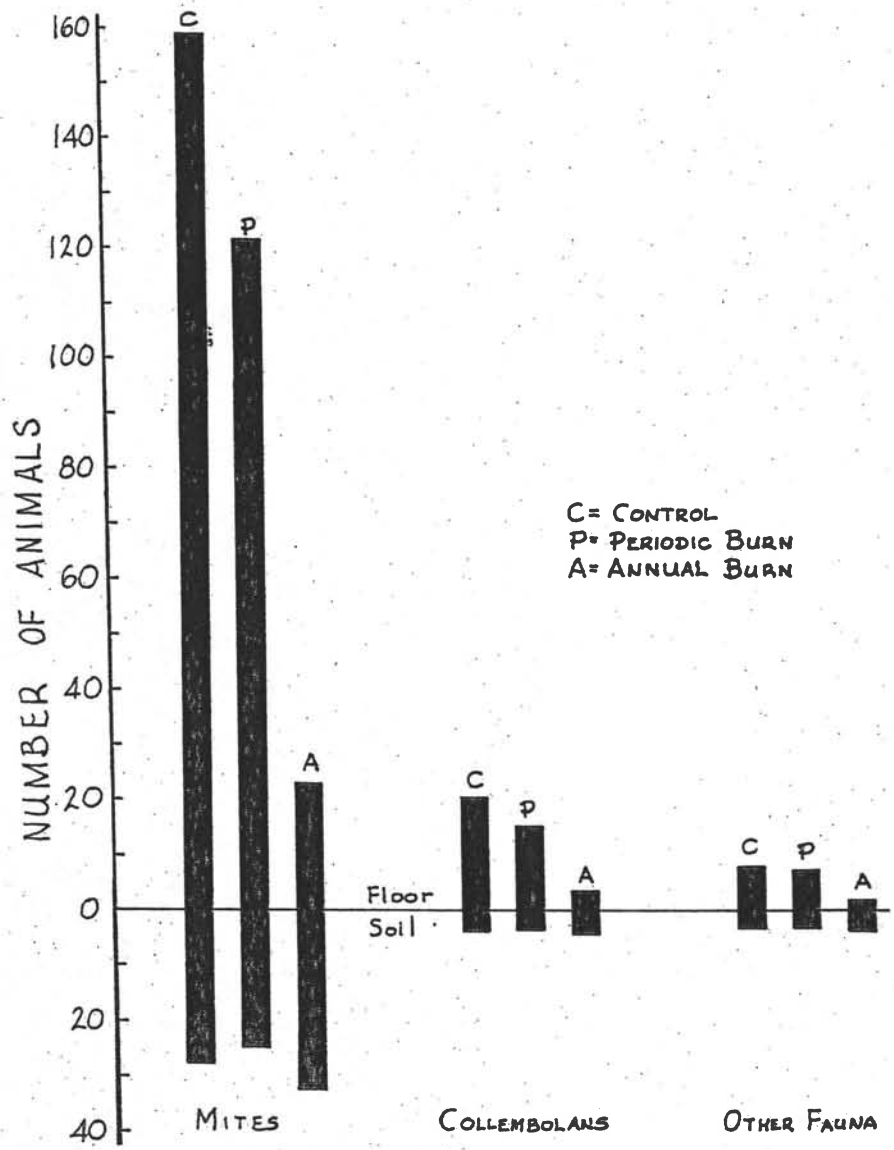

Figure 1.--Average number of animals extracted per 20-sq.-cm. sampl on the three treatments for the 10 sampling days.

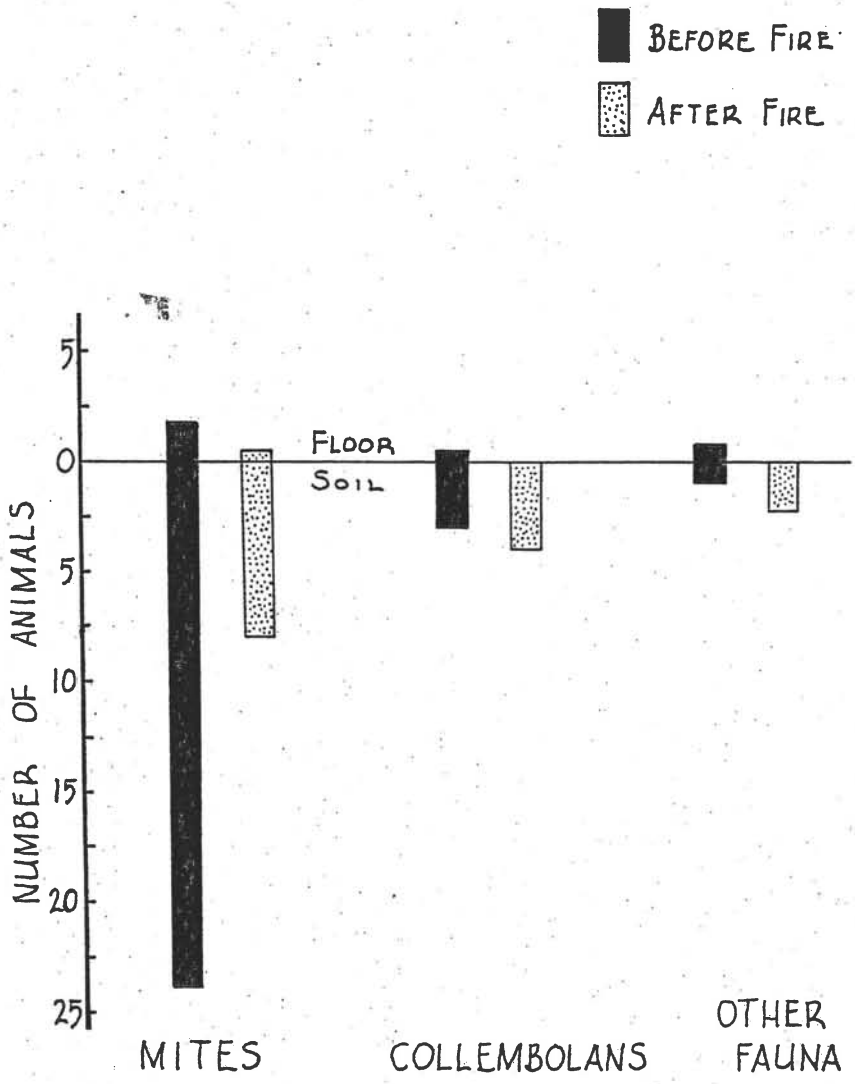

Figure 2.--Average number of animals extracted per 20-sq.-cm. sam
immediately before and 24 hours after an an annual summer burn
June 15-16, 1970.

EFFECTS OF PRESCRIBED BURNING ON THE MICROBIAL CHARACTERISTICS OF SOIL

J. R. Jorgensen and C. S. Hodges, Jr.
Southeastern Forest Experiment Station
Forestry Sciences Laboratory
Research Triangle Park, North Carolina

INTRODUCTION

Prescribed burning has been used to prevent litter buildup and to control the hardwood understory in established forests as well as to prepare seedbeds for regeneration. The effects of burning on the forest floor and vegetation are easily observed, and frequency of burn is often based only on these factors. Repeated burning, however, may also affect other less-apparent site constituents and could have detrimental effects on some of them. One of these site components is the soil microflora responsible for the decomposition of nutrient-containing organic residues and the resulting reuse or recycling of many nutrients during a rotation.

Investigators have reported how soil microflora are influenced by single wildfires, single prescribed burns, broadcast fires, and slash-pile burns; they have not considered repeated burning as might occur under intensive management. In this study we attempted to measure the long-term influence of repeated burning on bacteria + actinomycetes and on fungi found in the soil.

METHODS AND MATERIALS

In December 1966, plots on the Santee Experimental Forest near Charleston, S. C., were sampled to determine the influence of annual winter burns, periodic winter burns, or no-burn treatments on the soil microflora. The interval from the previous burn until sampling was 1 year for the annual winter burn, 8 years for the

periodic winter burn, and 20 years for the no-burn treatment. Average F + H accumulations were 0.137 g./cm.^{2} on annual burn plots, 0.356 g./cm.^{2} on periodic burn plots, and 0.422 g./cm.^{2} on no-burn plots.

Random samples of the F + H layer and of the 0-5 and 13-18 cm. layers of mineral soil were taken from each plot. The two mineral layers roughly corresponded to parts of the A1 and A2 horizons. Soil was assayed for bacteria + actinomycetes and fungi; details of the sampling and assay techniques have been reported (1).

RESULTS

Burning had no statistically significant effect on the number of fungi per gram of mineral soil or F + H layer, even though threefold average differences were found between annual and periodic burn plots (table 1). The fewest fungi in the F + H layer, the layer most affected by burning, were isolated from annual winter burn plots (1.18 million/g.) and the most were isolated from periodic burn plots (3.28 million/g.). The burning treatment had no effect on the number of fungi isolated from mineral soil.

Table 1.--Number of fungi and bacteria + actinomycetes in soil, by burn treatment and soil layer

Soil layer	Burn treatment	Fungi		Bacteria + actinomycetes	
		per g.	per cm.^{2}	per g.	per cm.^{2}
		- - - - - - millions		- - - - - -	
F + H	No burn	1.51	0.64	51.1	21.53
	Periodic burn	3.28	1.16	70.8	25.19
	Annual burn	1.18	0.16	28.2	3.88
0-5 cm.	No burn	0.12		4.1	
	Periodic burn	0.14		3.0	
	Annual burn	0.13		6.5	
13-18 cm.	No burn	0.03		1.3	
	Periodic burn	0.02		1.1	
	Annual burn	0.02		1.1	

The number of bacteria + actinomycetes in the F + H layer was significantly reduced to 28 million/g. in annual burn plots from 71 million/g. in the periodic burn (table 1). The no-burn area with a microorganism population of 51 million/g. did not significantly differ from the other two treatments. Populations in the mineral soil were not significantly affected by any treatment.

When the total number of fungi per unit of surface area was considered, populations on annual winter burn plots were only about one-fourth of those in the no-burn plots and one-seventh of those

in the periodic burn plots. Bacteria + actinomycetes were about six times more plentiful from the no-burn and periodic burn than from the annual burn plots. The large differences in populations per unit area compared to the small differences per gram, were in part the result of burning about two-thirds of the F + H layer in the annual burn plots.

Approximately 50 species or genera of fungi were isolated; one-third of these were considered common and are listed in table 2. Most of the fungi isolated normally produce spores or other distinctive structures on Martin's medium. Many soil fungi do not grow on this medium; if they do grow, they do not produce spores or distinctive characteristics sufficient to enable further identification.

Table 2.--Distribution, by burning treatment, of commonly isolated soil fungi

Fungus	Burning treatment		
	No-burn	Periodic	Annual
Aspergillus parvulus Smith	+[1]	+	+
Cephalosporium asperum March.			+
Cladosporium spp.	+	+	+
Cunninghamella echinulata (Matr.) Thaxt.	+		
Fusidium viride Grove	+	+	
Gliocladium roseum (Lk. ex Fr.) Bainier			+
Metarrhizium anisopliae (Metsch.) Sorok.			+
Mortierella spp.	+	+	+
Mucor fragilis Bainier	+		+
Paecilomyces varioti Bainier			+
Penicillium raistrickii ser.			+
Penicillium spp.	+	+	+
Pestalotia sp.			+
Phycomycete, nonsporing	+	+	+
Scopulariopsis spp.	+	+	+
Trichoderma spp.	+	+	+
Zygorhynchus moelleri Vuillemin	+	+	+

[1] Symbol indicates fungus common in at least one soil layer.

About 40 percent of the fungi isolated from all plots were identified as members of the genus Penicillium. Several species of Mortierella and one or more species of nonsporulating phycomycetes were also numerous. Trichoderma spp. were common regardless of burning treatment, and often their extensive growth prevented the ready identification of slower growing fungi.

Some fungi were associated with a particular burning treatment or soil layer. The P. raistrickii series, Gliocladium roseum, and several other less frequently occurring fungi were most common where annual burning was practiced (table 2). Mortierella marburgensis Linnemann was not found in annual burn plots, but was common

in all soil layers of the no-burn and periodic burn plots. Scopulariopsis spp. were found in all plots, regardless of burn treatment, but they were restricted to the 13-18 cm. layer of mineral soil.

DISCUSSION AND CONCLUSIONS

The long-term effect of annual winter burning was to reduce the weight of the F + H layer by about two-thirds and to produce comparable reductions in the number of microorganisms per unit area. There were also significant decreases of bacteria + actinomycetes per gram of F + H layer with annual burning, but no decrease of fungi. Annual and periodic burning had no effect on microbial populations in the mineral soil--in annual burning of only small accumulations of litter, light fires caused minimal increases in soil temperature; with periodic burning there was a long period between fires. If populations were reduced immediately after a fire, the reductions may have been partially offset by inoculum from unburned areas and the stimulation of the surviving microorganisms. This stimulation could occur through rapid release of inorganic nutrients, the greater availability to the microorganisms of heat-treated organic substrates, and the reduction in competition due to partial sterilization by the fire.

The effects of burning on microorganism populations were generally consistent with those of Wright and Tarrant (3). After allowing 7 months for recovery of microorganism populations, they observed the greatest effect of burning was in the upper portion of the soil and only in severely burned soil was there any influence of fire below 1.5 inches. Where light burns were applied, however, there were no changes in bacteria or actinomycete populations, but severe burns resulted in an increase in the number of these microorganisms. Fungal populations did not recover from the burning as quickly as bacteria, and both light and severe burns reduced their number.

Apparently a number of common soil organisms are stimulated by fire. We found, as did Wright and Tarrant (3), that Gliocladium spp. were more common in burned than unburned plots. Wright and Bollen (2), in the Pacific Northwest, reported burned areas were rapidly colonized by various genera of fungi, many of which were commonly isolated in South Carolina.

The amount of time between burning and sampling probably has an important effect on the degree of change in the microflora that can be attributed to burning. Since a year had passed since the previous annual burn, and 8 years since the previous periodic burn, some litter had accumulated. A general repopulation of burned plots by surviving organisms, plus inoculum from unburned areas during these periods, would have eliminated many of the immediate effects of fire.

Nitrogen mineralization, an important biochemical process carried on by soil microorganisms, was not affected by burning.[1] The proportion of mineral N to total N in nonincubated soil was similar for annual and periodic winter burns and for the no-burn treatment. After incubating these soils and extracting the mineral N, there was still no difference in the proportion of mineral N to total N, although the amount of mineral N increased in all cases.

In summary, there are few indications that prescribed burning has adversely altered the qualitative or quantitative composition of the fungi and bacteria + actinomycete populations to the extent that soil metabolic processes would be impaired. We did not, however, attempt to measure the influence of fire on basidiomycetes or fungi which produce few spores. Many of these organisms in the forest floor are responsible for the breakdown of resistant residues, the byproducts of which may influence the availability of nutrients to higher plants. Neither were pathogens investigated, and it is conceivable that some host-parasite relationships may be altered by burning. Detailed information is needed before conclusions can be drawn about the effects of burning and these specialized aspects of microbiology.

LITERATURE CITED

1. Jorgensen, J. R., and Hodges, C. S., Jr. 1970. Microbial characteristics of a forest soil after twenty years of prescribed burning. Mycologia 62: 721-726.

2. Wright, E., and Bollen, W. B. 1961. Microflora of Douglas-fir forest soil. Ecology 42: 825-828.

3. _____ and Tarrant, R. F. 1957. Microbial soil properties after logging and slash burning. Pacific Northwest Forest & Range Exp. Sta., USDA Forest Serv. Res. Note 157, 5 pp.

COMMENTS

Worldwide there is considerable lack of information on the soil animals, and there has been more work done in Europe than in the U. S. There is, however, a good deal of information available on what we call microflora--the fungi, the actinomycetes, and the bacteria. But the work by Dr. Metz and by some of his coworkers has pointed up one real tough question. You saw that slide showing the number of different types of animals he got out of one vial. If we could do the same things with the fungi, bacteria, and actinomycetes, we would see an even larger profusion of types. One of the difficulties in doing recovery work is that we are almost

---

[1] Wells, C. G., and Hatchell, G. E. Some effects of prescribed burning on Coastal Plain forest soil. (In preparation for Forest Sci. Monogr.)

restricted to looking at numbers of organisms. The real tough question is: "What is the recovery rate of specific organisms?" This is something that has hardly been touched.

Mention was made of the fact nitrification rates had been looked at, and this certainly is important. Ammonification and other transformations are also important, and we don't know a great deal about the sensitivity and recovery rate of organisms that do this.

There was an interesting masters thesis that came out of Australia recently about the influence of "hot" fires on the soil microflora and on the soil nutrients. I think this is a significant piece of work and I hope that eventually we may all have access to its publication. The student looked at the rate of nutrient release in a slash-burning experiment. He looked at the nutrients that were released because of the fire, and then applied similar amounts of nutrients to an unburned soil and measured the growth response. He found that there was a much greater response on the burned plots than could be attributed to simply the increased availability of nutrients. As a consequence, he made a detailed study of the response of the soil microflora to the burns. This resulted in his conclusion that influence of the fire on stimulated growth of reproduction was attributed to changes in the composition of microflora as much as, or perhaps moreso, than to release of the nutrients.

We have done some similar work by looking at the recovery of microflora on fumigated soil. This work was done in the forest nursery, and we found there is a stimulation of growth following fumigation provided that we don't wipe out the mycorrhizal fungi by fumigation. To show you how complex it gets: we found that with normal rates of fumigation we got a reduction in the number of fungal genera which contain our most important root-rotting organisms, but when we went to excessive levels of fumigation we apparently also wiped out many of the antagonistic microorganisms; and certain root-rotters that hadn't even been detected came back into the heavily fumigated soil in large numbers. Can we extrapolate our findings to fires? How does intensity of the fire determine what it will do to the microflora?

In certain areas of the world we have a problem of non-wettability of the soil associated with the microflora. Many of our fungi in the soil produce a waxy substance. It stays fairly local around the growth of the fungus as long as we leave the site undisturbed. We're now encountering serious problems in areas of California, for instance. When a fast fire moves over the ground it is not hot enough to destroy these waxy substances, but it is hot enough to vaporize them and they move downward into the soil just a few centimeters where they encounter cooler soil and re-precipitate, just like a distilling action. Then these waxy substances form a film throughout the soil at this new level, and the soil just refuses to wet up. Rewetting of soils is a major problem which occurs worldwide. Fortunately we have not encountered it in the Southeast yet, but maybe it's just because we haven't looked.

Fire can result in some disturbance in the structure of the finer-textured soils--a movement of finer particles into soil pores. If we get this sort of movement, it will change the size of the pore necks--the holes between the aggregates through which many of the microbes have to move. Some of these animals that Dr. Metz described are of a size where the pore neck cross-sectional area is important to their movement. If we reduce the size of this neck, we exclude certain of the larger organisms from getting around. Whether this is significant or not, we don't know, but it certainly is a possibility.

One thing we can say for sure is that summer burns are undoubtedly tougher on the microflora and microfauna, particularly the flora, than are winter burns. In summer the organisms are more susceptible to damage from small rises in temperature, whereas in the winter they are primarily in resistant spore stages or other resting bodies and are less susceptible to fire damage.

Bill Pritchett appropriately mentioned that probably a good bit of the organic matter which is burned in these rapid control burns is that which is easily oxidizable anyway and probably would be oxidized by the microflora and microfauna over the next few months. Some work that has been done both in the United States and northern Europe has really opened some eyes about how long this organic matter hangs around. We know that some of it that falls to the forest floor this year is oxidized before next year's litter fall gets there, but some of it goes on to form the F and H layers and the organic matter in the A_1 horizon i.e., organic matter which has gone through all the humification processes. These estimates, although they vary considerably, I think are real eye-openers because the average age of the organic matter in the A_1 horizon was 300 years in one study and 800 in the other. This indicates that some of this material is hanging around a long time before it gets oxidized, so I think Pritchett's point is particularly well taken. The microbes in the soil are not doing very much to this 300-year-old material, and they are not deriving much benefit from it. It is this oxidizable form which is important.

I think some people have worried about whether fire may destroy our inoculum of the mycorrhizal fungi. I think we can be quite optimistic here that unless we burn an exceedingly large area or burn it very hot, we're not going to have to worry too much about the mycorrhizal.

Nitrogen has been mentioned two or three times. When we burn it is indicated that we do release these bases and we do, at least at the interface of the mineral soil, have a profound influence on pH. This, in turn, can have a significant effect on nitrogen fixation, particularly by the blue-green algae. Jurgenson has studied the blue-green algae in forest ecosystems. When we have pH below 5.5 we do not find very much blue-green algae capable of fixing nitrogen. But with repeated burns, we have at the surface where the light will be a high pH wherein we can then look for some nitrogen fixation. Repeated burning has removed the foliage of this lower overstory so that the light can get in, and the blue-greens are photosynthetic.

I think, to summarize, I will go back to one point I made in starting this discussion, and that is: the real tough questions are the specific organisms. We must pick out those organisms that are of particular interest to us and then develop methods to look at the quantitatively, rather than take the shotgun approach we have been forced to do in the past just because of lack of appropriate methods This is in no wise a criticism of what has been done. What has been done is benchmark work and we needed it; now we need to go on to the next step.

Charles B. Davey
School of Forest Resources
North Carolina State University
Raleigh, North Carolina

EFFECTS OF PRESCRIBED BURNING ON LONG-TERM PRODUCTIVITY OF COASTAL PLAIN SOILS

Earl L. Stone, Jr.
Department of Agronomy
Cornell University
Ithaca, New York

It is now some 31 years since I became interested in the influences of fire on vegetation and soils, through working under C. A. Bickford and others at the Southern Forest Experiment Station. Then, as now, the effect of repeated fire upon the sustained productivity of Coastal Plain soils was a serious question. In the few years preceding 1940, the first major research publications on the subject had appeared--by Wahlenberg (34) and his coworkers (35), and Greene (12) at McNeill, Mississippi, and by Heyward and Barnette (16, 17) in the Southeast.

But this was still a time of much controversy about the purposeful use of fire for forest management, and many people were reluctant to re-examine their long-held opinions on the damaging effects of fire. Further, soil science then was a much younger discipline, at least among non-agriculturalists, than it is today. So I think it is fair to say that, although these two groups of publications were highly influential and were widely discussed and cited, forest researchers lacked sufficient understanding of soil processes and variability to appreciate these results in full measure. However, these publications have proved to be classic studies, and the conclusions reached still stand, despite some doubts and misgivings about the study procedures.

The new data and reviews presented at this Symposium are based on a broader scope and deeper understanding of soil science and a better knowledge of sampling and analytical procedures. We are now more aware how variable, complex, and messy natural soils are, even when we deal only with small experimental plots. We also have a better, although still imperfect, sense of "permanent"

versus "temporary" changes in soil: of those events that a soil "remembers" in its makeup and behavior and those that are soon "forgotten" or obliterated by subsequent events.

These new studies are necessary and important. But a significant feature is that they largely confirm the conclusion drawn from the earlier studies: that repeated light fires have only a small direct influence on the properties of Coastal Plain soils.

Let me recapitulate the findings of these several reports: Heating of the mineral soil by fire is only superficial and slight (15, 29). Total organic matter and nitrogen content are not reduced by repeated light fires, or even by 20 years of annual burning; rather, there is some indication of increase (16, 28, 35, 36). Overall supplies of bases and mineral nutrients are little affected by burning, although their concentration in the mineral surface may increase. Porosity and infiltration tend to decrease when the mineral surface is completely stripped of cover; but light fires commonly do not expose the entire surface, and recovery is rapid (3, 27, 28, 29, 36). Hence, the hydrological effects of burning appear minor on most Coastal Plain soils (29). The exceptions are certain fragile soils such as the loessial slopes of northern Mississippi or soils with surface structure impaired by previous cultivation (e.g., 32, 33). The information on microbial and faunal populations, so far as it goes, indicates that burning produces no major qualitative changes in composition and that the capacity for rapid recovery is great (20, 26).

Finally, complete absence of fire or equivalent disturbance would, of course, allow drastic changes in forest composition, which in turn would alter the surface soil in various ways. But this is an academic prospect; freedom from major disturbance is even less likely in the managed forests of the future than in those which gave rise to the present vegetation and soil.

Because previous papers of the Symposium detail these findings and make my conclusions rather obvious, it may be worth asking why these soil systems behave as they do and why burning in the Coastal Plain has quite different consequences than in many other forest regions (e.g., 1). In doing so, we may consider at least four approaches or kinds of evidence: (A) historical or evolutionary, (B) the conservative nature of soils, (C) projection from short-term studies, and (D) fire and the soil surface.

A. Historical or Evolutionary.--It is sometimes difficult for moderns to comprehend the impact that primitive men had upon the landscape. Available evidence indicates that the Indians used fire freely long before the Europeans arrived and that the latter continued the custom (9, 30), although apparently with diminishing frequency in the last century (14). There are abundant references as to the extent and frequency of aboriginal burning; two examples will suffice:

"(The Indians) leave their homes and retire into the woods for four or five months....and set fire to the woods for many miles together to drive out the deer and other game into small necks of land... by which means they kill and destroy what they please..." (4).

"...in all the flat countries of Carolina and Florida the waters of the rivers are, in some degree, turgid and have a dark hue, owing to the annual firing of the forests and plains..." (2).

Many investigators have discussed the influence of such burning on native vegetation. A recent paper by Paul Lemon (22) emphasizes the distinction to be made between infrequent, erratic, or exceptionally severe fires, which may force plant communities back to early successional stages, and frequent, mild burning. The effect of the latter is to maintain fire-conditioned "natural" communities. It seems fairly evident that, for some millenia, fire was in no sense an accidental feature but a major evolutionary pressure that shaped the entire development of Coastal Plain vegetation (9, 22, 30). The dominant life forms, species, and genotypes were selected for durability under regimes of frequent fire, including any adaptation to the properties of frequently burned soils.

This history applies with equal force to the recent evolution of Coastal Plain soils. Most of the upland soils are ancient and owe their present structural characteristics to the geomorphic events, climates, and vegetations of many 10's or 100's of thousands of years ago, of which we know little detail (7). But, at least in recent millenia, frequent burning and all of its consequences--including the vegetation it perpetuated--have been normal components of the soil environment rather than disruptive features. Viewed in this perspective, it is not at all surprising that comparisons of soils after only 10 to 20 years of burning reveal only small or nonsignificant differences.

B. The Conservative Nature of Soils.--Shifting time scales now to that of a century or less, one finds widespread misunderstanding about the rapidity and degree of soil changes. To be sure, certain kinds of changes are abrupt: Many forested soils lose fertility rapidly when first cleared and cultivated; fertilizer responses in forests are visible within months; runoff and erosion from cultivated lands are enormously sensitive to changes in soil treatment and cover.

But, barring active erosion, developed soils tend to behave as rather conservative bodies. The impact of a new treatment or environmental feature typically shows as a more or less rapid change followed by stabilization around a new "steady state" rather than as a continuous drift. Our best documented instances of this are the changes in organic matter and nitrogen in soils used for agriculture.

For example, the virgin prairie soils of Missouri lost organic matter rapidly when placed under continuous cultivation. However, after some 60 years, the prospect of a new equilibrium level could be foreseen, with the content of surface organic matter stabilizing at about 50 to 60 percent of the original value. Similarly, soils long cultivated prove exceedingly stable under further cultivation, as table 1 illustrates. The lack of change indicates that these soils have reached an equilibrium of sorts with treatment and environment. Introduction of a legume during one year of a 4-year rotation causes a small (ca. 15 percent) but perceptible increase in total nitrogen level.

Table 1.--Stability of total nitrogen in old, arable soils under 60 to 80 years of continuous cultivation. (Data based on Cooke's (5) account of observations at Rothamsted Experiment Station, England.)

Type of cultivation	Date	Nitrogen in surface 9 inches	Type of cultivation	Date	Nitrogen in topsoil after-- No fertilization	Nitrogen in topsoil after-- PK added
		Percent			- - - Percent - - -	
Continuous wheat	1865	0.105	4-year rotation with fallow	1867	0.127	0.123
	1944	.106		1953	.119	.121
Continuous barley	1882	.098	With clover	1867	.130	.135
	1946	.103		1953	.152	.152

Agriculture has no real parallel to prescribed burning in forests, but perhaps the closest approach is the annual burning of straw, as opposed to plowing under, in continuous grain culture. The results in table 2 represent only short-term studies, on relatively unleached dryland soils, without added fertilizer. Whatever the long-term consequences may be, plainly 10 to 12 years of annual burning have not affected productivity.

Table 2.--Influence of annual burning of straw on yields in continuous wheat culture. (Data based on Throckmorton's (31) observations on the drylands experiment stations.)

Location	Period of observation	Avg. yield of wheat when--	
		Straw unburned	Straw burned
		- - - Bu./acre - - -	
Hays, Kans.	1928-1940	13.3	13.7
	1931-1941	11.2	11.8
Mandan, N. Dak.	1930-1940	13.9	16.5
Pendleton, Oreg.	1931-1940	38.8	42.1

C. Short-term Studies.--Wells (36) has reported the 20-year results from studies of prescribed burning in South Carolina. For comparative purposes, some of the 10-year results of that study (27) are shown with those from similar treatments in Arkansas (28) in figure 1. The two studies are unique in using much the same sampling and analytical procedures. A few comments are in order:

(1) The values for surface organic matter in the South Carolina study (27) are not to be compared with those in Wells' (36) report, because the former are taken soon after burning from only three of the five replications. Reduction of the forest floor by fire is expected, but the quantities found in the annually burned plots before or after fire show the degree of surface protection.

(2) The differences in amounts of incorporated organic matter and nitrogen in the South Carolina data (27) seem unreasonably large and, in fact, are not significant. The subsequent sampling reported by Wells (36) shows smaller but real increases associated with burning. In contrast to these and earlier results (12, 16, 35), the Arkansas data give no indication that fire has affected incorporated organic matter and nitrogen.

(3) The South Carolina results (36) show appreciable, although nonsignificant, increases in base content and reaction of the mineral soil; these results are in accord with the earlier findings. Such changes

in a low-base soil are easily accounted for by ash from the burned litter, although this may not be the full explanation. The medium-textured Arkansas soils, initially much higher in base content and reaction, again are unaffected by as many as eight burns. However, these fires eliminated a dense hardwood understory containing many species with high-calcium litter (Cornus, Ulmus, Fraxinus, Carya) (11), and thus some measure of compensation may be involved.

(4) Extractable phosphorus of the upper soil increases with burning, significantly so in the South Carolina study (36), nonsignificantly in the Arkansas data. Again, the ash content of the litter offers a sufficient explanation, because soil warming is so slight (29).

(5) If bulk density is taken as an index of physical change, burning has had no appreciable effect at either location

This brief comparison emphasizes that any changes in surface soil that are induced by burns are at best small and often are not distinguishable amid the high point-to-point variability of normal soils. Taking the periodic or biennial burns as representative of prescribed burning, we find very little reason to expect appreciable soil changes during an additional 10- to 30-year period.

D. Fire and the Soil Surface.--But before drawing conclusions, we might look further at the results from the South Carolina plots burned annually for 20 years (36). Figure 2 combines the data presented by Wells plus some plausible estimates of litterfall and burning losses (from 17, 25, 37). Consideration of potassium and sulfur is omitted; no evidence on return of potassium via crown-wash is available nor are there any data for sulfur losses and atmospheric gains. It is likely that the latter now exceed volatilization losses.

After 20 annual burns, the average loss from decay and fire combined must now approximately equal the yearly litter fall. Much of the yearly addition of nitrogen in litter is volatilized by fire (8, 36), and much of the ash content is released to the soil surface. And here is a dilemma: The annual loss of nitrogen by burning probably is at least 20 lb. per acre, a value Wells also indicates for periodic burns. This loss would amount to 400 lb. over the 20-year period. Yet, as in two other studies (16, 35), comparison with the unburned plots indicates a net gain rather than a loss in the upper soil. How is the soil nitrogen maintained or increased? Rainfall inputs are surely too small to offset volatilization, even though all other losses were negligible.

It is well known that burning, especially winter burning, increases the legume component in the ground vegetation (e.g., 6, 9, 13). But adding 20 lb. of N per acre would require a legume biomass of several hundred pounds per acre, probably much more than commonly found under forest canopies.

Another source of symbiotic fixation is wax myrtle (Myrica cerifera), a nodulated non-legume. But annual fire greatly reduces the importance of this shrub, minimizing its possible contribution.

Wells (36) reports evidence for nonsymbiotic fixation on the annually burned plots, and especially on the wettest soils. This is an exceedingly important finding. But what are the organisms responsible, and why is there greater fixation on the burned plots?

Annual burning releases a very few pounds of phosphorus per acre and a very few tens of pounds of calcium and magnesium; periodic burning releases larger amounts at less frequent intervals. These small additions alter the average properties of the surface 2-inch layer of mineral soil only slightly, as this shallow layer is a mass of some 400,000 lb. per acre. Such small changes would not be expected to influence free-living nitrogen fixers significantly.

But 0- to 2-inch samples fail to represent the actual events in the first weeks or months after burning. Immediately after fire, Ca, Mg, P, and other ash elements are concentrated in highly available forms in a very thin layer at the residual organic or mineral surface. Soil reaction increases at points to above pH 8. This soil-air interface is exposed to light and warms rapidly. These charges certainly are not spatially uniform, and they are temporary. However, while they endure, they create an environment vastly different from that of the unburned surface, an environment hospitable to two groups of nitrogen-fixing microorganisms.

Isaac and Hopkins (18), and Lutz (23) have speculated about increased activity of Azotobacter on newly burned surfaces. These organisms are favored by high reaction, P and Ca availability, and temperatures to 30° C. Their growth rates may be exceedingly rapid, and their capacity for fixation is high. Nevertheless, the contribution of these heterotrophs is almost invariably small in soils in humid regions (19) and apparently remains so even in favorable systems of submerged soil (24).

Perhaps the blue-green algae are the most promising candidate-fixers. As observed by Jurgensen and Davey (21) in North Carolina forest and nursery soils, they are most numerous at the soil surface:

Depth	Algae
(Cm.)	(No./g. soil)
0.0- 0.5	96,500
0.5- 2.0	20,500
2.0- 6.0	2,100
9.0-10.0	100

Furthermore, as Granhall and Hendricksson (10) have observed in Swedish soils, the abundance of N-fixing forms increases greatly with soil reaction:

Soil pH	Soils with N-fixing algae	N-fixing genera
	(Percent)	(No.)
< 5.0	0	0
5.0-6.0	19	3
6.0-7.0	61	6
7.0-8.0	76	6
> 8.0	100	2

Jurgensen and Davey (21) have already hinted that burning might favor these organisms. In any case, further studies of nitrogen fixation in burned soils may well explain the mystery of sustained levels of soil nitrogen in the face of evident losses.

To summarize, we have only a limited capacity to predict soil changes over the course of half a century or more. But nothing in the developmental history of Coastal Plain soils or in experimental studies indicates probable decreases in soil productivity under regimes of prescribed burning. The possible exceptions are a few areas of highly erosive soils. Perhaps the long-held concerns about soil deterioration from burning should now be directed to the potentials for damage associated with harvesting and intensive management.

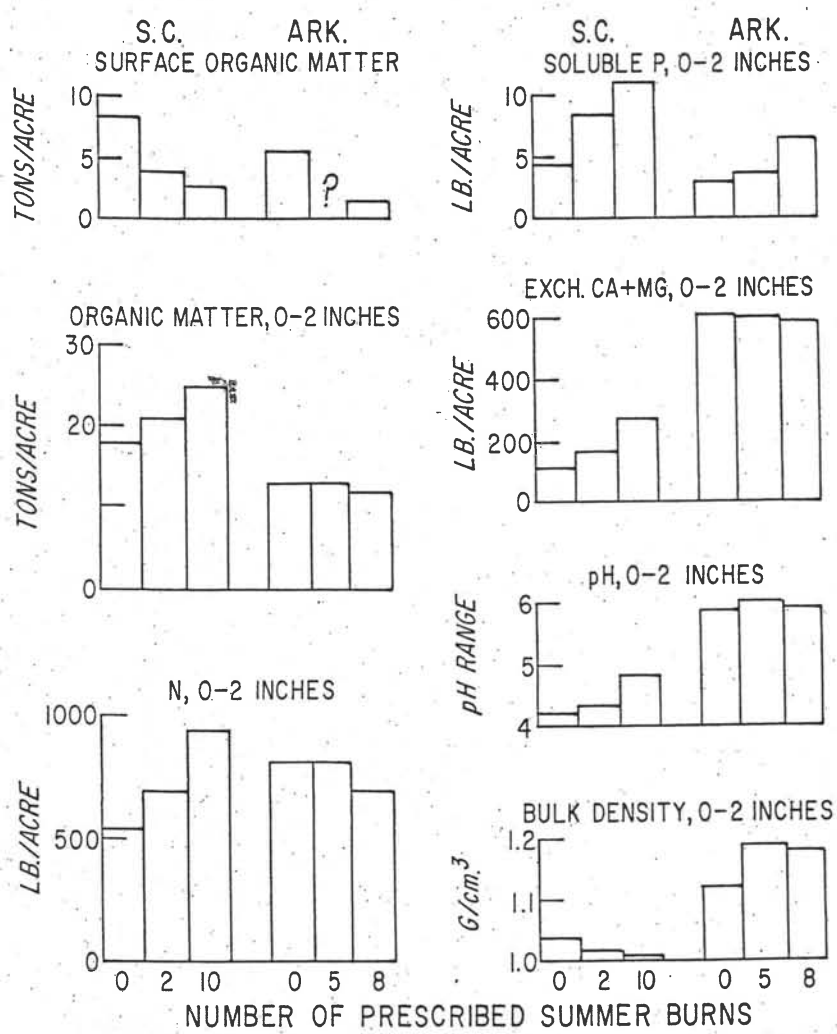

Figure 1.--Effects of a decade of experimental burning in loblolly pine stands. Arkansas data from Moehring, Grano, and Bassett (28); weights of surface organic matter estimated before last burn. South Carolina data converted from Metz, Lotti, and Klawitter (27); weights of surface organic matter estimated soon after fire. Ca + mg is sum of equivalent weights as Ca.

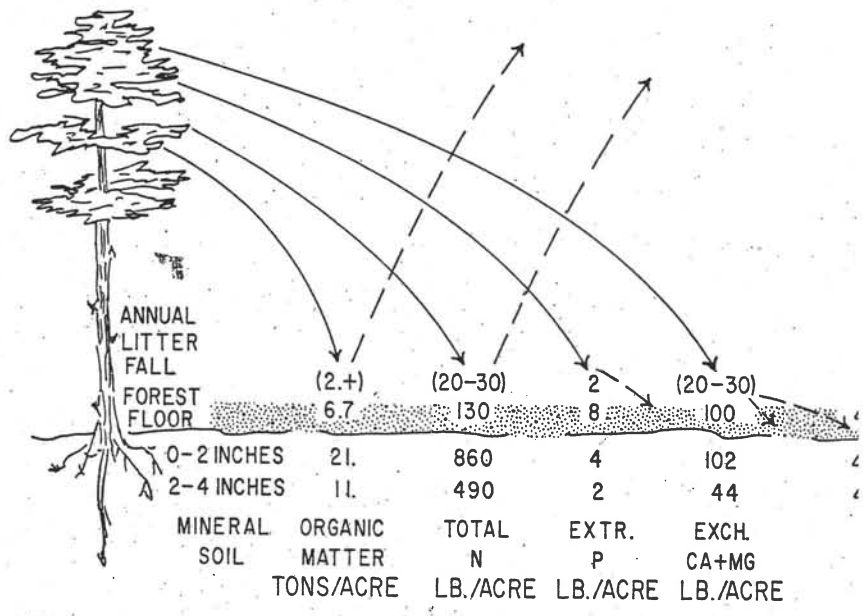

Figure 2.--Partial nutrient cycle in 50- to 60-year-old stands loblolly pine after 20 annual winter fires. Solid arrows and parenthetical values indicate litter decomposition. Dashed arrows indicate loss or liberation by annual fire; the amount roughly approximate litter additions. Liberation of Ca + Mg also raises the pH of the forest floor surface. Ca, Mg, and in the litter and forest floor are total amounts. Data on so and the forest floor derived from Wells' (36) South Carolina study; other values assumed from the literature.

LITERATURE CITED

1. Ahlgren, I. F., and Ahlgren, C. E. 1960. Ecological effects of forest fires. Bot. Rev. 26: 483-517.

2. Bartram, William. (1791) 1928. The travels of William Bartram. Mark Van Doren (Ed.). 414 pp. Macy-Masius; reprinted by Dover Publ.

3. Bower, David R. 1966. Surface soil recovers quickly after burn. South. Forest Exp. Sta., U. S. Forest Serv. Res. Note SO-46, 2 pp.

4. Brickell, John. (1737) 1968. The natural history of North Carolina. 424 pp. Reprinted by Johnson Publ. Co., Murfreesboro, N. C.

5. Cooke, G. W. 1967. The control of soil fertility. 526 pp. London: Crosby Lockwood and Son Ltd.

6. Cushwa, C. T., Brender, E. V., and Cooper, R. W. 1966. The response of herbaceous vegetation to prescribed burning. Southeast. Forest Exp. Sta., U. S. Forest Serv. Res. Note SE-53, 2 pp.

7. Daniels, R. B., Gamble, E. E., and Cady, J. G. 1970. Some relations among Coastal Plain soils and geomorphic surfaces in North Carolina. Soil Sci. Soc. Amer. Proc. 34: 648-653.

8. DeBell, D. S., and Ralston, C. W. 1970. Release of nitrogen by burning light forest fuels. Soil Sci. Soc. Amer. Proc. 34: 936-938.

9. Garren, K. H. 1943. Effects of fire on vegetation of the Southeastern United States. Bot. Rev. 9: 617-654.

10. Granhall, V., and Hendriksson, E. 1969. Nitrogen-fixing blue-green algae in Swedish soils. Oikos 20: 175-177.

11. Grano, Charles X. 1970. Eradicating understory hardwoods by repeated prescribed burning. South. Forest Exp. Sta., USDA Forest Serv. Res. Pap. SO-56, 11 pp.

12. Greene, S. W. 1935. Effect of annual grass fires on organic matter and other constituents of virgin longleaf pine soils. J. Agr. Res. 50: 809-822.

13. Halls, L. K., Southwell, B. L., and Knox, F. E. 1952. Burning and grazing in Coastal Plain forests. Ga. Coastal Plain Exp. Sta., Univ. Ga. Coll. Agr. Bull. 51, 33 pp.

14. Hammond, Harry . 1883. South Carolina: Resources and population; institutions and industries. 726 pp. Charleston: State Board Agr. S. C.

15. Heyward, Frank. 1938. Soil temperatures during forest fires in the longleaf pine regions. J. Forest. 36: 478-491.

16. _____, and Barnette, R. M. 1934. Effect of frequent fires on chemical composition of forest soils in the longleaf pine regions. Fla. Agr. Exp. Sta. Bull. 265.

17. _____, and Barnette, R. M. 1936. Field characteristics and partial chemical characteristics of the humus layer of longleaf pine soils. Fla. Agr. Exp. Sta. Bull. 302.

18. Isaac, Leo A., and Hopkins, H. G. 1937. The forest soil of the Douglas fir region and the changes wrought upon it by logging and slash burning. Ecology 18: 264-279.

19. Jensen, H. L. 1965. Non-symbiotic nitrogen fixation, pp. 436-480. In W. V. Bartholomew and F. E. Clark (Ed.) Soil nitrogen. Madison, Wis.: Amer. Soc. Agron. Monogr. 10.

20. Jorgensen, J. R., and Hodges, C. S., Jr. 1970. Microbial characteristics of a forest soil after twenty years of prescribed burning. Mycologia 62: 721-726.

21. Jurgensen, M. F., and Davey, C. B. 1968. Nitrogen-fixing blue-green algae in acid forest and nursery soils. Can. J. Microbiol. 14: 1179-1183.

22. Lemon, Paul C. 1967. Effects of fire on herbs of the Southeastern United States and Central Africa. Sixth Annu. Tall Timbers Fire Ecol. Conf. Proc.: 113-127.

23. Lutz, H. J. 1956. Ecological effects of forest fires in the interior of Alaska. U. S. Dep. Agr. Tech. Bull. 1133, 121 pp.

24. Magdoff, F. R., and Bouldin, D. R. 1970. Nitrogen fixation in submerged soil-sand-energy material media and the aerobic-anaerobic interface. Plant Soil 33: 49-61.

25. Metz, L. J. 1952. Weight and nitrogen and calcium content of the annual litter fall of forests on the South Carolina Piedmont. Soil. Sci. Soc. Amer. Proc. 16: 38-41.

26. _____, and Farrier, M. H. 1971. Prescribed burning and soil mesofauna on the Santee Experimental Forest. In Prescribed burning symposium proceedings. USDA Forest Serv. Southeast. Forest Exp. Sta.

27. _____, Lotti, Thomas, and Klawitter, R. A. 1961. Some effects of prescribed burning on Coastal Plain forest soil. U. S. Forest Serv. Southeast. Forest Exp. Sta. Pap. 133, 10 pp.

28. Moehring, D. M., Grano, C. X, and Bassett, J. R. 1966. Properties of forested loess soils after repeated prescribed burns. South. Forest Exp. Sta., U. S. Res. Note SO-40, 4 pp.

29. Ralston, Charles W., and Hatchell, G. E. 1971. Effects of prescribed burning on physical properties of soil. In Prescribed burning symposium proceedings. USDA Forest Serv. Southeast. Forest Exp. Sta.

30. Stewart, Omer C. 1956. Fire as the first great force employed by man, pp. 115-133. In W. L. Thomas (Ed.) Man's role in changing the face of the earth. Univ. Chicago Press.

31. Throckmorton, R. I. 1943. Methods of straw disposal as related to crop yields on the dryland experiment stations. Soil Sci. Soc. Amer. Proc. 7: 374-377.

32. Ursic, S. J. 1969. Hydrologic effects of prescribed burning on abandoned fields in northern Mississippi. South. Forest Exp. Sta., USDA Forest Serv. Res. Pap. SO-46, 20 pp.

33. Ursic, S. J. 1970. Hydrologic effects of prescribed burning and deadening upland hardwoods in northern Mississippi. South. Forest Exp. Sta., USDA Forest Serv. Res. Pap. SO-54, 15 pp.

34. Wahlenberg, W. G. 1935. Effect of fire and grazing on soil properties and the natural reproduction of longleaf pine. J. Forest. 33: 331-338.

35. _____, Greene, S. W., and Reed, H. R. 1939. Effects of fire and cattle grazing on longleaf pine lands as studied at McNeill, Mississippi. U. S. Dep. Agr. Tech. Bull. 683, 52 pp.

36. Wells, Carol G. 1971. Effects of prescribed burning on soil chemical properties and nutrient availability. In Prescribed burning symposium proceedings. USDA Forest Serv. Southeast. Forest Exp. Sta.

37. _____, and Davey, C. D. 1966. Cation-exchange characteristics of forest floor materials. Soil Sci. Soc. Amer. Proc. 30: 397-399.

COMMENTS

Dr. Stone has certainly presented a valid paper which should go far toward assuaging our fears about the long-term effects of fire on soil productivity. I agree with his last statement that we should not be overly concerned with the effects of fire in the southeastern Coastal Plain. We should recall, however, that this region is very large--even when we exclude Texas. It ranges from a latitude of 39° N. to 26° N. Within this range, there are differences in climate, types of understory vegetation, rainfall, and temperatures, which have not been particularly emphasized except from the standpoint of heat. Within the northern limits of this range, there are also differences in the degree of surface freezing. When the forest floor is reduced, the amount of freezing in other locations at our present latitude may actually be much greater than it is in Charleston. Certainly, we know that the forest floor has a significant effect on depth of freezing. As a matter of fact, when soils are frozen 2 inches on the surface of the bare soil, a littered forest floor at the same latitude and of the same soil type is not frozen at all.

I would like to emphasize one point which came up yesterday with respect to the use of fire with regeneration or site preparation. Even here, we must look toward the effects of fire in different soil types and in different land forms. For example, in the low humic gley soils, we should use fire to reduce the overabundance of residues from logging and chopping. However, in the deep sands and the lighter soils as well as in Piedmont soils, it would be better to disk the residues into the soil surface rather than burn them. There is some evidence to suggest that these recommendations are important.

We do have an educational job ahead of us. One of my fellow members of the Sierra Club has said something about burning in these words:

> To begin with, the lowest fire hazard is in the full-canopy, old-growth forests. The risk of losing timber to fires, therefore, is least when the forest is managed on a selection system in which the full canopy is permanently maintained. Fire danger is a function of temperature, of course; and providing shade in the closed canopy of the dense forests keeps the material on the ground cool. Also, air does not circulate freely under a closed canopy, and it is humid because of the moisture given off by the trees. In contrast, young plantations are highly inflammable because they tend to be hot and dry and because the combustible leaves, frequently having an oil content, are close to each other and to the ground.

This is the position paper of the Sierra Club, of which I am a member.

Obviously, great questions remain concerning forest production--questions that we are not yet fully prepared to answer. But we must keep our lines of communication open so that those who are writing position papers can come to a balanced judgment about what burning prescriptions are most beneficial.

T. E. Maki
School of Forest Resources
North Carolina State University at Raleigh
Raleigh, North Carolina

During the past day and a half, I have been interested to learn of the similarities between our situation in the Douglas-fir region and yours here in the southern pine region. These are the two most important areas for timber production in the country. One might almost say that both Douglas-fir and southern pine are dependent on fire for their survival. Large areas of Douglas-fir --in fact, the vast acres of even-aged stands--are there because of wildfires. If wildfires or fires set by Indians had not burned some of the old-growth stands of mixed conifers several hundred years ago, we would not be harvesting prime Douglas-fir stands today. When protected from fire, these stands, just like the pine stands in the South, have a different species composition. We do not have the hardwood problem that you have, but we do have problems with other coniferous species invading. In the past, these species were not as valuable commercially as Douglas-fir, but they are beginning to come into their own.

In the Douglas-fir regions, we do practice clearcutting and, hopefully, will continue to do so; and we do burn slash. Unfortunately, we do not have the long-term studies of fire effects on the

soil that you have in the South. We do have a number of isolated studies--essentially the ones cited by Dr. Ralston. Mr. Robert F. Tarrant of the Pacific Northwest Station and Dr. Ernie Wright, former pathologist, have worked extensively on the effects of burning. We practice slash burning not only for fuel reduction but also to make planting easier. Our general practice, particularly as we develop improved strains, is to plant the clearcuts.

The similarities between our two regions stop when we come to topography. The topography of the Douglas-fir region is steep as opposed to the level topography that you have here; consequently, our problems in the use of fire are somewhat different. As now practiced, slash burning in our region has little effect on the soil; therefore, we will probably come to the same conclusions as did Dr. Stone and the other speakers concerning the effects of burning. As we examine many of our clearcuts, we find that the litter is only charred--just as you have in the burned plots here.

We have also found that the effects of fire on microorganisms are transitory, although it has been suggested that there is inhibition or loss of mycorrhizal fungi. This inhibition will last for only about 1 or 2 years.

Interestingly enough, burning in the Douglas-fir clearcuts does not eliminate vegetation. Resprouting of vegetation is rapid. We also have one important plant that comes in prolifically after burning and fixes nitrogen efficiently. In fact, it depends on fire for seed germination. It also serves as protection for the Douglas-fir seedlings because it is high in protein and the deer feed on it rather than on the regeneration.

One thing that we have not looked at is air pollution. I believe we have a lesson to learn from the field burning practiced in western Oregon. Much of the land in that large area is devoted to the production of grass seed, and burning serves to control a fungal disease that markedly reduces the yield. The yields are also decreased if the stubble is not burned. Consequently, the increased burning has resulted in a tremendous amount of smoke, and the citizens are up in arms. As a result, the legislature has recently passed a ban on field burning. We as foresters can learn a lesson from this incident--if we use fire indiscriminately rather than judiciously, we may find ourselves in a similar plight. If we use our tools wisely, we will probably be able to use them much longer.

Chester T. Youngberg
Department of Soils
Oregon State University
Corvallis, Oregon

PUBLIC INFORMATION AND LEGAL ASPECTS OF PRESCRIBED BURNING

Leonard A. Kilian
North Carolina Forest Service
Raleigh, North Carolina

The informational and legal aspects of prescribed burning are not only current problems but they also pose even larger potential problems. The most pressing problems center around the question of air pollution. Therefore, most of my discussion will explore this area of concern.

One might ask, "Where is it a problem today? We haven't received many comments on our prescribed burning program." In many areas this is true. In other areas, quite searching questions have arisen regarding not only the legal but the informational aspects first.

LEGAL ASPECTS

A survey of the various forestry and forest fire laws of the southeastern states reveals many similarities. One of the most important, especially from a historical point of view, is that all of these states recognize the right of a landowner to burn on his own property as long as the fire remains under control. Many authorities have assumed that burning on one's own property is a constitutional right, and this reasoning is probably responsible for the similarities in the laws.

The right to burn on personal property is modified by the states in several ways. Some states require that all adjacent landowners be given notice by a specified time in advance of the proposed burn. Several states require notification of state and federal agencies responsible for fire control. Many states restrict or partially limit burning by requiring a permit during

certain hours of the day and certain months of the year. These permits to burn do not relieve the individual of any responsibility to control the fire. Their purpose is to encourage burning later in the day when the danger of escape is usually reduced or during a less dangerous season of the year. In some states, the permit is used to inform agencies responsible for fire control as to where and when an area will be burned and by whom.

The most significant recent legal development affecting prescribed burning is the adoption of air pollution regulations by many of the states. State regulations on air pollution have been adopted in Virginia, North Carolina, South Carolina, Georgia, Kentucky, Tennessee, Arkansas, Mississippi, Alabama, Louisiana, and Texas. Florida and Oklahoma are currently in the process of either adopting or revising regulations designed to reduce air pollution.

Burning land for forestry purposes has been exempt in most of the state regulations. A forest management exemption is specifically mentioned in many of them. This is the result of a close monitoring of the development of regulations by forestry interests and the presentation of requests for exemption by capable and knowledgeable forestry representatives, both public and private.

Although Alabama has air pollution regulations, they do not include provisions for regulating agricultural or forest burning. In Kentucky, the regulation does not exempt forest burning, but it does exempt agricultural burning.

North Carolina does specifically exempt forest management burning, and few problems have arisen in the state regarding these operations. We have, however, encountered problems with local air pollution boards, which have primary enforcement jurisdiction. The state law does not restrict local boards from exceeding state standards, and some boards have adopted more restrictive regulations. This has caused some local problems and misinterpretation of the application of the burning permit law, which the North Carolina Forest Service administers. We are now conferring with the Department of Water and Air Resources to obtain a more workable arrangement. The state recently established eight air control regions to help bring about standardization of regulations and their interpretation.

During a recent meeting at the University of North Carolina at Charlotte, a federal representative stated the federal government's intent to work toward standardization of air pollution regulations. When this occurs, the standardization procedure should be monitored, and the case for continued exemption of forest burning should be made to the proper authorities by able representatives of forestry interests.

As long as we have communication between responsible people, who are knowledgeable of the situation and receptive to a scientific approach, there is hope for continued exemption. If the case for prescribed burning were tried in an open forum today, however, it is the opinion of many foresters that the case would be lost.

In some states, legal problems have arisen when visibility on highways has been reduced by smoke from prescribed fires. The danger occurs when high speed traffic, traveling in otherwise clear conditions, is suddenly confronted with reduced vision because of heavy smoke. Warning signs are a partial cure. One organization found, however, that the posting of signs was in effect admitting at least partial legal responsibility, if an accident occurred. Because of this, the State Highway Commission has been asked to install warning signs in certain areas in North Carolina.

Some organizations carefully check the weather forecasts and burn only when conditions are such that the wind will not carry the smoke toward a primary or secondary road. Others will not burn within ¼ mile of a road if the present and predicted wind is away from the road, but they extend this restriction to ½ mile if the present and predicted wind is toward the road.

The reduced visibility caused by smoke in the vicinity of a prescribed burn can produce thorny legal situations, especially if someone is seriously or fatally injured in an accident. Accidents caused by reduced visibility in the vicinity of prescribed burns have occurred in Florida, North Carolina, and other states.

From a civil viewpoint, the legal responsibilities are generally the same in all states; that is, each person, firm, or corporation may be sued and tort procedures can be used against a public organization. Separate or combined suits may be filed against forestry organizations and individual employees. In some states, if the proper precautions are taken and all necessary regulations are complied with for the use of fire, there is no criminal violation even if the fire does escape. In other states, the escape of the fire is evidence that a criminal violation has occurred.

In this regard, liability insurance for forestry organizations and employees doing prescribed burning is available, and some organizations have purchased such policies.

The state forestry agencies of Mississippi, Louisiana, and Virginia have purchased a blanket policy for their employees. These policies generally have a $10,000 limit of liability and give protection to the organization and to employees engaged in the burning operations in the event of civil suit.

It is the opinion of many foresters in responsible leadership positions throughout the southeastern United States that prescribed burning will soon be eliminated by those who favor very strict air pollution standards. This may or may not be true. The greatest hope for being able to continue this practice lies in getting the answers to some of the more critical questions of air pollution and in keeping foresters, land managers, and others in related professions informed.

INFORMATIONAL ASPECTS

The possibilities for restrictions on the use of prescribed fire are only a small part of a giant challenge that forestry interests must meet more squarely in the future. We must learn how to improve communications with the general public and how to demonstrate to them our real concern for the environment. It is no secret that we are not adequately facing up to this challenge.

The record of foresters, forest-interest groups, and forestry organizations is one of environmental concern and of actual environmental enhancement. There have been exceptions, however, to the general trend of steady, solid accomplishments in conservation. In recent years, we have allowed economic concern to override environmental concern more often than the public is evidently going to allow. Forestry interests have a real stake in ensuring continued wise use. We must reexamine ourselves. If we find ourselves out of step with society, we must get into step. The story of past and future responsible concern must be told. It is true and it must continue to be true.

In any organization, the employees who perform the public information and public relations functions do so by dealing with present and potential problems. Their reasons for being is to present the organization to the general public in a favorable manner so that the products produced will be desired and accepted. This is true whether the product is a tangible item or an intangible service. Another function of these employees is to demonstrate to the community in which the organization operates--be that community a small town or a nation--that the work carried on is in the public interest.

The man in the street today is being made aware of all types of pollution by nearly every conceivable means of communications--his radio, his television, his newspaper and magazines, and in his conversations with other people. Few people today would deny that pollution of our environment is one of the most talked about current issues. The exaggerated examples used to bring attention to some of the problems are many times distortions of the true situation. Nevertheless, this general public concern is well justified. It has perhaps prompted our people and our large forestry organizations, both public and private, to redirect our collective attention to the basic responsibility of evaluating actions in relation to the environment and to each other. At times, as organizations and individuals get involved in "doing their thing" the "big picture" is forgotten. This might be the situation regarding prescribed fire. All factors should be considered, and benefits of burning versus problems created must be weighed. If it is found that the smoke and other products of burning damage the environment beyond the benefits attained, then we must switch to an alternative method of accomplishing the same goals. The economic aspects of the alternatives will have to be accepted as inevitable.

This may be considered axiomatic, but if you examine the performance of forestry organizations you can easily find instances where this type of decision has been difficult to make and more difficult to carry out.

I feel that we must face our responsibilities if we continue to use prescribed burning. This is one of the first requirements of good citizenship, both corporate and individual. If forest-oriented interests are to be accepted as participants in the determination of economic and land-use policy, the public must be convinced that this kind of responsibility will be met.

When the majority of the people in the southeastern United States see a large smoke column in the rural countryside today, they think it is a shame that so much of our forest lands are burned by wildfires. Only a few might wonder if the smoke is coming from a purposely started prescribed fire. Most of the general public would not even recognize it as smoke but think it was just part of the cloud formations. Perhaps we are fortunate that this lack of recognition is so commonplace. It might be one of the reasons prescribed burning has not received more critical attention from the mass media and the public.

This lack of attention will not continue. An increasing number of people are questioning the practice of prescribed burning, and the media are sending reporters to investigate the smoke columns. How should we react? What information should we give to media representatives, and who should give it? The situation is similar to the status of prescribed burning 20 years ago, when a few pioneer foresters began to burn operationally. At that time, however, it was the majority of the foresters--trained in an era that emphasized complete fire exclusion--that had to be educated and convinced of the value of prescribed fire.

The successful educational efforts used then included: (1) Informing only those who had to know or who had requested information--landowners, neighbors, reports, etc.; (2) Emphasizing the prescription aspects; (3) Pointing out the benefits and the damage that could result, but showing that the results were overwhelmingly favorable when the burning was done by professionals according to precise prescriptions; and (4) Demonstrating that prescribed burning based on research and experimentation was quite different from the control burns that were customary practice throughout the Southeastern Coastal Plains.

A recent survey indicated many organizations are taking an almost identical approach. They call it the positive approach. Simply stated this means that they point out the advantages of prescribed fire as logically and firmly as possible without overemphasis or becoming defensive. Some items have been added because of the concern over air pollution to show that burning at the proper time and under optimal wind and moisture conditions will produce minimal impact on populated areas.

This positive approach is probably the best course of action we can take with our present state of our knowledge and the attention the public has focused on this situation. We cannot hope, however, to have our "smoke columns remain part of the clouds."

The Southern Forest Fire Laboratory, Macon, Georgia is now preparing a handbook that will classify atmospheric conditions on the basis of smoke disposition. Using the guides in this handbook,

the manager keys the current weather to a standard similar to the blow-up fire curves used by fire control personnel. The resulting information will tell him what he can expect the smoke to do that day. This handbook will be a useful tool in deciding when, how, where, and whether to burn. It will also be an excellent public relations tool.

Some organizations have prepared themselves and their employees to meet the information and public relation challenges that will result from the public's concern about the effect of prescribed burning on the environment. Others have just begun their efforts, and some have not started to prepare to meet this challenge.

Organizations and members of organizations should endeavor to keep an open mind. Those that raise objections should be listened to closely and keenly. The most knowledgeable in these groups should be contacted and allowed to present the details of their objections and their ideas for improvement. One of the objections that the youth of today raise is that no one really listens to them. Most of them are very concerned and some have good suggestions. Their most urgent need is to know the truth--the facts concerning what they fear to be problems.

When new facts become available, the organizations should be ready to evaluate them and to rethink the approaches to an information program on prescribed burning. If a reorientation is needed, then a new approach should be quickly adopted.

Specifically, we must learn the extent and kind of pollution produced by prescribed burning and by wildfire. These facts must be contrasted and compared with the oxidation process of a natural no-burning situation. We think that pollution from prescribed burning is mild compared to that produced by autos, industrial exhausts, and power plants. The exception might be visual pollution. This visual pollution is very evident in the air and on the ground. We hope to prove that prescribed burning is the lesser evil compared to wildfire which is multiplied many times where prescribed fire is excluded. We have only meager research findings on any of this, except for damage comparison of burned versus unburned areas.

Much of the foregoing is a function of either research personnel or information and education staff members, in concert with top management. Most foresters and field employees are hard pressed to keep up with the technical developments in their most immediate area of concern and the day-to-day expenditure of energy required to get the on-the-ground job done. Each is vitally interested; but when they are asked to consider and make judgments on such matters as organizational policy on prescribed burning and the position of the organization regarding its involvement in caring for the overall environment, they might rightfully ask, "What are you fellows in the ivory tower doing with your time?"

Many of the questions concerning prescribed burning as it affects air pollution have not been answered. Research people are attempting to find the answers, but they may not have sufficent time.

The job of keeping informed on the legal aspect of prescribed fire, providing the correct inputs to those formulating laws and regulations, and inducing a favorable public opinion for the practice of prescribed fire is a present challenge. It will probably remain so for some time in the future.

COMMENTS

Although I have a technical background, having worked for chemical industries for some 20 years, and I am aware of and concerned about pollution, I knew nothing about prescribed burning until about 4 years ago. It was about that time that I, and others, began to work with the State Forester of South Carolina and pollution-control authorities to devise regulations under which the forest industries could live and which would satisfy a reasonable public.

I mention this because it emphasizes Mr. Kilian's remarks about the need for public relations and information programs. There are many more people like myself--technically trained but still unaware of what foresters mean when they talk about burning a forest by prescription. The education program must be designed to reach influential people in fields outside forestry and related disciplines as well as the general public.

The forest industry must tell the story of what prescribed burning is, why it is necessary, and what it does to protect forest lands and related resources.

I believe you have time to tell this story because heavy industry will receive the first thrust in areas of emotional stress when air pollution and its control are considered. You have the time, because you are in the shadow of those who are more suspect.

My final point is that forestry and all the related fields represented here must become involved in the formulation of these regulations. You must furnish accurate information to the authorities and to the public so that the regulations that do evolve will be based on sound technical knowledge, rather than emotional hysteria.

W. Burt Coffin
Department of Industrial Relations
South Carolina State Chamber of Commerce
Columbia, South Carolina

For a number of years, fire-control supervisors and resource managers in the South have read the handwriting on the wall concerning the pollution problems related to wildfires and prescribed burning. Being confronted daily with these problems, they pleaded for research and statistics to help in preparing for the battle they knew was to come.

In Florida, we received the message very clearly in 1969 when our state government was undergoing a complete reorganization from 159 boards and agencies to not more than 25 departments. The message was clear when air and water pollution control was given department status.

The public will no longer allow us to decide that we will allow certain areas to burn out because we feel it is not economical to make a direct attack. High speed highways, urban areas, and the public's new awareness of the environment leave us very little room for deciding what action we'll take on most land area fires.

In September, 1970, we were presented with the first draft of a proposal by the Department of Air and Water Pollution Control to regulate outdoor burning. After a public hearing, many conferences and rewrites, the proposal addressed itself to four types of burning:

1. Agricultural and silvicultural fires
2. Burning for cold or frost protection
3. Land clearing (does not include burning for agricultural, site preparation or forestry operations)
4. Industrial, commercial, municipal and research open burning

In the beginning, we requested to be designated as the approving authority for burning in category 1, and we were supported by all agriculturally related groups. The rules also require that we be notified of any burning for land clearing in a rural area, adjacent to or near forest, grass, woods, wild lands or marshes. The first proposal simply stated that burning would be done between the hours of 9:00 a.m. and 5:00 p.m. After considerable discussion on this, the Department of Air and Water Pollution Control agreed to change time to "from 9:00 a.m. to 1 hour before sunset and at other times when there is reasonable assurance that atmospheric and meteorological conditions in the vicinity of the burning will allow good and proper diffusion of air pollutants."

The specific rule with which we are principally concerned is as follows:

"<u>Regulation of Agricultural and Silvicultural Fires</u>

Open burning between the hours of 9:00 a.m. (Standard Time) and one hour before sunset (except fires for cold or frost protection) in connection with agricultural, silvicultural or forestry operations related to the growing, harvesting

or maintenance of crops or in connection with wildlife management are allowed, provided that permission is secured from the Division of Forestry of the Department of Agriculture and Consumer Services prior to burning. The Division of Forestry may allow open-burning fires at other times when there is reasonable assurance that atmospheric and meteorological conditions in the vicinity of the burning will allow good and proper diffusion and dispersement of air pollutants.

The Division of Forestry may, or at the request of the Department of Air and Water Pollution Control the Division of Forestry shall, suspend after reasonable notice any such permission whenever atmospheric or meteorological conditions change so that there is improper diffusion and dispersion of air pollutants which create a condition deleterious to health, safety, or general welfare, or which obscure visibility of vehicular or air traffic."

Very frankly, I feel that forestry is now on the defensive and the chances for more restrictions will increase daily. We have not always used the best of judgment in our prescribed burning when we could have imposed reasonable restrictions on ourselves. For example, the only way we have been able to stop prescribed burning in our state, even when conditions are extremely dangerous, is to ask the Governor to impose a ban on outdoor burning. It doesn't help, either, when landing operations are hampered at the airport in our capital by smoke from prescribed burning on National Forests, and the Governor is circling, attempting to land. It is difficult to convince someone driving through miles of thick woods that 60% of the air pollution is caused by automobiles, 20% by industry and refuse disposal, 15% by power plants, leaving only 5% from other sources, which would include prescribed burning and wildfires.

The big problem is that our smoke can be seen, and the air pollution agencies are under the gun to make progress quickly. We can help ourselves by practicing some restraint in our burning. It is obvious in our state that, under the proposed outdoor burning regulations, we won't be able to allow all burning that is requested; but I believe that we have a system that will allow a reasonable degree of latitude to continue the necessary burning, providing everyone understands that we must all accept some restrictions in our activities.

Harold J. Mikell
Division of Forestry
Florida Department of Agriculture
& Consumer Services
Tallahassee, Florida

AIR-QUALITY ASPECTS OF PRESCRIBED BURNING

John H. Dieterich
Southeastern Forest Experiment Station
Southern Forest Fire Laboratory
Macon, Georgia

INTRODUCTION

My assignment is to discuss some of the air-quality aspects of prescribed burning. Unfortunately, this is an area that has received only minor attention in the past--perhaps an indication in itself of the unimportance previously placed on the use of prescribed fire as a contributor to changes in air quality. Early studies of air pollution have concentrated on identifying the major contributors; and, although automobiles are today the primary source of emissions, it is safe to say that, prior to 1910, coal-burning cities and industrial developments were receiving the burden of complaints. The relative importance of the various contributors has changed in the past, and changes are assured for the future. As existing technology on the abatement of air pollution is put into operation and new devices for the control of pollution are developed, the balance will continue to change. An obvious question is whether wildfires and prescribed fires will be important contributors to air pollution 10 years from now.

The benefits of prescribed burning are well known to almost everyone attending this Symposium. Although we recognize that there may be detrimental effects of burning--particularly when fire is not properly applied--our research has concentrated more on improving the techniques of fire application, and on searching out new areas where prescribed burning can be used, rather than on the consequences of using fire. Now, for the first time, we are faced with the realization that even though we may fully accomplish our objectives for a specific burning operation and are able to do so without damage to the soil, the watershed, or the residual stand, we may

still be contributing to local or regional changes in air quality. We have on hand only limited knowledge concerning the effects of forest fires--both wild and controlled--on air quality. Fortunately, research is underway in several parts of the country that should provide some of the missing information we need so badly. In addition to our work at the Southern Forest Fire Laboratory in Macon, Georgia, research is underway at several locations.

The Northern Forest Fire Laboratory at Missoula, Montana, has been working in cooperation with Region 1 of the Forest Service and Washington State University, Pullman, Washington, to find ways of minimizing the impact of smoke from prescribed burning. At the University of Washington in Seattle, air pollution work has been conducted in an effort to better understand the relationship between slash burning and air quality (6, 10). Emphasis has been on sampling and analysis of combustion products and on the development of management guides to reduce the impact of smoke on communities near the burning area.

The Statewide Air Pollution Research Center in Riverside, California, conducted some of the first studies to identify the combustion products coming from the burning of agricultural and forest wastes. The Center has burned forest fuels from California, the Pacific Northwest, and from our area here in the South.

The Forest Fire Meteorology Project at the Forest Fire Laboratory in Riverside, California, has been studying the influence of weather on smoke dispersion. This work represents an attempt to predict smoke movement in terms of commonly experienced weather patterns.

Two university groups have become involved in the use of instrumented light aircraft for the study of the effects of prescribed fires and wildfires on air quality. Washington State University has flown numerous plume-tracking flights over western fires (8). The University of Florida, Gainesville, has been conducting studies of the characteristics of smoke plumes from large sources of emission. Light aircraft provide an important tool for the study of changes in air quality that can be expected to accompany wildfires and prescribed burns.

Our work at the Southern Forest Fire Laboratory is largely the responsibility of a small task group made up of a chemist, a meteorologist, a physicist, and two research foresters. Our objectives are to:

A. Pull together, interrelate, and publish all existing information pertinent to the impact of fire, prescribed or wild, on the environment in the southern United States.

B. Prepare and publish a manual of interim guidelines on smoke management.

C. Identify the products released into the environment when forest fuels are burned with prescribed or wild fire as contrasted with the slower processes of natural decomposition.

D. Determine the effects of these products on air quality.

E. Develop interim models for predicting effects of various means of oxidation of forest and range vegetation on air quality as guides to making decisions.

We are assembling information that relates to source, as well as to transport and diffusion. One of the big jobs we have is to complete an emission inventory for the Southeast that will provide reliable estimates of the various combustion products of wildfires and prescribed burns. To complete this inventory, we are burning fuels in the laboratory and sampling the combustion products from these fires (particulates, total hydrocarbons, CO, and CO_2). We are attempting to determine how many acres are burned each year by controlled burns and wildfires; and we want to know, at least in a general way, how much fuel is consumed per acre by the various types of fire.

Currently at the Fire Laboratory in Macon, we are studying the usefulness and adaptability of the Air Pollution Potential (APP) forecast (15) provided by the National Weather Services. We want to know how wildfires and prescribed burning affect visibility and how particulate loading in the atmosphere varies by season, burning activity, and urban and rural locations. We have conducted some preliminary, small-scale field operations that will help us in future planning for this work.

EMISSION INVENTORIES

Emission inventories have been completed for nearly all the major sources of air pollution. These inventories attempt to describe the quantity of various combustion products emitted per unit of time from the individual sources. This information is vital in helping to determine the significance of the various contributors and in helping to establish realistic standards for air quality in specific areas.

We are not at all sure that the emission inventories made for all types of forest burning are either accurate or realistic. This uncertainty is understandable when one considers the complexities of completing an inventory of this type. For instance, we have reasonably good records of the acres burned by wildfires, but the same information is not readily available for prescribed burns. The rate of burning differs for wildfires and prescribed fires, and the amount of fuel consumed per acre varies with fuel type, availability, and moisture content. Furthermore, there are different emission factors that could be applied to various types of fuel--both living and dead.

One source (4) lumps together all types of refuse disposal, which apparently includes both agricultural and forest burning, and the entire category still accounts for only 3 percent of the total load of major air pollutants. It lists automobiles as contributing roughly 60 percent, industry 18 percent, power plants 14 percent, and residential and commercial heating 5 percent.

Another source (19) estimates that 34 million tons of particulates are produced by wildfires and that 6.5 million tons are produced by prescribed burning, for a total of 40.5 million tons per year.

Forest fires are included in the emission inventory made by the National Air pollution Control Administration for the year 1968 (18). The inventory includes the five primary air pollutants: Co, sulphur oxides, hydrocarbons, nitrogen oxides, and particulates. The category "forest fires" includes both wildfires and prescribed burning. Results of this nationwide inventory indicate that, of the 214.2 million tons of air pollutants produced in 1968, forest fires produced 17.3 million tons or about 8 percent of the total burden. These figures can be broken down as follows:

Particulates	-- 6.7 million tons per yr.	-- 3.1 percent
Carbon monoxide	-- 7.2 million tons per yr.	-- 3.4 percent
Hydrocarbons	-- 2.2 million tons per yr.	-- 1.0 percent
Nitrogen oxides	-- 1.2 million tons per yr.	-- 1.0 percent

If we consider each of these four air pollutants separately, we find that forest fires account for nearly 24 percent of the total particulates produced from all sources, 7 percent of the total production of CO, slightly less than 7 percent of the total production of hydrocarbons, and 5.8 percent of the total production of nitrogen oxides--the latter probably from wildfires, which sometimes develop extremely high temperatures.

In preparing an emission inventory for the United States, regional differences must be considered. Burckle and Dorsey (3) estimate that, of the 6.5 million tons of particulates produced by prescribed burning in the United States, 5.5 million tons come from burning of the heavy fuels in the West and 1 million tons from burning in the South. The difference in particulate production between regions is due primarily to the amount of fuel consumed per acre, because the South uses fire on 2.5 million acres, as compared with only 1 million acres for the remainder of the country. This wide variation between estimates of particulate production from wildfires and prescribed fires emphasizes the need for continued work in this area to (A) obtain a more accurate measure of the acres burned for forestry purposes, (B) develop more reliable emission factors for the various types of fuel consumed by wildfires and prescribed fires, and (C) describe more accurately the amount of fuel consumed by various types of fires.

ACREAGE BURNED BY PRESCRIBED FIRE

To complete an emission inventory for prescribed burning, we need to know how many acres are being burned by prescribed fire each year. Yearly records have not been maintained, but a 1964 survey of prescribed burning in the South indicated that about 2.25 million acres were being burned annually, mostly for hazard reduction. At that time six states were burning over 100,000 acres--Georgia leading all states with over 800,000 acres.[1] In a more recent survey

[1] USDA Forest Service. Prescribed burning survey. 1964. (Unpublished report on file at the Southeast. Forest Exp. Sta., Sout Forest Fire Lab., Macon, Ga.)

for 1970, we found that roughly 2.5 million acres were being burned and that the burning trend was down for some states and sharply up for others.[2/] There are still seven states burning over 100,000 acres, and Georgia continues to lead all states with over 800,000 acres again being reported in the 1970 survey.

In a 12-state area of the South that supports 198 million acres of forested land (14), burning roughly 1 percent of the land with prescribed fire hardly seems sufficient to bring about any significant reduction in burned area or in the number of large wildfires; yet, this is exactly what appears to have happened.

A closer look would tell us that hardwoods occupy approximately 120 million acres and that burning would not be used on these lands (16). The small landowner owns approximately 75 percent of the land (14), and he frequently finds it either too expensive or too risky to burn small blocks. Alternatively, he finds it unnecessary to burn because of the protection provided by a broken land-use pattern of pastures and cultivated fields.

Most of the 2.5 million acres burned by prescribed fire during 1970 were probably on the 57 million acres owned and managed by public agencies or private industry--both of which depend heavily on hazard reduction burning to protect their holdings from wildfire. Because of stand age and condition, burning would not be needed, nor could it be applied to the entire 57 million acres. To extend this a bit further, perhaps only 40 of the 57 million acres could benefit from prescribed burning. If most of the 2.5 million acres burned by prescribed fire in 1970 were on this 40 million acres, we would be providing annual protection on approximately 6 percent of the area that really needs it. With a 3- to 4-year burning rotation, protection could then be provided on 18 to 25 percent of the land--certainly a level that would go a long way toward reducing the incidence of large damaging fires and contribute toward an improved record of fire protection.

WEATHER, PRESCRIBED BURNING, AND AIR QUALITY

A study conducted by the Weather Bureau in 1957 may be significant in our effort to secure a better understanding of weather conditions that contribute to changes in air quality (9). The purpose of this and a companion study (7) was to define the synoptic climatology of stagnating high-pressure systems in the eastern United States. The frequency and extent of these stagnant airmasses could then be used to help predict the occurrence of major accumulations of air pollution in urban and rural areas. The studies covered a 25-year period, 1936 to 1960, and provide information on the total cases of air stagnation, total number of days with stagnant air, and seasonal occurrence of stagnation of 4, 5, 6, and 7 days' duration. Some good news and some bad news came from these studies: First, the bad news. Most of Georgia, South Carolina, and western North

---

[2/] USDA Forest Service. Prescribed burning survey, 1970. (Unpublished report on file at the Southeast. Forest Exp. Sta., Sout Forest Fire Lab., Macon, Ga.)

Carolina are included in the region having the highest number of cases (4 days or more) and the highest number of days with stagnant air in the eastern United States during the 25-year period. Over 70 cases of stagnation were identified in this area of the Southeast, and over 350 days with stagnant air were experienced. These figures are in contrast to an average of 15 cases and 75 days experienced in Louisiana.

Now for the good news. Most of the cases of stagnation (4 days or more) occurred during the months when relatively little prescribed burning is done (April to November). Only 11.9 percent of the cases occurred during the months when prescribed burning is heaviest (December to March). October had the highest frequency of cases, followed closely by September, June, and August. Light winds that accompany a stagnating airmass would make burning unpredictable, and every effort should be made to avoid burning during such periods.

As previously mentioned, the National Weather Service issues Air Pollution Potential forecasts on a synoptic scale for the entire United States (15). These forecasts warn of conditions conducive to the poor smoke dispersion generally associated with stagnating high-pressure systems. A large percentage of APP alerts would occur during periods when burns are usually not conducted anyway. However, if burns are scheduled and an APP alert is received, the burn should be postponed in order not to add to the developing air-quality problem. With experience, these APP forecasts can be improved and made more specific for the areas scheduled for burning. Such local forecasts would identify localized problems with stagnating air and help do a more effective job of managing the smoke from prescribed fires.

PRODUCTS OF COMBUSTION

Forest fires produce a variety of combustion products, most of which are not unique to forest fuels. We can consider these products individually, as contributors to the total problems, or as products that are destined for physical and chemical changes that may make them either more, or less, objectionable from the standpoint of air quality. Extensive research is needed to describe more accurately the environmental consequences of combining these materials with each other and with other air pollutants.

Particulates

One of the most important of the combustion products is smoke. This particulate material, either solid or liquid and ranging in size from 0.001 to 10.0 microns, can be measured and estimates made of the amount produced per unit of fuel consumed.

When particulates are present in large quantities, they can cause a drastic reduction in visibility and create locally hazardous conditions for movement of surface and air transportation--as well as causing damage to exposed materials and posing a threat to human comfort. Particulates may be important from a health standpoint if they combine with other pollutants to form harmful

chemical products. This synergistic effect, or the condition whereby two or more chemical products combine to produce a compound that may be more toxic or damaging than any of the individual products, makes it extremely difficult to analyze products of combustion individually and conclude that they are, or are not, damaging to plants, animals, or humans.

A common measure of particulate concentration is weight per unit volume as expressed in micrograms (µg.) of particulates per cubic meter of air. The instrument most commonly used for sampling particulates for studies of mass concentration is the high-volume air sampler. This instrument tells only a portion of the pollution story but is widely used by public agencies as one means of collecting data on air quality. When particulate concentrations in urban areas are present at a level of 75 to 80 µg./m.^{3}, some action should be taken to reduce further output of emissions.

A geometric mean computed for various cities for a recent 5-year period ranked Chattanooga, Tennessee, No. 1 with 180 µg./m.^{3} (17). Other cities in the South in descending order of magnitude were: Birmingham, Alabama, 141; Nashville, Tennessee, 128; Memphis, Tennessee, 113; Atlanta, Georgia, 98; Greensboro-Highpoint, North Carolina, 60; and Miami, Florida, 58. Particulate concentrations depend not only on source or location but are also a function of weather factors that encourage or discourage air movement. Formulas are available for estimating expected visibility for different particulate concentrations (17). With a typical rural concentration of 30 µg./m.^{3}, the visibility is about 25 miles. For common urban concentrations of 100 to 200 µg./m.^{3}, the visibility would be 7.5 to 3.75 miles.

At this point it might be well to summarize some of our research findings concerning the measurement of particulates--their transport and dispersion. For some of you this will be a review, because this work was previously reported on by Ward and Lamb at the Tall Timbers Fire Ecology Conference in New Brunswick last summer (21). We wanted to accomplish two objectives: (A) Through the use of a network of high-volume samplers, determine the effect of widespread prescribed burning on the amount of particulates in the atmosphere and (B) study the production and movement of particulates from an operational prescribed burn.

During January and February of last year, we operated a network of high-volume air samplers in eight counties in middle Georgia. Measurements were made continuously during a 2-week period in February. For a portion of the time, there was little or no burning; later in the period, prescribed burning increased. Although figures on the acreage burned were not available, particulate concentrations correlated fairly well with the number of observed smoke plumes in the area. On the days most suitable for burning, the first of which was February 7, the observed smoke plumes and the filter weights showed a general increase:

Date	Observed smoke plumes	Avg. filter wt.*
	No.	g./m.^{3}
Saturday, Feb. 7	83	27
Sunday, Feb. 8	12	18
Monday, Feb. 9	70	23
Tuesday, Feb. 10	49	39
Wednesday, Feb. 11	84	52
Thursday, Feb. 12	100	55
Friday, Feb. 13	117	65

* (Average filter weight from all high-volume samplers operating in the area.)

On February 13, there were 120 smoke plumes recorded in the area; these produced an average filter weight of about 65 μg./m.^{3}. This was an active burning day, but the filter weights were still well below the 78 to 80 μg./m.^{3} mentioned earlier as a critical level for urban areas.

On March 13, we instrumented an operational hazard reduction burn in a 20-year-old plantation in central Georgia. The plantatior was owned by the Union Camp Company, and company personnel conductec the burning as they would have under normal operating conditions. We located a network of high-volume samplers in the area, and an instrumented aircraft flew through the plume to measure particulate concentrations at various locations downwind from the fire. Some useful data were obtained from the cross-sectional flights of the plume. But perhaps most important, this one field effort demonstrated a technique that can be used for future studies of the concentration and movement of smoke plumes.

Research at the Atmospheric Sciences Research Center at New York State University has revealed that, even though visible smoke sources in many areas have been largely eliminated, the air pollution problem continues to become more critical (13). Improved technology has made it possible to eliminate much of the visible smoke, leaving only the invisible particles suspended in the atmosphere. These particles may, in the long run, be more undesirable because they remain suspended in the atmosphere for extended periods. It is conceivable that this problem may affect the use of prescribed burning. It may be more desirable to produce smoke having large-sized particles so that the particle fallout will occur rapidly, rather than trying for a "clean, hot" burn that produces little visible smoke but large concentrations of invisible particles.

There are some other products of combustion that are produced in quantity by prescribed burns and wildfires. Each of these bears careful study. But it is encouraging to note that, with only minor exceptions, these compounds in the amounts produced strictly from forest burning do not pose a threat to the environment.

Carbon Monoxide

This gas must, of course, be considered as an air pollutant because it is highly toxic. Manmade processes are recognized as being the greatest source of CO, followed closely by the oceans--probably the greatest natural source of this gas (1). The background levels of CO in the atmosphere (0.05 to 0.2 p.p.m.) appear to be remaining fairly constant in spite of the estimated annual production of 200 million tons of the gas from natural and manmade sources.

In a study of mass fires in California, CO concentrations were measured at three locations during a fire on a 30-acre site where 160 tons of fuel per acre were distributed (11). The following concentrations of CO were detected: 60 p.p.m. at the edge of the plot; 100 p.p.m. on the ground in the center of the plot; and 1,200 p.p.m. at a height of 30 feet over the center of the plot.

A slash fire in western Washington produced CO levels of 40 p.p.m. 60 feet from the edge of the fire (10). This level dropped to 10 p.p.m. at 150 feet. In terms of weight, fields of burning grass in the Willamette Valley of Oregon produced an average value of 132 pounds of CO per ton of fuel (2). In contrast, 1 ton of gasoline burned in an internal combustion engine produces about 900 pounds of CO. The CO concentrations found close to burning forest fuels appear to diminish rapidly to the low levels normally found in rural areas. Perhaps, then, we can conclude that CO from prescribed burns does not pose an immediate threat to people, plants, or animals but that it may be important in photochemical reactions both as a product and a reactant.

Hydrocarbons

Although hydrocarbons are another combustion product emitted in significant amounts from burning forest fuels, it is encouraging to note that these products are generally quite different from the hydrocarbons released by internal combustion engines. There are perhaps thousands of hydrocarbon compounds produced when fossil and wood fuels burn. However, only a few of these are considered to be contributors to the problem of photochemical smog.

Darley et al. (5) have estimated the hydrocarbons produced by burning agricultural wastes. They found that burning green brush produces over 27 pounds of hydrocarbons per ton of fuel, that dry brush produces 4.7 pounds and that redwood chips produce 2.2 pounds. Again, these figures are in contrast to the approximately 130 pounds of hydrocarbons produced per ton of gasoline.

In the combustion room of the Macon Laboratory, we are measuring total hydrocarbons produced by burning. However, this measure by itself is not a good indicator of photochemical activity. Measured hydrocarbons need to be further broken down to identify the olefins and aromatics--the compounds that can combine with other products in the presence of sunlight to produce photochemical products.

Carbon Dioxide

This colorless, odorless gas formed by natural decomposition of organic substances is also produced by complete combustion of carbon-containing materials. Strictly speaking, CO_2 is not considered an air pollutant, and it is not included in the National Emission Inventory (18). It is significant to note that there are currently no programs to control the amount of CO_2 released into the air, nor are there plans for such programs (12).

We are also measuring CO_2 emissions from the fuels burned in the combustion room at the Macon Laboratory. Results from field and laboratory experiments conducted in California and Oregon (2) indicate that it may be possible to use laboratory data for certain gases (of which CO_2 is one) for extrapolation of larger-scale emission inventories. If this holds true for the fuels burned at the Macon Laboratory, we may soon be able to improve our accuracy in predicting the emissions from some of our common southern fuels.

SUMMARY AND CONCLUSIONS

In conclusion, there are some basic considerations that must be recognized in evaluating the air-quality aspects of prescribed burning.

Most obvious is the fact that we actually know very little about the effects of forest fires on air quality. Our biggest void appears to be in the development of a reliable emission inventory which, if completed, would tell us where, when, and how much of each of the various combustion products are produced from prescribed burns and from wildfires.

We must recognize that both wildfires and prescribed fires contribute to changes in air quality. One of our most important tasks ahead is to determine the significance of these changes locally, regionally, and nationally in relation to other sources. This determination must be made for conditions as they exist today, and some effort must be made to project these findings into the future.

The advantages of using prescribed fire must be weighed against possible detrimental effects of fire on air quality. This consideration must include a scientific evaluation of the consequences of not using fire for any of the purposes for which fire is now employed.

The use of prescribed fire for land management and protection carries with it an obligation to conduct burning operations in such a way as to eliminate or minimize adverse environmental impacts. Effective management of smoke from our burning efforts is largely dependent on our ability to forecast weather for specific areas and to utilize these forecasts to direct the smoke away from major highways, airports, and metropolitan areas (20). If we fail to observe these basic precautionary measures now, we may soon be faced with more restrictive burning regulations.

Concerning the legal or legislative aspects of prescribed burning, we need to develop information that can be used to help establish realistic standards for air quality in rural areas. Although some states have no restrictions on open burning for forestry purposes, it seems likely that all states will eventually be operating with some type of regulation that restricts, or otherwise limits, the type and amount of open burning that can be done. We need to be prepared to provide sound facts and information to the agencies responsible for establishing regulations concerning the burning of forest wastes, and we need to cooperate with them if it becomes necessary to revise existing regulations. One of our most important jobs is to make known to the regulatory agencies the advantages and disadvantages of using fire in managing forest lands. If the decision is then made to further restrict open burning, we must be prepared to search for alternatives that can be used to accomplish what needs to be done.

Finally, we must continue to improve our methods and techniques for using prescribed fire--regardless of whether burning regulations become more restrictive. This Symposium is a significant step in that direction. The research we do must be more productive and provide data that will make it possible for us not only to prepare more precise fire prescriptions but also to complete all burns in such a way that the beneficial aspects will be emphasized and the undesirable effects minimized.

ACKNOWLEDGEMENT

I wish to acknowledge the excellent material and technical assistance provided by the Air Pollution Control Office of the Environmental Protection Agency. I am also indebted for the assistance provided by the Statewide Air Pollution Control Center, Riverside, California; the Environmental Engineering Department, University of Florida; the Georgia Forestry Commission; Union Camp Corporation; and the International Paper Company's Southlands Experimental Forest.

LITERATURE CITED

1. American Meteorological Society. 1970. Carbon monoxide--where does it come from and where does it go? Amer. Meteorol. Soc. Bull. 5: 908.

2. Boubel, Richard W., Darley, Ellis F., and Schuck, Edward A. 1969. Emissions from burning grass, stubble, and straw. J. Air Pollut. Contr. Assoc. 19: 497-500.

3. Burckle, J. O., and Dorsey, J. A. 1968. Air pollution and open burning in forestry operations. South. Fire Chiefs & Inform. & Educ. Chiefs Joint Meeting 1968, 10 pp. Houston, Tex.

4. Corman, Rena. 1969. Air pollution primer. 104 pp. New York: Nat. Tuberc. Resp. Dis. Assoc.

5. Darley, Ellis F., Burleson, F. R., Matier, E. H., and others. 1966. Contribution of burning of agricultural wastes to photochemical air pollution. J. Air Pollut. Contr. Assoc. 16: 685-690.

6. Fritschen, Leo, Bovee, Harley, Buttner, Konrad, and others. 1970. Slash fire atmospheric pollution. Pacific Northwest Forest and Range Exp. Sta., USDA Forest Serv. Res. Pap. PNW-97, 42 pp.

7. Hosler, Charles R. 1963. Climatological estimates of diffusion conditions in the United States. Nucl. Safety 5: 184-192, Winter.

8. Koppe, Robert K., and Adams, Donald F. 1969. Dispersion of prescribed fire smoke. J. Air Pollut. Contr. Assoc. (In press.)

9. Korshover, Julius. 1957. Synoptic climatology of stagnating anticyclones east of the Rocky Mountains in the United States for the period 1936-1956. U. S. Dep. Health, Educ., & Welfare, SEC TR A60-7, 15 pp.

10. Murphy, James L., Fritschen, Leo J., and Cramer, Owen P. 1970. Research looks at air quality and forest burning. J. Forest. 68: 530-535.

11. Nielsen, Hugo J. 1970. Mass fire data analysis, final report, IITRI Project J6099. DASA Rep. 2018, Def. At. Support Agency under NWER Subtask NA 005, 47 pp.

12. Peterson, Eugene K. 1969. Carbon dioxide affects global ecology. Environ. Sci. Technol. 3: 1162-1169.

13. Schaefer, Vincent J. 1971. The threat of the unseen. Sat. Review 54(6): 55-57.

14. Southern Forest Resource Analysis Committee. 1969. The South's third forest...how it can meet future demands. 111 pp.

15. Stackpole, John D. 1967. The air pollution potential forecast program. U. S. Dep. Com./Environ. Sci. Serv. Admin., Weather Bur. Tech. Mem. WBTM-NMC 43, 8 pp.

16. USDA Forest Service. 1965. Timber trends in the United States. Forest Resource Rep. 17, 235 pp.

17. U. S. Department of Health, Education, and Welfare. 1969. Air quality criteria for particulate matter. Public Health Serv. Consum. Protect. Environ. Health Serv., Nat. Air Pollut. Contr. Admin. Pub. AP-49, 211 pp.

18. _____ 1970. Nationwide inventory of air pollutant emissions 1968. Public Health Serv. Consum. Protect. Environ. Health Serv., Nat. Air Pollut. Contr. Admin. Pub. AP-73, 36 pp.

19. Wadleigh, Cecil H. 1968. Wastes in relation to agriculture and forestry. USDA Forest Serv. Misc. Pub. 1065, 112 pp.

20. Ward, Darold E., and Dieterich, John H. 1970. Prescribed burning...benefits and obligations. South. Lumberman 221(2752): 121-122.

21. Ward, D. E., and Lamb, R. C. 1970. Prescribed burning and air quality--current research in the South. Tenth Annu. Tall Timbers Fire Ecol. Conf. Proc. 1970. (In press.)

COMMENTS

Mr. Dieterich has certainly given a complete presentation and covered the present research related to air quality and prescribed burning. I am not aware of any work in this area other than that mentioned in his report.

Mr. Dieterich has also pointed out some of the difficulties in assessing the impact of prescribed burning on air quality. Variations in assessing present emission factors--coupled with differences in estimating the amount of material burned--have caused confusing and conflicting information to appear in the literature. This confusion is probably due to the lack of attention, from the standpoint of air pollution, that prescribed burning has received in the past.

Some of the previous speakers have referred to the historical use of fire, and Mr. Robert Cooper has mentioned the self-cleansing mechanism of the atmosphere. All of this is very true; however, we must remember that fire is no longer the single source of air pollution. It is only a part; and, when coupled with other sources, fire could have a tremendous impact on air quality as well as overload the cleansing ability of the atmosphere.

We must now think of air quality in terms of control regions. The States have primary responsibility for specifying the manner in which national standards of ambient air quality will be achieved and maintained within each region. All sources of air pollution--both urban and rural--will have to be considered by the States in their implementation plans.

With this in mind, I urge you to proceed with your research to establish reliable emission factors and obtain better estimates of fuel burned. I think it should be pointed out that this task will be difficult. For example, emissions will be influenced by such variables as fuel type, moisture content of the fuel, compaction, wind speed, relative humidity, topography, and so on.

Nevertheless, this work must be completed, and a reliable emission guide must be published and used. With such a guide, the agencies charged with controlling air pollution will be able to evaluate realistically the impact of prescribed burning on air quality. This impact can then be weighed in terms of benefits gained from the use of this technique on the one hand and changes in air quality on the other.

Richard C. Dickerson
National Air Pollution Control Administration
Raleigh, North Carolina

EFFECTS OF PRESCRIBED BURNING ON THE ECOSYSTEM

Charles F. Cooper
National Science Foundation
Washington, D. C.

Almost every preceding paper has dealt with one or another aspect of the effects of prescribed burning on the Coastal Plain ecosystem. Therefore, I would like to examine prescribed burning in the light of what economists refer to as externalities--or what we foresters are more apt to call off-site effects. Here are included those costs, tangible and intangible, of a prescribed burning program that must be paid by those who are not its direct beneficiaries.

The preceding papers have been excellent reports on the effects of fire on wildlife, on long-term soil productivity, on aesthetics, and on local air pollution. I would like to concentrate on some topics that have not been as fully covered: effects of prescribed burning on regional water supplies, on regional and global atmospheric phenomena, and on people. Because, lest we forget, people are an integral part of the ecosystem too. Finally, I would like to say a word about ecological stability in silvicultural systems that may include prescribed burning, and about the role of prescribed burning in a regional land-use policy.

WATER RESOURCES

In evaluating its effect on water resources, it is important to consider prescribed burning not in isolation but as a part of a total silvicultural system. This system will in the future very probably include the application of inorganic nitrogen fertilizers as well as the prescribed application of fire.

There is increasing evidence from agricultural areas that heavy nitrogen fertilization may lead to unacceptable levels of nitrate in ground water and in surface runoff (3, 7). This can have direct effects on human health, particularly in infants. The question is, will the same thing occur if nitrogen fertilizer is widely applied to forests? And will the combination of fertilization and prescribed burning aggravate the problem?

The output of N and P from forests, including those intensively managed by present standards, is exceedingly low (4). Nutrients in ground water under forests have not been intensively studied, but I think the same is true there. In the only quantitative experiments known to me which measured the fate of fertilizer elements applied to forest stands, N and P were almost wholly retained by the soil. The forests concerned in Washington (2) and Pennsylvania (13) were both underlain by heavy glacial till with a high exchange capacity. The situation might be somewhat different in sandy soils of the Atlantic Coastal Plain. In view of the well-known fact that burning of surface litter and duff releases soluble nitrogen compounds, it would appear that artificial fertilization should not be done in the same season as prescribed burning until more information is available concerning retention of nitrate and other ions under a wide range of conditions.

Vegetation plays an important role in the nitrogen balance of soil and water. Experiments at the Hubbard Brook Experimental Forest in New Hampshire have shown that clearcutting of a forest stand induced a sixtyfold increase in the nitrogen content of runoff water. Nitrate levels exceeded Public Health Service standards for drinking water, and nuisance algae became abundant in the previously clear stream (11). Are not similar effects likely as a result of the removal of vegetation by prescribed burning, particularly in view of the ease with which nutrients can be leached from fresh ash?

This question overlooks the drastic nature of the treatment at Hubbard Brook. Not only was the stand clearcut, but all logs and slash were left to decay and release their contained nutrients. More important, repeated herbicide applications prevented root sprouting and growth of secondary vegetation. The site remained bare. If there had been any appreciable quantity of living roots in the soil, as there would have been without the herbicide treatment, most of the nitrogen which was lost would instead have been taken up by new vegetation. Even the most severe prescribed burning treatment will not leave the site as bare as was the Hubbard Brook watershed during the experimental cycle. Nutrient losses of the magnitude experienced at Hubbard Brook are not to be expected after prescribed burning, although there are some losses due to solubilization and volatilization of formerly stable and insoluble organic nitrogen fractions.

It has been suggested, in Arizona and elsewhere, that removal of accumulated litter and duff by prescribed burning may reduce water retention and make more moisture available for streamflow. This effect is marginal in semiarid forests, and is unlikely to be significant in the more humid forests of the Southeast.

Neither will the reduction of vegetation quantity by prescribed burning be an effective water conservation measure in the Southeast except under treatments so drastic that most cover is destroyed. So long as the site remains occupied by plants, with a leaf area index of perhaps 1.5 or more, transpiration will continue at very nearly the rate determined by the incoming energy supply rather than by the structure of the vegetation. For the same reason, prescribed burning, unless very drastic, is unlikely to aggravate the drainage problem in Coastal Plain areas of high water table.

Sediment yields and nutrient levels in runoff after the first rains following a severe wildfire are often several times normal, particularly in steep mountainous areas (4). This need not be true of carefully planned burns in the more level country of the Piedmont and the Coastal Plain.

In conclusion, it appears that properly managed prescribed burning should not adversely affect either the quality or the quantity of ground or surface water in the Southeast. This is particularly true if only relatively small areas are burned at one time and if they are interspersed among unburned tracts, a practice which is silviculturally desirable in any case. Caution does need to be used in combining nitrogen fertilization with fire treatment, especially on sandy soils.

ATMOSPHERIC RESOURCES

Let us dispose first of the fears which some alarmists have raised, that the earth will run out of oxygen unless we take active steps to maximize global photosynthesis. Broeker (1) and other investigators have effectively disproved this contention. Complete combustion of the reduced carbon in all existing living plant and animal tissue would require only a fraction of one percent of the atmosphere's oxygen. Statements that this vital resource is in danger of serious depletion if we mismanage our forests are simply not valid.

The carbon dioxide picture is less clear. Because the carbon dioxide content of the atmosphere is only about 1/700 of the oxygen content, CO_2 is more sensitive to man-induced change than is oxygen. There is now no doubt that the mean atmospheric content of carbon dioxide has been steadily increasing through most of this century, chiefly as a result of the combustion of fossil fuels and oxidation of soil organic matter following land clearing. Although there has been much discussion of the meaning of this carbon dioxide increase for global temperatures, the quantitative predictive models needed to answer the question simply do not exist. Nevertheless, it would appear prudent to do whatever we can to restrain the rate of increase of CO_2 in the atmosphere.

Combustion of woody material of course releases carbon dioxide. But so does biological oxidation--decay of unburned material. Only the rate is different. The role of forests in regulating atmospheric CO_2 depends wholly on the total quantity of reduced carbon in the biomass of the region. Only to the

extent that silvicultural practices, including prescribed burning, reduce the mean live and dead biomass of an entire region below that which it would be in the absence of burning is the average carbon dioxide content of the atmosphere significantly affected. One purpose of prescribed burning, of course, is to reduce the amount of nonproductive woody material and to eliminate excess fuel. Nevertheless, the difference in quantity of fixed carbon in burned and unburned stands is too small to affect the global carbon dioxide balance significantly.

Neither are the other biologically active constituents of the atmosphere likely to be appreciably influenced by prescribed burning. The sulfur content of forest fuels is too low to contribute significant amounts of sulfur dioxide to the atmosphere (12). Practically all the nitrogen volatized from burning organic matter is released as inert nitrogen gas rather than in biologically active forms (6). Smoke from field and laboratory combustion of slash, mostly Douglas-fir, in western Washington contains small amounts of several hydrocarbons and alcohols of low molecular weight. Only traces of unsaturated compounds have been identified (9). None of the important components are known to be implicated in formation of photochemical smog or of plant-damaging oxidants. Before we can make firm statements about the harmlessness of wood smoke, however, we need results from additional laboratory studies of material from a variety of species and under a wide range of burning conditions and fuel compositions.

This brings us to particulate matter in the atmosphere. Airborne particles, or aerosols, influence the transparency of the atmosphere, and play an important role in precipitation processes.

Fine particles influence the heat balance of the earth by reflecting and absorbing radiation from the sun and from the earth. Particles enter the atmosphere from natural sources, including sea spray, windblown dust, and volcanoes. Burning of forests and forests wastes appears to be a major source of airborne particles on a global scale (15).

Aerosols can produce changes in the reflectivity of the clear atmosphere, in the amount of reflective clouds, and in the reflectivity of individual clouds. The magnitude of these effects is not known and in general it is not possible to state whether small changes in atmospheric turbidity would result in a warming or a cooling of the earth's surface (15).

The fact that forest fires have always been major contributors of aerosols on a worldwide scale might suggest that substitution of prescribed fires for wildfires would change the global situation but little. The counter argument might be made that man-made urban industrial particulates have increased to such an extent that it is now necessary to curb agricultural and forest particulate emissions to a level well below the "natural" state. However, some meteorologists contend that emissions from volcanic eruptions can account for most, if not all, of the recent observable variation in atmospheric turbidity (8). All the evidence is obviously not in,

but at present it does not appear that global effects on atmospheric turbidity are such as to rule out the practice of prescribed burning.

Atmospheric aerosols also affect precipitation. There is evidence, from the Pacific Northwest, Australia, and elsewhere, that massive burning of agricultural or forest residues has affected rainfall downwind. I do not propose to review these studies because, in my opinion, the meteorological situation and the fuel and burning conditions were so different as to render these observations nearly meaningless for extrapolation to the case of prescribed burning in the Southeast. The only really relevant observations that I know of were made by Ronald Holle (10) at the NOAA Experimental Meteorology Laboratory at Miami.

Particles in wood smoke are of two principal types with respect to their influence on water drop formation: cloud condensation nuclei, upon which drops can form that are large enough to fall by gravity, and the very small Aitken nuclei, which result in tiny buoyant cloud droplets. A minimum number of cloud condensation nuclei is required for rain formation, but particularly in coastal regions they are seldom in short supply. They originate from sea salt, from terrestrial dust, and from other sources as well as from smoke. If, however, there are too many condensation nuclei, few drops can grow large enough to fall of their own weight, and rainfall is prevented. It had been hypothesized that burning of vegetation during South Florida's dry spring weather added excessive cloud condensation nuclei to the atmosphere, and prolonged the drought by inhibiting rainfall.

Observations do not support this hypothesis. Although vegetation fires produce some cloud condensation nuclei, most smoke particles are in the Aitken class. Spring droughts over South Florida are associated primarily with atmospheric dryness on a synoptic scale, and with northerly winds aloft, rather than with a lack of condensation nuclei. Dynamic circulation processes easily explain the observed rainfall patterns. Holle (10) suggested that a large scale effect of fire on rainfall can be expected only if (A) large fires are burning on the day when meteorological conditions change; and (B) these conditions keep the smoke over land and carry the nuclei into the growing clouds. Such a combination of events is rather unlikely to occur on the particular day a drought is ending. Holle did find some indication that rainfall from large individual cumulus clouds may have been significantly reduced if they were in the immediate vicinity of large fires. None of this, however, suggests a major climatic effect from prescribed burning of managed forests in the Southeast.

DIVERSITY FOR PEOPLE AND PLANTS

My final remarks have to do mostly with diversity--for plants and for people. I suspect that part of whatever local opposition there is to prescribed burning--to the extent that it is something more than an overbuying of Smokey Bear commercials--is subconsciously associated with reaction against a resource management system that emphasizes uniformity of landscape. John R. Platt (14) suggests that

at the heart of what we call beautiful is "a pattern that contains the unexpected." Of course, Sir Francis Bacon made the point much more eloquently nearly four centuries earlier: "There is no excellent beauty that hath not some strangeness in the proportion." A small patch of freshly burned land may provide just the needed unexpectedness in the pattern of an intensively managed forest, whereas endless rows of plantation trees with a sparse burned-out understory is all pattern and no strangeness.

"Pattern that contains the unexpected" may also be at the heart of ecological diversity. A virtual dogma of traditional ecology is that "A major means for assuring the continuity of life appears to be the number of species per unit area, diversity." That is the key sentence in the introduction to a recent symposium volume on "Diversity and Stability in Ecological Systems" (16). Almost without exception, however, planned increase in economic yield of plant and animal products is accompanied by a decrease in richness and diversity of species (5). The whole history of agriculture and forestry is basically a history of efforts to create simple systems in which preferred species are kept free of other plants that reduce yields through competition or interference with harvest. This is basically what prescribed burning of managed stands is all about.

Without accepting the extreme position of some academic ecologists that man-simplified ecosystems cannot persist, we must nevertheless recognize that simple ecological systems are in general less stable--more subject to sudden damage from external causes--than more complex systems. Much of the modern strategy of resource management, including that of pest control, is in a real sense a substitution of technological diversity for natural ecological diversity.

My conclusion is that, while it may make management technology more difficult, in the long run we are more likely to have a permanently productive forest system if emphasis is put on small blocks, differing in age and composition, and each handled according to a different management prescription and operational schedule. This is contrary to the prevailing trend. It is likely to lead to fewer problems, nevertheless, than reliance on large even-aged pure stands all temporarily weakened at the same time by an extensive prescribed burn in a single season. The latter, if the trend is carried too far, could be a prescription for disaster rather than for increased production.

PRESCRIBED BURNING AND REGIONAL LAND USE POLICY

Following up those last remarks, I'd like to bring out a couple of things that have disturbed me about this conference. The papers and discussions have revolved around the pros and cons of prescribed burning within the context of even-aged pine silviculture. There has been no serious consideration of whether even-aged pine silviculture is indeed an optimal land-use policy for the Southeast. If it is not, the whole controversy evaporates. I suspect that pine culture is in fact an efficient land-use policy for this region, but that is only an assumption on my part. I would have liked

to see a serious discussion of alternative land-use policies, including those in which prescribed burning would logically play no part.

Secondly, even within the context of even-aged pine silviculture, there has been little discussion of alternatives to prescribed burning--their costs, benefits, advantages, and disadvantages. I fear that we have come close to accepting the fallacy of single-use planning for which the Corps of Engineers has been so widely castigated of late. Those who ultimately determine resource policy are increasingly demanding that technical people like ourselves present an array of alternatives for political and social choice. The proceedings of this conference are likely to comprise an excellent statement of the arguments for prescribed burning in the Southeast. They will be woefully incomplete, though, to the extent that they do not address themselves to the alternatives to prescribed burning as a management tool. Only through adequate consideration of all available alternatives can a sound regional land-use policy be formulated. Development of such a policy is a major task for research and for management in the future.

LITERATURE CITED

1. Broeker, Wallace S. 1970. Man's oxygen reserves. Science 168: 1537-1538.

2. Cole, Dale, and Gessel, Stanley P. 1965. Movement of elements through a forest soil as influenced by tree removal and fertilizer additions, pp. 95-104. In C. T. Youngberg (Ed.) Forest-soil relationships in North America. Corvallis, Oreg. State Univ. Press.

3. Commoner, Barry. 1970. Threats to the integrity of the nitrogen cycle: Nitrogen compounds in soil, water, atmosphere, and precipitation, pp. 70-95. In S. Fred Singer (Ed.) Global effects of environmental pollution. New York: Springer-Verlag.

4. Cooper, Charles F. 1969. Nutrient output from managed forests, pp. 446-463. In G. Rohlich (Ed.) Eutrophication: Causes, consequences, correctives. Washington, D. C.: Nat. Acad. Sci.

5. _____ 1970. Man's impact on the biosphere. J. Soil & Water Conserv. 25: 124-127.

6. DeBell, D. S., and Ralston, C. W. 1970. Release of nitrogen by burning light forest fuels. Soil Sci. Soc. Amer. Proc. 34: 936-938.

7. Delwiche, C. C. (Ed.). 1969. Biology and ecology of nitrogen. 166 pp. Washington, D. C.: Nat. Acad. Sci.

8. Friend, James P. 1971. Volcanic sources of atmospheric aerosols. Paper presented at Annu. Meeting Amer. Meteorol. Soc., Jan. 11-14, San Francisco.

9. Fritschen, Leo, and others. 1970. Slash fire atmospheric pollution. Pacific Northwest Forest & Range Exp. Sta., USDA Forest Serv. Res. Pap. PNW-97, 42 pp.

10. Holle, Ronald L. 1969. The effect on rainfall of cloud condensation nuclei from vegetation fires over South Florida during spring droughts. ESSA Tech. Monogr. ERLTM-AOML 4.

11. Likens, Gene F., and others. 1970. Effects of forest cutting and herbicide treatment on nutrient budgets in the Hubbard Brook watershed-ecosystem. Ecol. Monogr. 40: 23-47.

12. Murphy, J. L., Fritschen, L. J., and Cramer, O. P. 1970. Research looks at air quality and forest burning. J. Forest. 68: 530-536.

13. Pennypacker, S. P., Sopper, W. E., and Kardos, L. T. 1967. Renovation of wastewater effluent by irrigation of forest land. J. Water Pollut. Contr. Fed. 39: 285-296.

14. Platt, John R. 1970. Perceptions and change. Ann Arbor: Univ. Mich. Press.

15. Study of Critical Environmental Problems (SCEP) Committee. 1970. Man's impact on the global environment. Cambridge: MIT Press.

16. Woodwell, G. M., and Smith, H. H. 1969. Diversity and stability in ecological systems. Brookhaven Nat. Lab., Symp. Biol. 22, 264 pp.

COMMENTS

I am pleased that Dr. Cooper brought up the experiments on the Hubbard Brook Experimental Forest and placed them in proper perspective. Dr. Cooper described the drastic nature of the treatment at Hubbard Brook and concluded that nutrient losses of the magnitude experienced there probably would not be produced by typical regeneration practices.

Recently, however, Dr. Curry, a geologist from the University of Montana, cited the Hubbard Brook findings before the Church Committee in Washington, D. C. In essence, he said the research showed that cutting of timber resulted in extreme damage to forest soils that could take from 4,000 to 10,000 years to repair, and he recommended a 4-year moratorium on all timber cutting in the West. We must be prepared to reply to such inaccurate interpretations of on-going research.

We have gathered at this meeting probably the strongest array of foresters and related disciplines in the South to discuss the critical question of how best to use fire in our forest. The presentations are based on sound scientific research. The problems we face, however, are much broader than the possible restriction of the use of prescribed fire. We need a great deal more research to find answers to problems in the entire field of forest management as related to quality of the environment.

Most research by the Forest Service, industries, and the universities has been aimed at answering the questions of the forest manager, and--collectively--we have done a good job. The total research effort, however, has not been substantive enough, deep enough, or broad enough to provide information that will be of help on policy questions that concern environment quality.

As Dr. Cooper said, we need biological models that present alternatives to show the consequences of management actions on the full spectrum of biological, ecological, and ecosystem factors. We need also comparable economic models to show the number of jobs offered by the various alternatives, to show the effect on the price of paper, lumber, and plywood for our homes, and the economic value of recreation and wildlife assets. The economic models are just as important as the biological and the physical models of the atmosphere that were described by Dr. Cooper. Finally, we need improved decision-making systems. We do not need improved decisions makers. We have able men, but so far we have not been able to give them all the tools they need to make the better decisions.

R. Keith Arnold
U. S. Forest Service
Washington, D. C.