

May, 1974

To the Graduate Council:

I am submitting herewith a dissertation written by Lawrence Samuel Barden entitled "Lightning Fires in Southern Appalachian Forests." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Ecology.

Frank W. Woods
Major Professor

We have read this dissertation
and recommend its acceptance:

Edward E.C. Ulrich

Clifford C. Hansen

John K. Kinnick

Accepted for the Council:

Hilton A. Smith
Vice Chancellor for
Graduate Studies and Research

4

LIGHTNING FIRES IN SOUTHERN
APPALACHIAN FORESTS

A Dissertation
Presented to
the Graduate Council of
The University of Tennessee

In Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy

by
Lawrence Samuel Barden

August 1974

ACKNOWLEDGMENTS

Throughout the study I received generous support from my major professor, Frank W. Woods. The Graduate Program in Ecology, under the directorship of James T. Tanner, provided financial assistance for travel and computer services, and an NDEA fellowship supported my doctoral program. Professors Clifford C. Amundsen, Edward E. C. Clebsch and John C. Rennie served on the doctoral committee and reviewed the dissertation. Virginia Patterson of the University of Tennessee Computer Center wrote two major computer programs for the study. Mary O. Astad, B. W. Chumney and Ralph H. Kunz of the U. S. Forest Service and Marion W. Meyers of the National Park Service furnished the fire reports.

To these and to my wife, Louise, who made it possible, I express my appreciation.

ABSTRACT

The purpose of this study was to describe characteristics of lightning fires, including frequency, size, season and severity, and to determine their effects on the composition of pine-hardwood stands in the Appalachian Mountains of Tennessee and North Carolina.

An analysis of fire reports from Great Smoky Mountains National Park and from Cherokee, Nantahala and Pisgah National Forests, an area of 800,000 ha, shows that during 1960-1971 there was an average of six lightning fires per year per 400,000 ha (one million acres). The median size of lightning fires was 0.8 ha and the largest 33 ha. More than 90 percent of all lightning fires occurred during April through August with the highest frequency in May. Lightning fires tended to be much less severe than man-caused fires. No lightning fire on record was crowning when the fire crew arrived.

An analysis of the effects of 13 fires on the composition of pine-hardwood stands in Cherokee National Forest and Great Smoky Mountains National Park suggests that lightning fires generally caused small changes in the pine/hardwood basal area ratio, due primarily to differential survival of pines and hardwoods. Southern pine beetles (Dendroctonus frontalis Zimm.) attacked pines on two of the sites of lightning fires, reducing the percent pine in the total basal area from about 70 percent to approximately 25 percent.

If lightning fires were permitted to burn in Great Smoky Mountains National Park, they probably would not maintain the widespread pine forests which now clothe southern slopes at lower elevations. However, such fires may permit enough new pine reproduction on dry ridges to

preserve Table-Mountain (Pinus pungens Lamb.), pitch (P. rigida Mill.), shortleaf (P. echinata Mill.) and Virginia pine (P. virginiana Mill.) as fugitive species in the Park.

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PART I

CHARACTERISTICS OF LIGHTNING FIRES
IN SOUTHERN APPALACHIAN FORESTS

I. INTRODUCTION

In many forest regions, lightning fire is a normal ecological force. Before the days of forest fire suppression, fires shaped many species by selective action and altered the forest composition. But in the early days of forestry in the United States, the primary thrust in national forests and in national parks was to control all wildfires. This, too, was a kind of selective action and, in some regions, the efficient control of fire has caused major changes in forest composition. Recently, administrators of several national parks in the U.S., including Sequoia-Kings Canyon in California (Kilgore and Briggs 1972), Yellowstone in Wyoming and Montana (Houston 1973) and Grand Teton in Wyoming (Loope and Gruell 1973) have realized the importance of fire as a natural ecological influence and have begun allowing some lightning fires to burn unimpeded.

In contrast to these western parks, all fires in Great Smoky Mountains National Park in Tennessee and North Carolina are suppressed as rapidly as possible. How wise is this policy of complete fire suppression? By extinguishing all lightning fires, has the National Park Service eliminated an important natural influence from the forests of the Park?

The purpose of Part I of this study is to describe characteristics including frequency, size, season and severity of lightning fires in the Appalachians of Tennessee and North Carolina. Hopefully, the study will help to provide a factual basis for the new fire policy called for in the Resource Management Plan of Great Smoky Mountains National Park. The new policy would permit some lightning fires to burn freely to

maintain plant communities which depend on fire for their perpetuation. At present the Park Service extinguishes all fires in the Park.

When national forest or park personnel put out a forest fire, the district ranger prepares a fire report which describes the fire and shows its location on a map. Fire reports from Great Smoky Mountains National Park and from Cherokee, Nantahala and Pisgah National Forests in Tennessee and North Carolina provided the data for this study. The data were used as reported.

Study Area

Stretching more than 480 km (300 miles) from northern Georgia to southern Virginia, the southern Appalachians consist of several mountain chains: the Blue Ridge, Great Smokies, Chilhowee, Stone, Bald, Holston, Iron and others. The region's width varies from 32 km (20 miles) in Virginia to 100 km (70 miles) in Tennessee and North Carolina (Fenneman 1938). Its highest peaks rise above 2000 m (6500 feet) while its deepest river valleys lie below 300 m (1000 feet) in elevation.

As shown in Figure 1, much of this region in Tennessee and North Carolina falls into four federal administrative units:

Cherokee National Forest (CNF)	244,000 ha (603,000 acres)
Great Smoky Mountains National Park (GSMNP)	209,000 ha (517,000 acres)
Nantahala National Forest (NNF)	183,000 ha (452,000 acres)
Pisgah National Forest (PNF)	195,000 ha (481,000 acres)
Total Area	831,000 ha (2,053,000 acres)

From low elevations such as Gatlinburg, Tennessee (445 m, 1460 feet) to high peaks such as Clingman's Dome (2024 m, 6640 feet) in

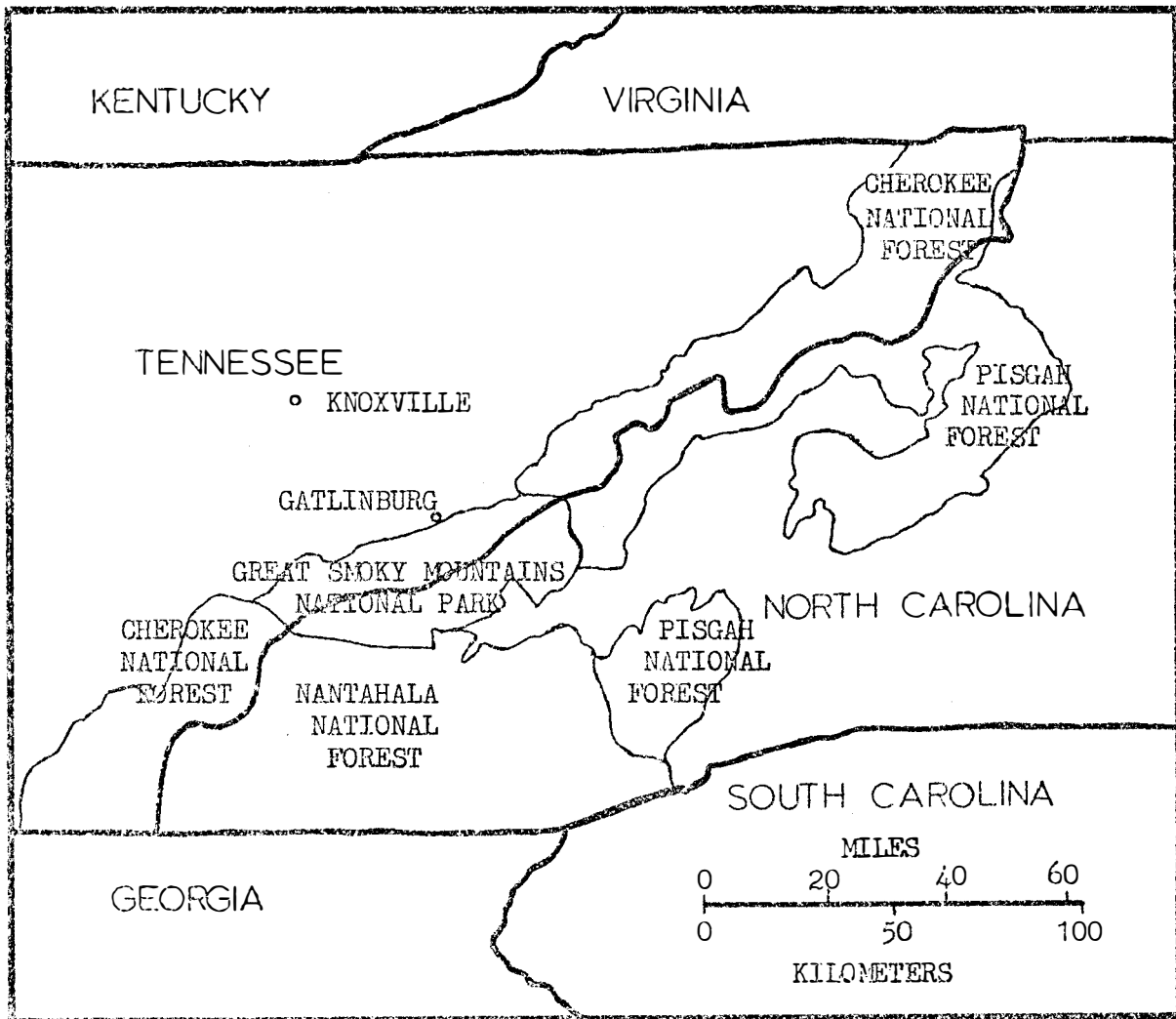


FIGURE 1. AUTHORIZED BOUNDARIES OF FEDERAL ADMINISTRATIVE UNITS IN THE STUDY AREA

GSMNP, the climate changes remarkably. At Gatlinburg the average annual temperature is 13°C (56°F) and annual precipitation averages 1470 mm (58 inches) while at Clingman's Dome the figures are 8°C (46°F) and 2310 mm (91 inches). In Thornthwaite's (1948) classification of climates, Gatlinburg is humid mesothermal while Clingman's Dome is wetter than perhumid microthermal (Shanks 1954). The winter months and July are the wettest; late spring and early fall are relatively dry.

Forest composition changes with elevation and exposure. Forests in stream valleys consist of such mesophytic species as eastern hemlock (Tsuga canadensis), Carolina silverbell (Halesia carolina), yellow buckeye (Aesculus octandra), white basswood (Tilia heterophylla), sugar maple (Acer saccharum) and yellow birch (Betula alleghaniensis). Submesic to subxeric sites at middle and lower elevations support oak-hickory forests with such species as northern red oak (Quercus rubra), White oak (Q. alba), Chestnut oak (Q. prinus), pignut hickory (Carya glabra) and mockernut hickory (C. tomentosa). Before 1940, American chestnut (Castanea dentata) was a dominant species here, but now only sprouts remain to represent the species.

Xeric southerly slopes at lower elevations (below 950 m) support pine-hardwood or pine forests with such species as Virginia pine (Pinus virginiana), pitch pine (P. rigida), shortleaf pine (P. echinata), Table-Mountain pine (P. pungens), chestnut oak (Quercus prinus), scarlet oak (Q. coccinea), red maple (Acer rubrum), blackgum (Nyssa sylvatica) and sourwood (Oxydendrum arboreum).

Above 1370 m (4500 feet) red spruce and Fraser fir (Picea rubens and

Abies fraseri) dominate the forests, except in the southwest half of the study area where a hardwood forest similar to that of the stream valleys occurs. The well-known but limited heath and grassy bald communities occur on exposed ridges at high elevations. Mountain-laurel (Kalmia latifolia) and Rhododendron spp. are the chief taxa of heath balds, and the grass, Danthonia compressa Aust., is the most common species of the grassy balds (Whittaker 1956). Nomenclature follows Little (1953) for woody species. The comparisons shown in figures 5-9 are significant at the $\alpha = 0.01$ level using chi-square contingency tests.

II. RESULTS AND DISCUSSION

Fire Season

In the southern Appalachians the peak of the lightning fire season occurs in May, after the spring maximum of man-caused fires in April (Figure 2) and before thunderstorms reach their greatest frequency in July and August (Alexander 1935). April through August account for more than 90 percent of all lightning fires while 40 percent occur in May alone (Figure 2). The area burned per month by lightning fires is similarly distributed (Figure 3).

The two seasons for man-caused fires correspond to times when litter is driest: March through May and October through November (Figure 2). The spring fire season, March through May, accounts for 60 percent of man-caused fires and 80 percent of the total area burned. October and November, on the other hand, account for only 25 percent of the fires and 13 percent of the area burned (Figures 2 and 3). Thus, for man-caused fires the spring season is generally more severe than the fall season. However, the largest and most severe historical fires in the region occurred in September, 1925, and October, 1952.

In comparing other parts of North America with the southern Appalachians, we find that fire seasons in Florida are similar to those in the study area except that the spring maximum of man-caused fires comes one month earlier, in March, and that of lightning fires one month later, in June (Komarek 1964). In Alaska man-caused fires peak in May and lightning fires in June (Hardy and Franks 1963). In the northern Rocky Mountains most lightning fires coincide with the maximum frequency of thunderstorms in July and August (Barrows 1951).

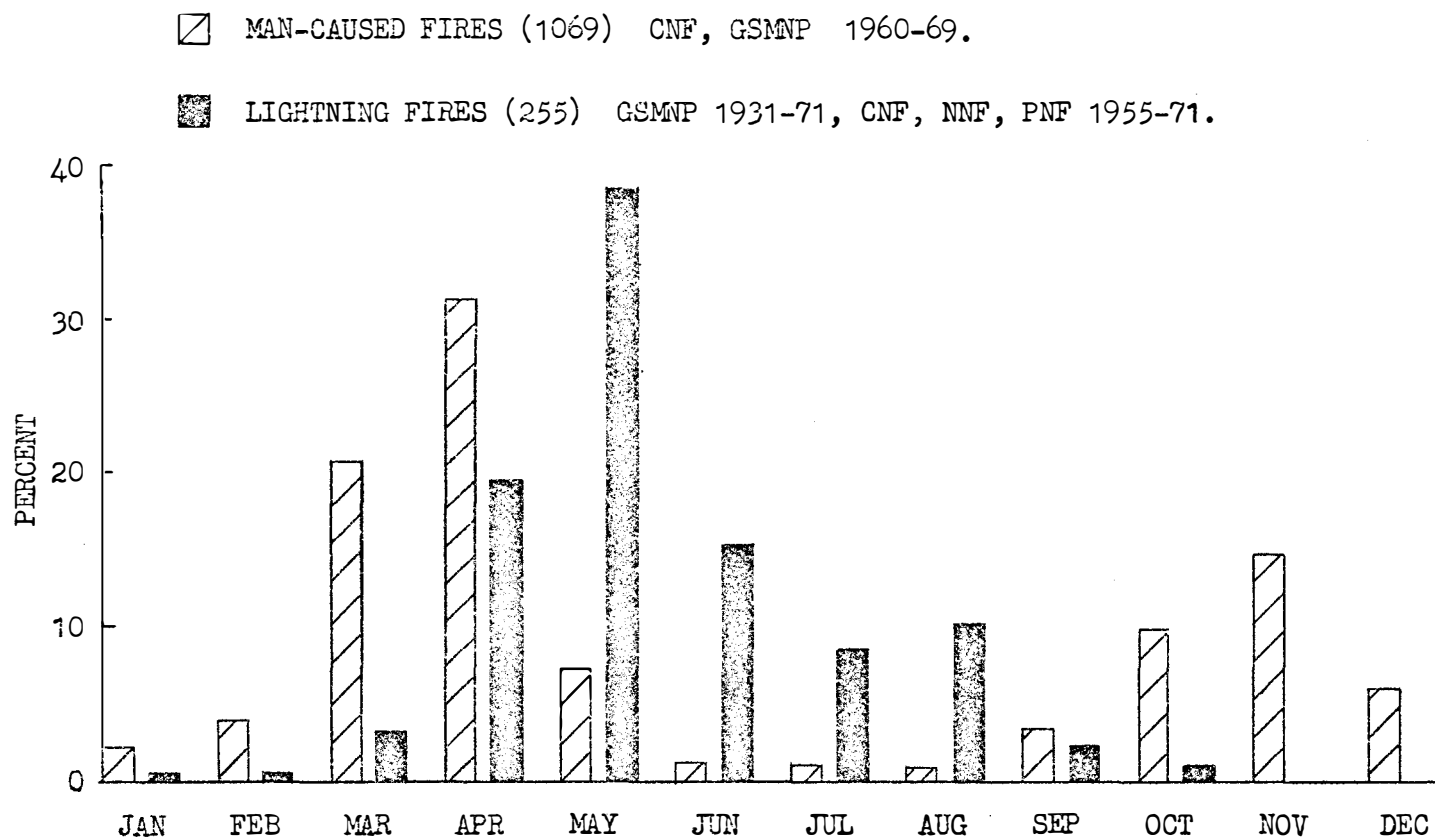


FIGURE 2. INCIDENCE OF WILDFIRES IN THE APPALACHIANS OF TENNESSEE AND NORTH CAROLINA

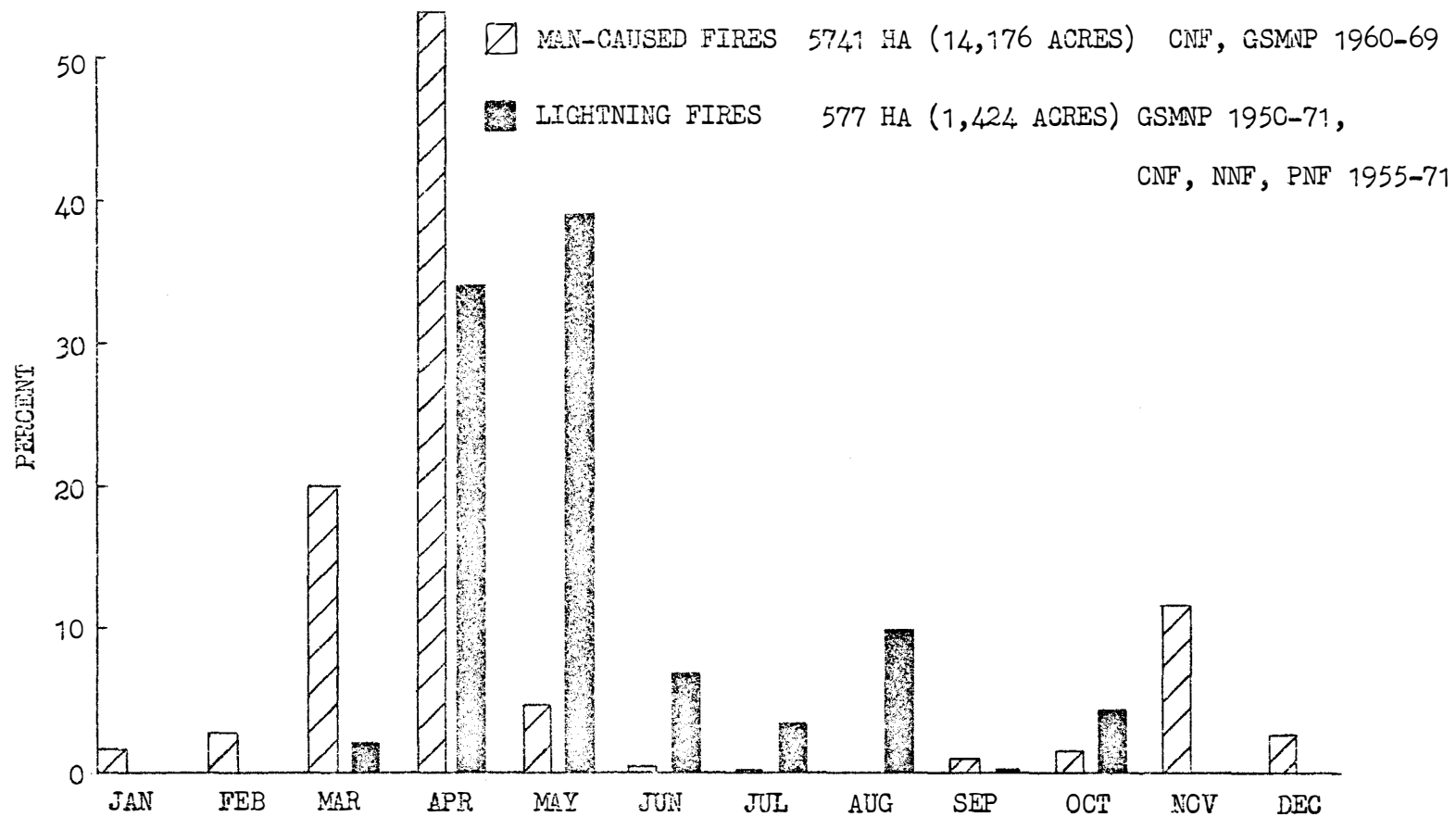


FIGURE 3. AREA BURNED BY WILDFIRES IN THE APPALACHIANS OF TENNESSEE AND NORTH CAROLINA

Frequency of Fires

During the 12 years with complete data from all administrative units (1960-1971), lightning fires were not evenly distributed in time. The average number of fires per year was 12, but actual numbers ranged from three in 1961 to 41 in 1962. Nor were fires uniformly distributed by the relative area of each administrative unit. During these years CNF had far more lightning fires than would be expected for its size and GSMNP had fewer (Table 1).

Lightning started 15 percent of all fires in GSMNP (77 of 500, 1940-1969) but only five percent in CNF (55 of 1032, 1960-1969). This difference probably resulted from the activities of hunters, loggers and landowners in the national forest.

How does the frequency of lightning fires in the southern Appalachians compare with that of other parts of North America? During 1960-1971 the entire study area averaged six lightning fires per year per 400,000 ha (one million acres). This frequency is greater than that of the Great Plains, Mississippi Basin and northeast regions of the United States, but much less than that of western and extreme southeastern states where, on the average, lightning starts 20 or more fires per year per 400,000 ha (Schroeder and Buck 1970).

Size of Fires

The distribution by size classes of lightning fires is very similar to that of man-caused fires (Figure 4). Both have a median size of 0.8 ha (2.0 acres). The chief difference between the two types is the maximum size of fires. The largest lightning fire on

TABLE 1
 LIGHTNING FIRES IN GREAT SMOKY MOUNTAINS NATIONAL PARK
 AND IN CHEROKEE, NANTAHALA AND PISGAH
 NATIONAL FORESTS, 1960-1971

Unit	Percent of Total Study Area	Fires		Chi-Square
		Observed	Expected From Percent Area	
<u>name</u>	<u>%</u>	<u>#</u>	<u>#</u>	<u>value</u>
GSMNP	25.2	17	37.2	11.0
CNF	29.4	68	43.5	13.8
NNF	22.0	38	32.6	0.9
PNF	23.4	25	34.7	2.7
Total	100.0	148	148.0	28.4 P < 0.001

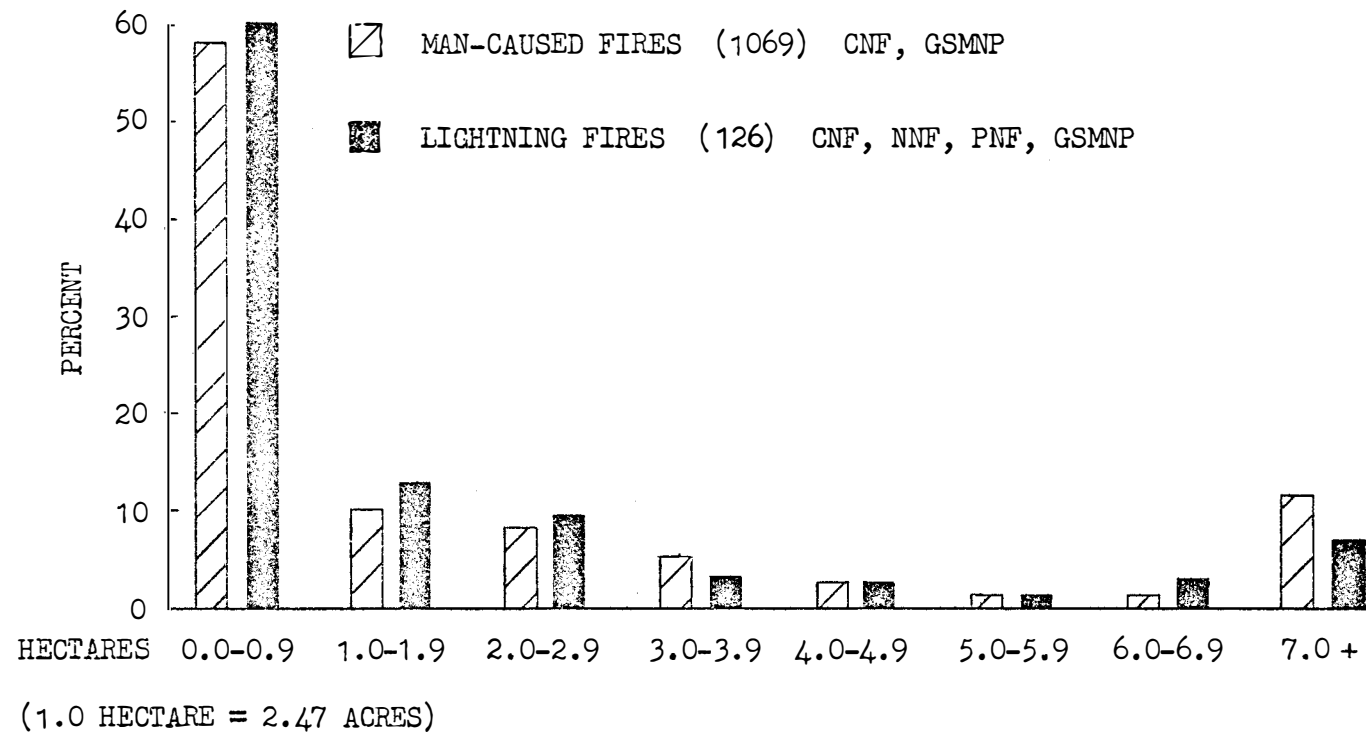


FIGURE 4. INCIDENCE BY SIZE CLASS OF WILDFIRES IN THE APPALACHIANS OF TENNESSEE AND NORTH CAROLINA

record in the study area burned 33 ha (81 acres). In contrast, during 1960-1969 there were 23 man-caused fires in CNF and two in GSMNP which were larger than 33 ha. Most of them occurred in April, 1963, when a severe fire season overtaxed the fire control crews of CNF. During that month the largest fire of the decade burned 1085 ha (2680 acres). Because of these few large man-caused fires the average size of lightning fires (3.4 ha, 8.4 acres) was smaller than that of man-caused fires (5.4 ha, 13.5 acres).

Lightning fires in the western states are distributed even more asymmetrically by size than lightning fires in the study area. Barrows (1951) reported that during a 15-year period on national forests in the northern Rocky Mountains west of the Continental Divide, 84 percent of 25,000 lightning fires was less than 0.1 ha (0.25 acres) in size, yet the average size per fire was 19 ha (46 acres). This difference means that a very small percentage of fires burned many thousands of hectares. Likewise, in the "let-burn" zone of Sequoia-Kings Canyon National Park, California, 46 of 53 lightning fires (87 percent, 1968-1971) went out before they had burned 0.1 ha. The other seven fires burned 250 ha (617 acres) (Kilgore and Briggs 1972). Thus, in the southern Appalachians the median size lightning fire was larger than that in mountains of the western states, but the average size was much smaller.

Lightning fires accounted for 15 percent of the total area burned in GSMNP (88 of 604 ha, 1960-1971) but only four percent of that burned in CNF (234 of 5558 ha, 1960-1969). As with the total number of fires, this difference probably resulted from the activities of loggers, hunters and private landowners in the national forest.

Before the era of vigorous fire control, forest fires were more frequent and larger than in recent years. For example, GSMNP records from 1931 through 1933 show that during these three years 93 man-caused fires burned at least 25 km^2 (10 square miles) within the park boundary. In contrast, during 1960-1969 there was an average of nine fires and 0.33 km^2 (0.13 square miles) burned per year.

The largest historical fire in the study area burned roughly 20,000 ha (50,000 acres) near Johnson City, Tennessee, in September, 1925, after a summer of record drought (Knoxville Sentinel, September 9, 1925). In October, 1952, a fire burned 10,000 ha (25,000 acres) near Erwin, Tennessee, while hardwood leaves were in autumn color (Knoxville News-Sentinel, October 30, 1952).

Elevation and Forest Type

Because lightning tends to strike the highest point of the landscape, ~~we~~ ¹⁾ expect lightning fires to be more frequent at higher elevations than lower. However, data from GSMNP contradict this idea. Lightning fires above 1524 m (5000 feet) were less frequent than expected from a uniform distribution by land area while those below 610 m (2000 feet) were much more frequent than expected (Table 2).

If elevation above sea level is ignored and lightning fires are grouped according to the relative position of the point of origin on the slope - top, middle or lower third of the slope - then more than half of the lightning fires on the study area (57 of 108) started in the top third and about one-fifth (20 of 108) in the lowest third. This apparent contradiction is resolved with the understanding that there are many lower-elevation peaks and ridges in GSMNP. As might be expected

TABLE 2
LIGHTNING FIRES BY ELEVATION IN GREAT SMOKY MOUNTAINS NATIONAL PARK

Elevation	Percent of Total Park Area	Fires		
		Observed	Expected From Percent Area	Chi-Square
<u>meters (feet)</u>	<u>%</u>	<u>#</u>	<u>#</u>	<u>value</u>
Above 1524 (Above 4999)	7.4	2	6.9	3.48
1220-1524 (4000-4999)	22.7	22	21.1	.04
915-1219 (3000-3999)	28.6	28	26.6	.07
610-914 (2000-2999)	26.9	17	25.0	2.56
Below 610 (Below 2000)	14.4	24	13.4	8.38
Total	100.0	93	93.0	14.53 P < 0.01

since human activity centers at lower elevations, lightning fires were proportionally more common at higher elevations than man-caused fires (Figure 5).

The distribution of lightning fires by elevation is also related to the month of occurrence. Fires before May generally started at higher elevations and fires after May at lower elevations than those during May (Figure 6). A possible reason is that hardwood forests which predominate at higher elevations leaf-out during late April and May and shade the litter, thereby maintaining a high relative humidity near the ground (Geiger 1965) and curtailing the fire season (McCarthy 1923). Lower elevation stands dominated by pine, on the other hand, are generally more open than hardwood stands, so that direct sunlight may dry out the litter enough to burn even during late spring and summer, normally a period of low fire incidence in the southern Appalachians. The springtime growth of herbaceous ground vegetation may also help curtail fires.

Figure 7 illustrates the sharp contrast in elevation of fires in the two forest types. Above 914 m (3000 feet) most fires are in hardwood stands, but below that elevation fires are more common in pine stands. The relative scarcity of pine stands above 914 m (3000 feet) explains the low fire incidence there, but at lower elevations hardwood stands cover as much or more area than pine and pine-hardwood stands (Tennessee Valley Authority 1941). The preponderance of fires in pine stands at lower elevations possibly results from two factors: the potential flammability of pine litter throughout the growing season and the relatively early and short period of flammability of hardwood litter

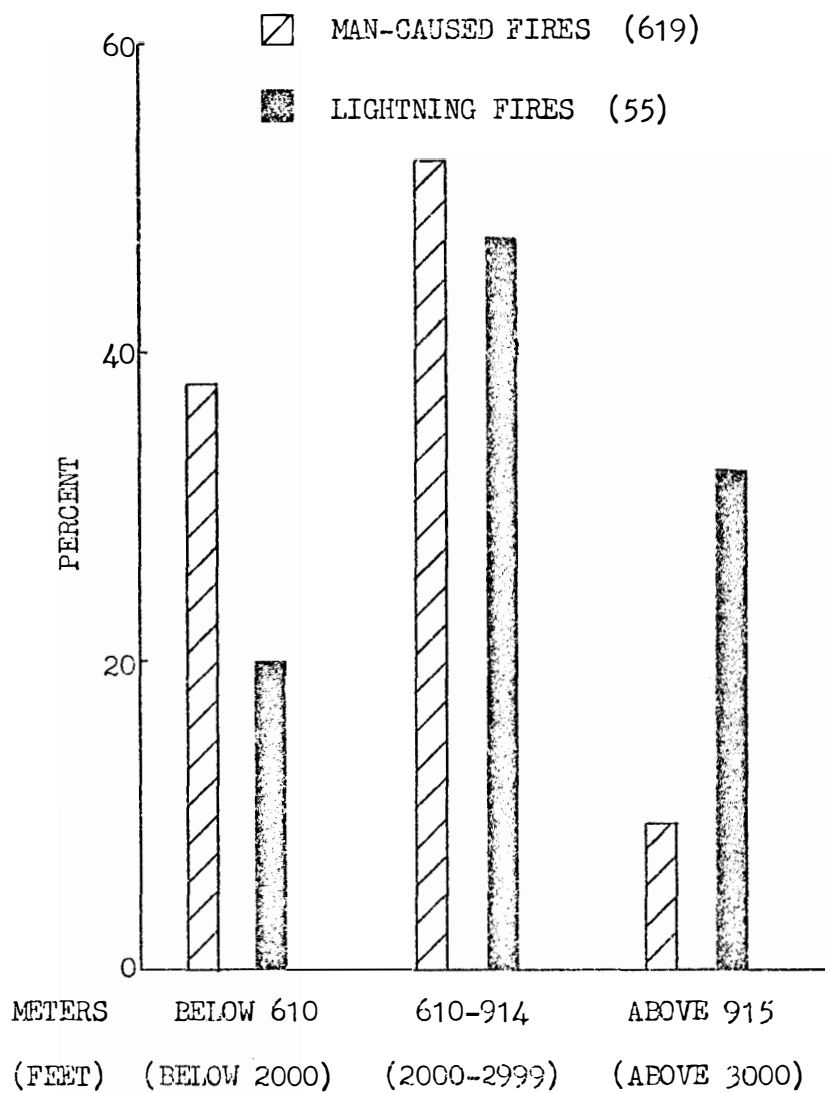


FIGURE 5. ELEVATION OF WILDFIRES IN CHEROKEE NATIONAL FOREST,
MARCH - AUGUST, 1960-1969

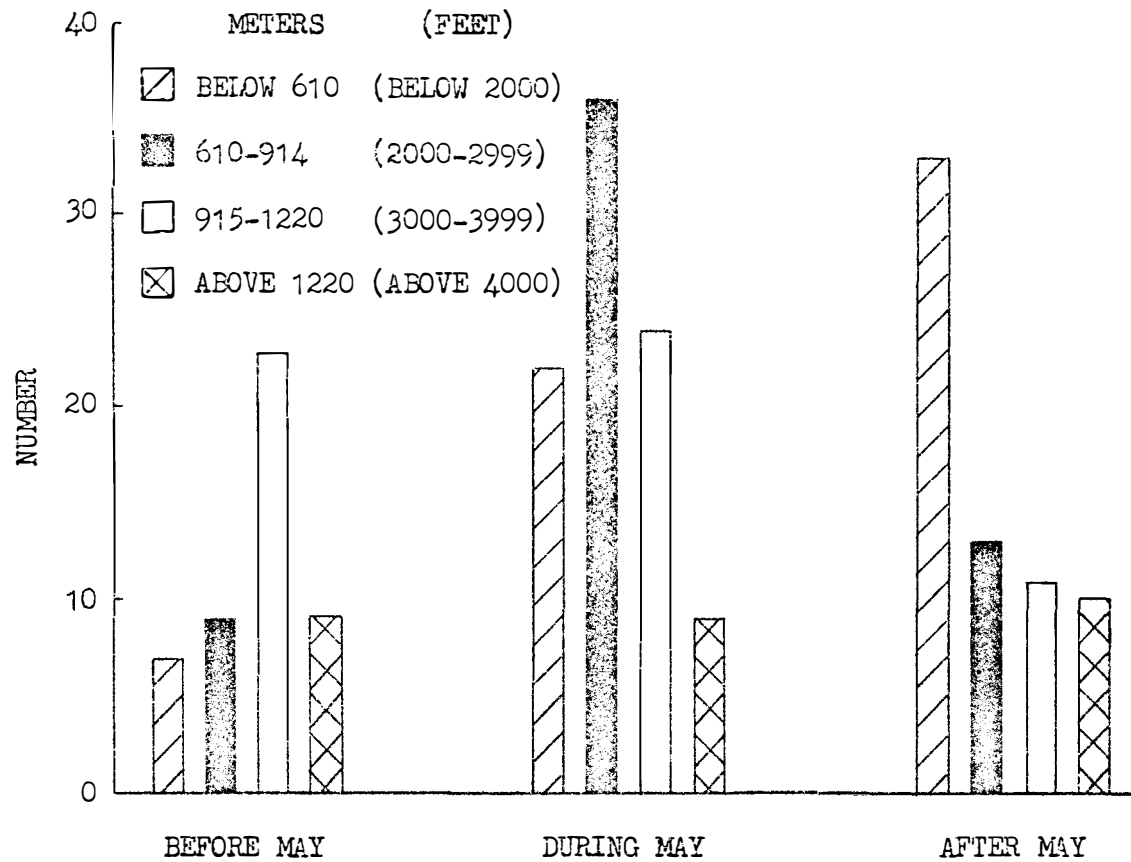


FIGURE 6. ELEVATION OF LIGHTNING FIRES BEFORE, DURING AND AFTER MAY
 IN THE APPALACHIANS OF TENNESSEE AND NORTH CAROLINA

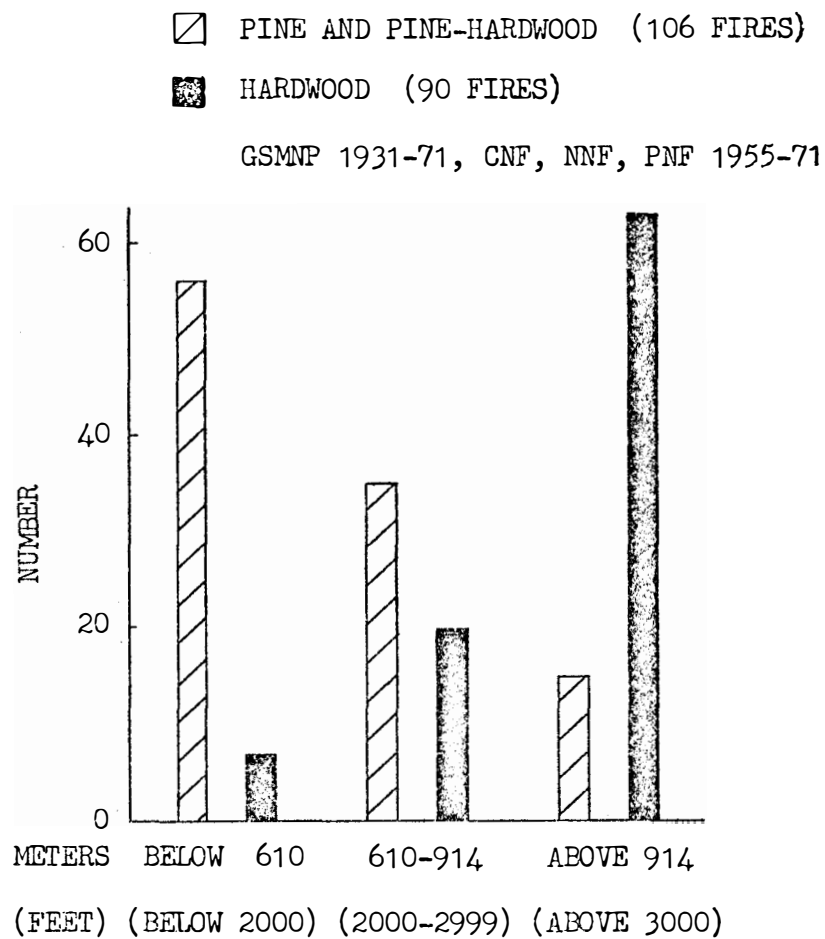


FIGURE 7. ELEVATION OF LIGHTNING FIRES IN HARDWOOD AND PINE STANDS IN THE APPALACHIANS OF TENNESSEE AND NORTH CAROLINA

at lower elevations where hardwoods leaf-out during early to mid-April. This seasonal change is further illustrated by Figure 8 which shows that before May more lightning fires start in hardwood stands than in pine stands, but during May and to a greater extent after May the reverse is true.

Severity

Each fire report describes the character of the fire when the fire crew arrived. The five classifications - crowning, spotting, running, creeping and smoldering - are subjective but useful for comparing lightning fires with man-caused fires. None of the lightning fires on record (185 fires) was described as crowning or spotting. In contrast, seven percent of man-caused fires on CNF during the lightning fire season were crowning or spotting when the fire crew arrived (Figure 9). Omitting the crowning classification from comparison, man-caused fires still tended to be much more severe than lightning fires. One reason for this difference, as Shaw and Kotok (1923) suggest, is that lightning fires tend to spread slowly at first because rain usually wets the litter.

Weather Associated with Fires

To compare weather associated with man-caused and lightning fires, I define a "severe fire period" as a block of consecutive days within which there were four or more fires 20 ha (50 acres) or larger in size on CNF. During such periods man-caused fires were numerous and large, but lightning fires were relatively uncommon. For example, during the spring fire seasons of 1960-1969 on CNF there were four "severe fire

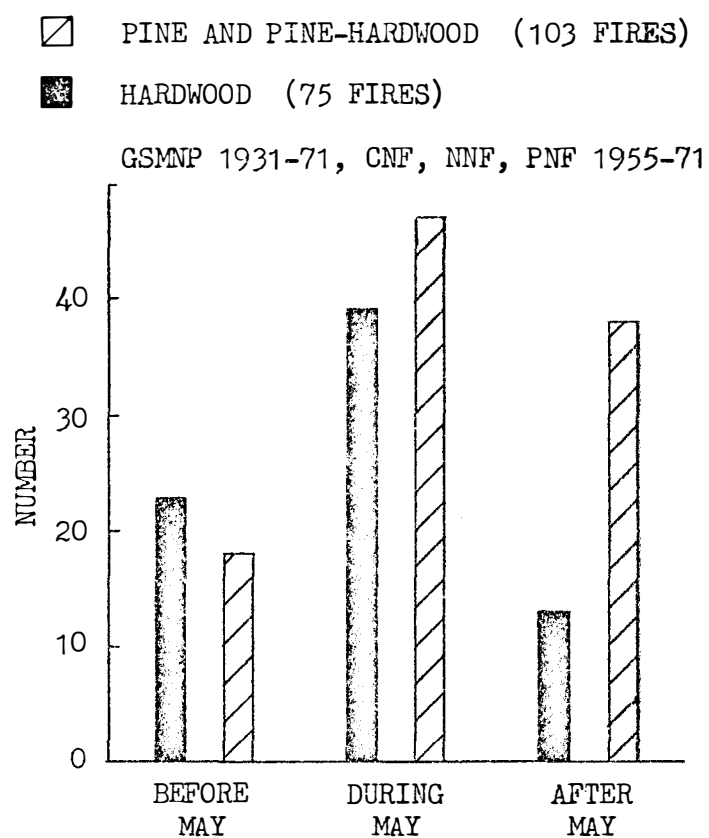


FIGURE 8. LIGHTNING FIRES IN HARDWOOD AND PINE STANDS BEFORE, DURING AND AFTER MAY IN THE APPALACHIANS OF TENNESSEE AND NORTH CAROLINA

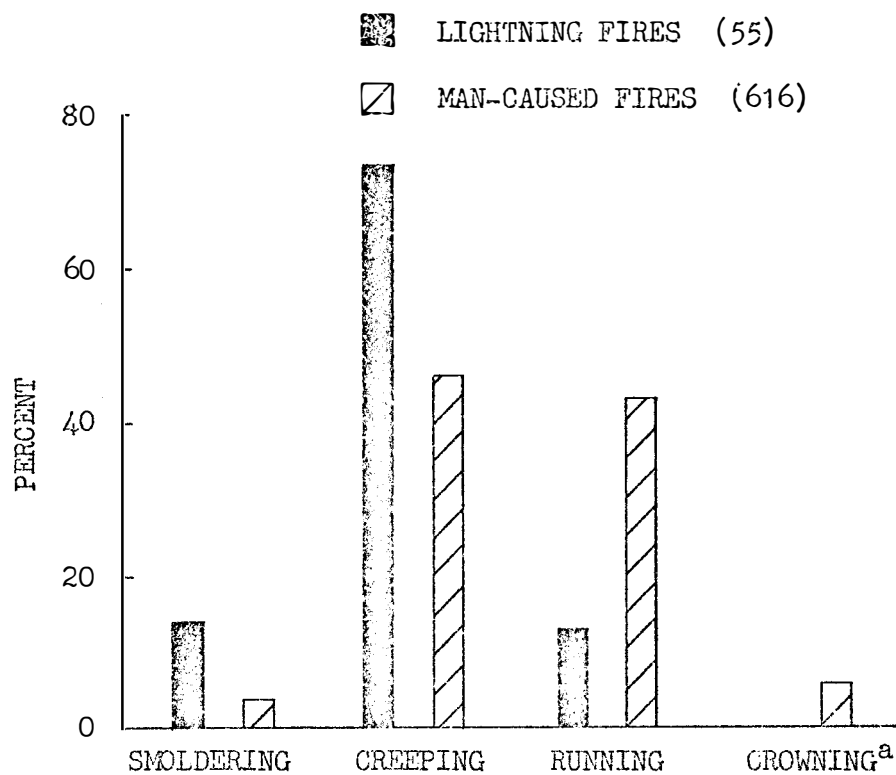


FIGURE 9. SEVERITY OF WILDFIRES IN CHEROKEE NATIONAL FOREST, MARCH - AUGUST, 1960-1969

^a Includes spotting.

periods," totaling 210 days, when 235 man-caused fires burned 3200 ha (7920 acres). In contrast, during these four periods, there were only 10 lightning fires which burned 8 ha (20 acres) on all four administrative units (800,000 ha, 2 million acres).

The requirements for thunderstorm formation suggest why large man-caused fires and lightning fires did not occur at the same time. In addition to an unstable air mass and a trigger, such as turbulence caused by a hill, thunderstorm formation requires a relative humidity of roughly 75 percent or more in the warm air at the earth's surface (Trewartha 1968). On the other hand, large fires of any kind generally do not occur unless relative humidity is less than 30 to 40 percent (Krueger 1961, Fahnestock 1965). In addition, thunderstorms which start fires generally dampen the litter (Gisborne 1926, 1931). Thus, weather which favors thunderstorms reduces the chances that a fire will become large.

To test for differences in humidity on days when large lightning and man-caused fires started, a median test (Siegel 1956) was applied to data from the U. S. Weather Station at the Knoxville, Tennessee, municipal airport. The maximum and minimum relative humidities on days when large (more than 20 ha) man-caused fires started in CNF were compared with those on days when large (more than 6 ha) lightning fires started. These sizes were chosen so that there would be about 20 days in each sample. Of course, the relative humidity at Knoxville is not the same as that at the fire site in the mountains, but it is an index of the dryness of the large air masses which control fire weather. Both maximum and minimum humidities were significantly lower on days when

large man-caused fires started than when large lightning fires started ($P < 0.02$). On days when large man-caused fires started, the median maximum and minimum relative humidity at Knoxville were 74 and 29 percent, respectively. On days when large lightning fires started, the maximum and minimum were 86 and 37 percent.

III. CONCLUSIONS

An analysis of fire reports from Great Smoky Mountain National Park and from Cherokee, Nantahala and Pisgah National Forests which cover two million acres in the Appalachians of Tennessee and North Carolina provided the following conclusions about forest fires caused by lightning.

1. More than 90 percent of all lightning fires occur during April through August. May, the month of highest frequency, accounts for 40 percent. The area burned by lightning fires is similarly distributed by months.
2. In contrast to the single lightning fire season, there are two seasons for man-caused fires - March through May and October through November. The spring season is generally much more severe than the fall, but the two largest recorded fires in the study area in east Tennessee occurred in autumn.
3. During 1960-1971 the study area averaged six lightning fires per year per 400,000 ha (one million acres).
4. The proportionate distribution by size classes of lightning fires is very similar to that of man-caused fires. Both have a median size of 0.8 ha (2.0 acres). The chief difference is that a few man-caused fires are larger than the largest lightning fire.
5. Lightning fires before May tend to originate at higher elevations and fires after May at lower elevations than those during May.

6. Before May more lightning fires originate in hardwood stands than in pine stands, but during May and to a greater extent after May the reverse is true.
7. Lightning fires tend to be much less severe than man-caused fires. No lightning fires on record were crowning when the fire crew arrived.

PART II

EFFECTS OF LIGHTNING FIRES ON COMPOSITION OF PINE-HARDWOOD
FORESTS IN THE SOUTHERN APPALACHIANS

I. INTRODUCTION

The main objective of Part II of this study was to determine the effects of lightning fires on the composition of pine-hardwood stands in the southern Appalachians. The results should help clarify the process of forest succession in the region and could suggest a need to revise the present fire policy of Great Smoky Mountains National Park.

Study Area

The study area consisted of Cherokee National Forest (244,000 ha; 603,000 acres) and Great Smoky Mountains National Park (209,000 ha; 517,000 acres). These contiguous, federally administered areas stretch 330 km (200 miles) along the southern Appalachian Mountains. The entire National Forest and half of the National Park lie in eastern Tennessee, with the remainder of the Park in western North Carolina. The physiography, climate and forests of the study area have been adequately described elsewhere (Fenneman 1938, Shanks 1954, Whittaker 1956). Burned areas which were sampled in this study were on southerly slopes, between 396 m (1300 feet) and 914 m (3000 feet) in elevation. All burns were in pine-hardwood forests with such tree species as Virginia pine (Pinus virginiana), pitch pine (P. rigida), shortleaf pine (P. echinata), Table-Mountain pine (P. pungens), chestnut oak (Quercus prinus), scarlet oak (Q. coccinea), red maple (Acer rubrum), blackgum (Nyssa sylvatica) and sourwood (Oxydendrum arboreum). Nomenclature follows Little (1953).

II. METHODS

Criteria for Choosing Fires for Sampling

During 1960-1971 Cherokee National Forest and Great Smoky Mountains National Park personnel reported 1423 man-caused forest fires and 85 lightning fires. Fires which burned before 1960 were of little use in this study because the sampling procedure required an estimate of the diameters of fire-killed stems, many of which had completely decomposed at the sites of older fires. The criteria for choosing lightning fires for sampling were: (1) the forest type should be listed on the fire report as pine or pine-hardwood and (2) the minimum size should be recorded on the fire report as two hectares (five acres), an arbitrary limit chosen to provide an adequate sample. Fires were also classified as "cool" surface fires, "hot" surface fires and crown fires. Since lightning fires are commonly "cool" surface fires, most of the searching in the field for suitable study sites was for the less frequent "hot" surface fires. Tables 1 and 2 describe the forest composition and sites of the fires, which were sampled in 1973.

A "hot" surface fire, in this study, is one which top-killed more than 80 percent of the 8-10 cm dbh hardwoods, but spared most of the larger trees in the canopy. A "top-killed" tree is one whose stem has been killed; its roots may or may not have been killed. Two lightning fires (numbers 7 and 8) were found which met the criteria for "hot" surface fires. In addition, a third fire (number 9) which was man-caused was sampled to supplement the data on "hot" surface fires. Six "cool" lightning fires (numbers 1-6) which top-killed less than 80 percent of the 8-10 cm dbh hardwoods were also sampled.

TABLE 1

AVERAGE PRE-FIRE COMPOSITION AT EACH FIRE SITE:
PERCENTAGES OF TOTAL BASAL AREA

Species	Fire Number												
	1	2	3	4 ^b	5	6	7	8	9	10	11	12	13
<u>Acer rubrum</u>	+	+	2	7	4	2	0	0	0	+	1	1	2
<u>Amelanchier laevis</u>	0	0	0	+	0	+	0	+	0	0	0	0	0
<u>Carya tomentosa</u>	+	+	5	1	0	0	+	0	2	+	0	0	0
<u>Cornus florida</u>	0	0	+	1	0	0	+	0	0	0	0	0	0
<u>Nyssa sylvatica</u>	1	4	8	+	5	4	1	2	1	1	+	0	1
<u>Oxydendrum arboreum</u>	0	3	+	10	0	3	+	0	1	+	3	+	6
<u>Pinus echinata</u>	1	0	10	1	0	0	6	0	48	16	0	0	0
<u>P. pungens</u>	0	0	0	0	31	32	0	82	0	0	1	62	6
<u>P. rigida</u>	82	69	2	8	40	20	9	13	0	0	5	30	+
<u>P. strobus</u>	0	0	+	14	0	0	0	0	0	0	0	0	0
<u>P. virginiana</u>	4	0	22	0	+	+	48	0	10	14	0	0	1
<u>P. spp.^a</u>	0	0	0	0	0	0	0	0	0	48	58	0	52
<u>Quercus alba</u>	0	+	0	6	0	0	0	0	0	0	0	0	2
<u>Q. coccinea</u>	4	12	+	28	5	22	0	2	+	0	24	1	23
<u>Q. falcata</u>	0	1	0	0	0	0	0	0	0	0	0	0	0
<u>Q. marilandica</u>	0	0	0	0	0	0	0	0	20	1	+	0	3
<u>Q. prinus</u>	3	9	41	21	14	17	15	0	9	10	1	5	2
<u>Q. stellata</u>	4	0	0	0	0	0	0	0	+	0	0	0	0
<u>Q. velutina</u>	1	+	9	0	0	0	20	0	8	1	+	0	3
<u>Q. spp.^a</u>	0	0	0	0	0	0	0	0	0	9	7	0	0
<u>Robinia pseudoacacia</u>	+	+	0	1	1	0	0	+	0	0	+	0	+
<u>Sassafras albidum</u>	+	0	+	0	+	+	+	+	+	0	0	0	0
Total Basal Area (m ² /ha)	26	23	20	25	26	24	18	32	10	17	27	4	19

+ Present, but less than 0.5 percent

^a Fire-killed trees, species not determined.

^b Liriodendron tulipifera and Magnolia fraseri, 1 percent each.
Acer pensylvanicum and Tsuga canadensis, less than 0.5 percent.

TABLE 2

DATE, LOCATION AND SITE CHARACTERISTICS OF EACH FIRE

Fire	Location	Date of Fire	Median Slope	Aspect	Elevation	Average Pre-fire Diameter per Tree	
						Pine	Hardwood
<u>#</u>			<u>degrees</u>		<u>meters</u>	<u>cm</u>	<u>cm</u>
1	GSMNP	8/7/62	28	SW	490	15	7
2	GSMNP	5/31/65	28	S	790	16	12
3	GSMNP	7/16/68	35	E	640	11	13
4	CNF	5/11/62	32	SE	670	28	12
5	GSMNP	5/13/62	20	SW	760	21	14
6	CNF	5/22/70	29	S	850	12	11
7	GSMNP	7/16/68	30	SE	640	13	16
8	CNF	5/22/70	25	S	850	11	8
9 ^m	GSMNP	3/28/69	25	SE	400	12	9
10	GSMNP	8/14/56	40	SE	610	30	22
11 ^m	GSMNP	11/11/67	14	S	910	19	14
12	CNF	5/7/65	30	SW	850	6	6
13 ^m	CNF	3/30/63	22	E	610	14	8

^m Man-caused (all others are lightning fires).

In Part I of this study it was shown that in the southern Appalachians it is extremely uncommon for lightning fires to destroy the forest canopy. However, one large crown fire might change forest composition more than many successive surface fires. Therefore, data from the only lightning-caused crown fire which was found (number 10), were supplemented with data from two man-caused crown fires (numbers 11 and 13). In addition, a lightning fire (number 12) which top-killed a dense, ten-year-old stand of Table-Mountain and pitch pine was treated as a crown fire, for a total of four crown fires. Because the purpose of studying crown fires was to describe extreme effects, the burned areas chosen for sampling were virtually devoid of surviving trees.

Sampling Procedure

After a burned area had been chosen for sampling, its perimeter was surveyed and mapped. Sampling points were systematically located on the map with a transparent grid of squares. At each sampling point in the field, two concentric, circular plots and a variable radius plot with a basal area factor of 10 (Beers and Miller 1964) were established. The minimum number of sampling points per fire was set at 15 because of the nature of the sign test (Siegel 1956) which was used in the statistical analysis.

A scaled bamboo rod was used to lay out the smaller of the two circular plots and to measure areal cover of post-fire reproduction. The crowns of post-fire reproduction were visually approximated by circles whose diameters were measured to the nearest decimeter (Bentley, Seegrism and Blakeman 1970). Radii of the small plots were 2.18 m (15 m^2) or 2.52 m (20 m^2).

Radii of the large circular plots were visually estimated, with frequent measurements of distances to borderline trees. The diameter breast height (dbh) of each stem taller than 2 m on the large plots was also visually estimated to the nearest 2 cm for stems smaller than 15 cm dbh and to the nearest 10 cm for larger ones. The narrow classes were used for small stems because small differences in diameter produce large differences in percent of small stems top-killed. The percent top-kill of 8-10 cm dbh hardwood stems was used as a measure of fire severity (McCarthy and Sims 1935). Radii of the large plots were 8 m for Fires 1-8, 6 m for Fires 9-12 and 4 m for Fire 13. The data were recorded in the field with a tape recorder and transferred directly to coding sheets in the office for keypunching onto computer cards.

Definition of Succession

Oosting (1944) in a study of the effects of fire on composition of a loblolly pine stand in North Carolina, used the replacement of pines by hardwoods as a working definition of forest succession. Although many other definitions are possible, I also use "the replacement of pines by hardwoods" as a working definition of forest succession. To describe the successional state of the forest I use the parameter: percent of pine basal area in the total basal area of the stand. By this definition, if the percent of pine basal area in a burned stand increases as a result of a fire, the burn has retarded, or set back, succession.

Sampling Bias

There are several types of personal biases which can introduce systematic errors into estimates of basal area. First, the observer might consistently over- or underestimate tree diameter. Second, the observer might consistently include or delete too many trees along the border of the plot. Third, the observer's bias toward hardwoods might differ from that toward pines. For example, the observer might overestimate pine diameters and underestimate hardwood diameters.

The first two biases are indistinguishable in their effects; they would inflate or deflate the estimate of total basal area, but would not influence the calculated percentage of pine on a plot. The third bias would affect the calculated percentage of pine on a plot, but the difference in percentage of pine between the treatment and "substitute control" plot (discussed below) will not change sign (positive to negative or reverse) because of the bias.

The data may be tested for the three types of bias in the estimates of basal area because there were two independent methods of estimation: the visual and the point sample estimate. An analysis of the data (discussed below) showed that one or both of the first two types of bias (overestimating tree diameters or including too many borderline trees) probably did occur. The third type of bias (differential bias between pines and hardwoods) probably did not occur.

Visual estimates of basal area were adjusted for the bias in the estimate of total basal area. For example, if the point sample estimate of average basal area on an entire fire site were 24 m² per ha and

the visual estimate were 30 m² per ha, all visually estimated values of basal area on that fire site would be adjusted by a factor of $24/30 = 0.8$. This adjustment does not affect the conclusions.

Experimental Design

The usual experimental designs such as analysis of variance and paired 't' test could not be used in this study for three reasons. First, as a fire burns along an ecocline from a xeric toward a mesic site, its intensity usually diminishes. Fire crews often build fire breaks along such ecoclines. A comparison of plots inside and outside the fire break will almost inevitably lead to the conclusion that xeric species are more abundant in the burned area. Second, fire severity often varies greatly, even within a small burned area. Thus, the intensity of treatment is not uniform. Third, topography in the southern Appalachians generally consists of rounded summits and ridges, and narrow, steep-sided valleys (Fenneman 1938). Forest composition often changes from pine-hardwood to hardwood over distances of 30 meters or less, causing large variance/mean ratios.

Because of these difficulties, a new experimental design was developed. Each plot was viewed as a single experiment consisting of both a treatment and a "substitute control." The present composition of living vegetation on the plot shows the results of the burning treatment. The "substitute control" plot is a conceptual reconstruction of the forest stand as it would have been had fire not occurred.

On the treatment plot, post-fire composition consists of basal area of surviving trees plus post-fire regeneration. On the "substitute control" plot, the hypothetical composition in the absence of

fire is calculated from the basal area of survivors and top-killed trees adjusted for change in basal area since the fire.

A comparison of the treatment with the "substitute control" composition shows whether the percent pine has increased, decreased or not changed on each plot. Under the null hypothesis that fire has not altered the composition, approximately the same number of plots on a fire site can be expected to increase as decrease in percent pine. Departures from the null hypothesis may be tested for significance with the sign test (Siegel 1956). For example, if 12 of 15 plots on a fire increase in percent pine ($P < 0.036$ under the null hypothesis), the alternate hypothesis that fire has changed (increased) the percent pine is accepted. A two-tailed test was used because the direction of change was not known beforehand.

The chief statistical advantage of using one plot as both a treatment and "substitute control" is that there is no variance associated with the comparison of two populations of trees. A disadvantage is that growth rates are not known, but this problem can be overcome, as will be shown later.

The use of the treatment plot as its own "substitute control" requires several assumptions. First, because the dbh of each fire-killed stem must be estimated, it is assumed that none of them has completely decomposed. Except for one fire, the maximum elapsed time between burning and sampling was 11 years, insufficient time for small stems to completely disappear on dry slopes. The exception (discussed later) was a 17-year-old fire (number 10), the only lightning-caused crown fire in a mature pine-hardwood stand.

Second, it is assumed that stems killed by the fire can be distinguished from those which died of other causes. If a stem died several years before a fire, it would have burned or would appear more charred and decomposed than a stem which was alive at the time of the fire and would not be included in the data. All post-fire stem mortality was assumed to be caused by the fire unless it was clearly not related. For example, on one of the "cool" lightning fire sites (number 5) a southern pine beetle (Dendroctonus frontalis Zimm.) attack during the two or three years preceding the year of sampling, 1973, killed most of the large pines. Because the fire was "cool" and had occurred in 1962, fire-killed and beetle-killed stems were easily distinguished from each other.

If it is assumed that all post-fire stem mortality on the treatment plot was caused by fire then it is also tacitly assumed that stem mortality would have been negligible on the "substitute control" plot. Exceptions to this assumption would be most likely among shaded understory pines and, consequently, would tend to decrease the difference in percent pine between the treatment and "substitute control" plots.

Let T (treatment) represent the percent of pine in the total basal area of trees presently living on the burned plot.

$$(1) \quad T = 100(P_s + P_r) / (P_s + P_r + H_s + H_r), \text{ in which}$$

P_s = present basal area of pines which survived the fire,

P_r = present basal area of post-fire pine reproduction,

H_s = present basal area of hardwoods which survived the fire,

and

Hr = present basal area of post-fire hardwood reproduction.

The values of Ps, Pr, Hs and Hr are known for each plot.

Because the basal area of survivors has increased since the fire, two statements regarding growth can be made:

$$(2a) \quad Ps = Po(1 + p) \qquad (2b) \quad Hs = Ho(1 + h), \text{ in which}$$

Po = basal area of surviving pines at the time of the fire,

Ho = basal area of surviving hardwoods at the time of the
fire,

p = actual increase since the fire in basal area of surviving
pines, expressed as a fraction of Po, and

h = actual increase since the fire in basal area of surviving
hardwoods, expressed as a fraction of Ho.

Transposing parentheses, Po and Ho may be expressed in terms of
Ps and Hs:

$$(3a) \quad Po = Ps(1 + p)^{-1} \qquad (3b) \quad Ho = Hs(1 + h)^{-1}$$

Let S ("substitute control") represent the hypothetical present
percent of pine basal area on the plot in the absence of fire.

$$(4) \quad S = \frac{100(Po + Pk)(1 + p^*)}{(Po + Pk)(1 + p^*) + (Ho + Hk)(1 + h^*)}, \text{ in which}$$

Pk = basal area of top-killed pines,

H_k = basal area of top-killed hardwoods,

p^* = hypothetical change in basal area of pines, including ingrowth, if fire had not occurred, expressed as a fraction of $(P_o + P_k)$, and

h^* = hypothetical change in basal area of hardwoods, including ingrowth, if fire had not occurred, expressed as a fraction of $(H_o + H_k)$.

Substituting Equations (3a) and (3b) into (4),

$$(5) \quad S = \frac{100(P_s(1+p)^{-1} + P_k)(1+p^*)}{(P_s(1+p)^{-1} + P_k)(1+p^*) + (H_s(1+h)^{-1} + H_k)(1+h^*)}.$$

For relevant values of the eight variables in (5), S is bounded and continuous,

$$0 \leq S \leq 100.$$

Because the values of P_s , P_k , H_s and H_k are known for each plot, S is actually a function of the four rate variables, $S = S(p, p^*, h, h^*)$. When p , p^* , h and h^* lie in the vicinity of zero, the Taylor expansion of S about the origin, $(0,0,0,0)$, is a good approximation of S . Neglecting terms of second and higher order, this expansion is:

$$(6) \quad S = S_o + (\partial S / \partial p) \cdot p + (\partial S / \partial p^*) \cdot p^* + (\partial S / \partial h) \cdot h + (\partial S / \partial h^*) \cdot h^*$$

where the partials are evaluated at the origin and

$$(7) \quad S_0 = S(0,0,0,0) = 100(P_s + P_k)/(P_s + P_k + H_s + H_k).$$

At the origin the partial derivatives of S are:

$$(8) \quad \partial S / \partial p = -100P_s(H_s + H_k)/B^2,$$

$$(9) \quad \partial S / \partial p^* = 100(P_s + P_k)(H_s + H_k)/B^2,$$

$$(10) \quad \partial S / \partial h = 100(P_s + P_k)H_s/B^2,$$

$$(11) \quad \partial S / \partial h^* = -100(P_s + P_k)(H_s + H_k)/B^2, \text{ where}$$

$$B = P_s + P_k + H_s + H_k.$$

Since the values of P_s , P_k , H_s and H_k are known for each plot, the values of the partials are also known constants. The maximum absolute value of each of the partials is 25 (when $P_s = H_s$ and $P_k = H_k = 0$). Equations (6) and (8-11) show that the value of the function, S, increases as p^* and h increase and the value of S decreases as p and h^* increase. When p , p^* , h and h^* are small, as they often are on dry slopes or after recent fires, the sum of the last four terms in Equation (6) is small and S is approximated by S_0 :

$$S = S_0.$$

The actual shift in percent pine on a plot is $T-S$, but the exact value of S is not known because the values of p , p^* , h and h^* are unknown. Therefore, in the presentation of results, $T-S_0$ is used in place of $T-S$. This approximation is not used in the statistical analysis; there the value of $S(p, p^*, h, h^*)$ is estimated by making certain assumptions (discussed below) about the values of p , p^* , h and h^* .

III. RESULTS AND DISCUSSION

Sampling Bias

The visual estimates of total basal area probably were biased because they were larger than the point sample estimate for 12 out of 13 fire sites ($P < 0.004$, two-tailed sign test, Siegel 1956). The visual estimates have been adjusted for bias, as described previously. Neither the bias nor the adjustment affect the conclusion of the study.

A differential bias in the visual estimation of basal area of pines and hardwoods probably did not occur. The ratio of visual estimate to point sample estimate was larger for hardwoods than for pines on seven out of 13 fire sites and smaller on the remaining six. The ratio of seven to six is consistent with the null hypothesis that there was no systematic bias.

Individual Fires

The analysis of the effects of fire on composition will begin with the fire of lowest intensity and proceed to the fire of greatest intensity. Tables 1 and 2 (pages 30 and 31) describe the vegetation and site at each fire. The Appendix gives the basal area and percent pine on each plot, and Table 3 summarizes the results.

Fire 1. Fire 1, an extremely "cool" surface fire, burned through a pitch pine stand in August, 1962. The calculated change in percent pine for the entire fire was an increase of 1 percent, but reasonable estimates of p , p^* , h and h^* in S (Equation 5) could change many of the positive approximate shifts ($T-S_0$ in the Appendix) to negative, rendering the results statistically not significant.

TABLE 3
EFFECTS OF FIRE ON STAND CHARACTERISTICS

Fire	Top-kill		Coverage Post-fire Pine Reproduction	Change in	
	8-10 cm dbh Hardwoods	Total Basal Area		Percent Pine (T-Sc)	Average Diameter Per Tree
<u>#</u>	<u>%</u>	<u>%</u>	<u>%</u>	<u>%</u>	<u>cm</u>
1	9	3	0	1 ⁿ	1.0
2 ^a	24	65	1	-53*	-2.6
3	24	9	0	-3 ⁿ	2.0
4	40	9	0	2 ⁿ	2.7
5	52	12	1	2 ⁿ	2.1
5 ^b	0	61	1	-42**	-4.5
6	54	20	0	5 ⁿ	1.6
7	80	39	1	-11 ⁿ	6.8
8	85	38	1	3**	2.6
9 ^m	90	44	1	22*	4.6
10	- ^c	73	52	-3 ⁿ	-22.2
11 ^m	91	96	6	-30 ⁿ	-12.7
12	100	88	22	-11 ⁿ	-0.5
13 ^m	100	93	14	-17 ⁿ	-6.2

^a Effect of beetle kill and fire (see text).

^b Effect of beetle kill only.

^c Many small stems had completely decomposed.

^m Man-caused fires.

ⁿ Not significant at $\alpha = 0.05$ level.

* $P < 0.05$.

** $P < 0.01$.

Fire 2. Fire 2 burned in a pitch pine stand in May, 1965.

Southern pine beetles attacked the stand at about the same time and the two types of mortality among pines could not be separated. Southern pine beetles often attack pines which have been injured by lightning and, subsequently, spread into nearby pines (St. George 1930).

On all 19 plots at Fire 2, the approximate changes in percent pine (T-So) were negative. Most differences were large negative shifts. Data derived from published growth tables (Schnur 1937, Slocum and Miller 1953, Schumacher and Coile 1960) indicate that stands of pine and hardwood on below-average sites for tree growth such as the one at the site of Fire 2 increase in basal area by less than 2 percent per year (0.02/year). Under the assumptions,

$$p \text{ and } h^* \leq 0.10/\text{yr and}$$

$$p^*, h \geq 0,$$

the approximate shift in percent pine (T-So) on only four of the 19 plots (2, 4, 5 and 6) could change sign (negative to positive) because of the rate terms in S. The ratio of 15 negative to four positive signs is statistically significant ($P < 0.05$), and it is concluded that the combination of beetle attack and "cool" surface fire reduced the percent pine in the total basal area of the stand from about 70 percent to approximately 17 percent.

The analysis of plot 4 will illustrate the method for determining possible effects of p , p^* , h and h^* on the approximate difference (T-So). Using the values of P_s , P_k , H_s and H_k from the Appendix and applying the maximum rates (compounded annually) for terms which decrease the value

of S,

$$p, h^* = 0.10/\text{yr} = 1.14/\text{eight years since fire},$$

and the minimum rates for terms which increase S,

$$p^*, h = 0/\text{yr} = 0/\text{eight years}, \text{ then}$$

from Equation (5),

$$S = 46.8 \text{ and } T-S = 20.6.$$

Under the assumptions, the effect of the rate variables could change the negative approximate shift in percent pine ($T-S_o = -6.6$) to positive for plot 4.

Fire 3. Fire 3 burned in an oak-pine stand in July, 1968. The structure of the pre-fire stand was unusual because the overstory was predominantly hardwood while the understory was nearly 50 percent pine. The origin of the stand is discussed later, under Fire 7. Of the 21 plots, 18 showed small negative shifts ($T-S_o$) in percent pine. Most of these small changes resulted from the deaths of shaded understory pines. In contrast to Fire 2, at Fire 3 many of the small negative shifts could change to positive under the assumptions made with regard to Fire 2. Thus, the calculated shift in percent pine, less than 2 percent, is not statistically significant.

Fire 4. The site of Fire 4 was the most mesic of all those studied. About 75 percent of the basal area was in hardwoods. Of the 25 plots at Fire 4, 13 contained no pine and were excluded from analysis. The other 12 plots showed small increases in percent pine, but reasonable

assumptions about p , p^* , h and h^* could change at least three of these shifts to negative. If Fire 4 caused a change in percent pine, the change was small and not statistically significant.

Fire 5. Fire 5 burned through a stand of pitch pine and Table-Mountain pine in May, 1962. About eight years later southern pine beetles began killing most of the surviving pines. At the time of sampling, 1973, the beetle-killed trees could be easily distinguished from the fire-killed trees. As a result, the effects of fire and beetles on composition of the stand can be shown separately. In late spring, 1973, when the data were collected, beetles had not attacked the pines on plots 5, 6 and 8, which will be excluded from the statistical analysis of the beetle attack, but six months later the pines on these three plots were also dying.

Of the 18 plots at Fire 5, 15 showed small increases in percent pine as a result of the fire. However, the results were not statistically significant. If any shift in composition occurred as a result of fire, it was less than a 2 percent increase in percent pine basal area.

In contrast to the fire, southern pine beetles drastically altered the composition of the stand. Based on the assumptions of Fire 2, with three growing seasons between the attack and sampling, all of the 15 plots which beetles attacked showed large decreases in percent pine ($P < 0.01$). For the entire burned area, beetles removed more than 80 percent of the pine basal area and reduced the percent pine in the stand from about 70 percent to approximately 30 percent.

Fire 6. Fire 6, the most recent fire studied, burned a pine-hardwood stand in May, 1970. Of the 24 plots at Fire 6, seven contained no pine and were excluded from the analysis. Of the remaining 17 plots, two decreased and 15 increased in the approximate shift ($T-S_0$) in percent pine. However, reasonable assumptions about p , p^* , h and h^* render the results statistically not significant. If a shift in composition occurred, it was less than 5 percent.

Fire 7. Fire 7, a "hot" surface fire, burned a pine-hardwood stand in July, 1968. Before the fire the basal area of the overstory was about equally divided between pines and hardwoods, but in the understory there was about three times as much pine as hardwood basal area. Fire 7 and Fire 3 were actually two parts of the same fire, but were separated on the basis of intensity.

A study of fire scars and increment cores from Fire 7 showed that the understory pines originated after a "hot" fire in the early 1920's which apparently spared only the largest overstory trees. Since then, the surviving overstory trees have gradually filled the canopy space and shaded the young pines. By 1968, most understory pines were growing very slowly and many probably would have died within a few years even without the 1968 fire. The calculated effect of Fire 7 was to reduce the percent pine from 63 to 52 percent; however, using the assumptions from Fire 2, the results are not statistically significant.

Fire 8. Fire 8 occurred in a stand of Table-Mountain pine in May, 1970. Half of the 22 plots were converted to pure pine by the fire. Fire 8 and Fire 6 were parts of one fire which was divided on the basis of intensity into "cool" and "hot" sections.

Three assumptions are made about rates of increase in basal area for Fire 8:

1. $0 \leq h \leq h^*$,
2. $p^* \leq 0.10/\text{yr}$, and
3. $0 \leq p$.

The first assumption is that the rate of increase in basal area of hardwoods in the presence of fire (h) is less than or equal to the hypothetical rate in the absence of fire (h^*) because of the destruction of potential hardwood ingrowth. Ingrowth is generally defined as stems which grow into the smallest measured diameter class during a given period. Also, the rate of increase of surviving hardwoods (h) and surviving pines (p) must be greater than zero unless there were no survivors.

The second assumption is based on data derived from published growth tables (Schnur 1937, Slocum and Miller 1953, Schumacher and Coile 1960). Under these assumptions and with three growing seasons between the fire and sampling, only three of the 22 plots (plots 8, 13 and 22) might have decreased in percent pine as a result of the fire. The other 19 plots increased ($P < 0.01$), and it is concluded that fire raised the percent pine from about 95 percent to about 98 percent on the site of Fire 8.

Fire 9. Fire 9, a man-caused fire, burned in March, 1969. The most intensely burned part of this large surface fire (40 ha total area) was surveyed and sampled to supplement the data from "hot" surface fires

caused by lightning. Of the 25 plots, two were excluded from the statistical analysis because the fire had killed all stems and no post-fire reproduction had reached a height of 2 m. Based on the assumptions of Fire 8, with five growing seasons between the time of the fire and sampling, six of the remaining 23 plots could have decreased in percent pine as a result of the fire (plots 1, 9, 10, 14, 18 and 23). The ratio of 17 increases to 6 decreases in percent pine is significant ($P < 0.05$), and it is concluded that fire shifted the percent pine from approximately 58 percent to 81 percent.

Fires 10-13. Fires 10-13 were crown fires which top-killed most of the trees on the fire sites. The calculated effect of each fire was to decrease the percent pine, but the decreases were not statistically significant. Wherever fire killed all of the trees in a mixed pine-hardwood stand, hardwoods quickly sprouted and predominated in the basal area of the plot during the first decade after fire. Such plots generally show a decrease in percent pine. On the other hand, where fire spared a few trees on the plots, the survivors were predominately pines. These plots commonly showed an increase in percent pine. The combination of positive and negative changes in percent pine after crown fires rendered the results statistically not significant.

Fire 11 exemplifies the predominance of hardwoods after crown fire. Six growing seasons passed between the time of the fire (November, 1967) and sampling. On the 12 plots where no trees survived, post-fire reproduction taller than 2 meters consisted almost entirely of hardwood sprouts. Although the ratio of 12 decreases:0 increases in percent pine

is highly significant ($P < 0.01$), it would be incorrect to conclude that the fire has converted a pine stand to a hardwood stand. For the 12 plots there was an average of 522 small pine saplings (less than 2 m tall) per hectare classified as "free-to-grow." A free-to-grow sapling is one whose terminal leader and upper branches are free of overhead shade.

In 1940, Oosting (1944) observed the predominance of hardwoods in a nine-year-old stand which had been nearly pure loblolly pine before a severe crown fire. Twenty years later, in 1960, the stand had returned to approximately its pre-fire composition (Oosting and Livingstone 1964). Apparently, the young pines accelerate in height growth while hardwood sprouts gradually slow down (Wenger 1955).

IV. SUMMARY

The summarized results (Table 3, page 42) suggest that lightning fires in southern Appalachian forests generally cause small changes in the pine/hardwood basal area ratio in mixed stands. Their effect on stand structure is to increase the average diameter of the trees because they selectively remove small trees and spare large ones. This effect of lightning fires on stand structure could help explain the forests of large, widely spaced trees which the botanist, William Bartram, found in the southeastern United States in the late 18th century (Van Doren 1928).

Pine reproduction covered 1 percent or less of the burned area on the sites of surface fires (Fires 1-9). After severe crown fires (Fires 10-13), up to 52 percent of the burned area was covered by pine regeneration. Thus, the small changes in composition after surface fires result primarily from differential survival of pines and hardwoods, while changes after severe crown fires are caused by differential rates of regeneration and growth.

Southern pine beetles attacked pines on two of the sites of surface fires (Fires 2 and 5), reducing the percent pine in the total basal area from about 70 percent to approximately 20-30 percent. This shift would seem to be long-lasting because pine regeneration was negligible. Hoffman and Anderson (1945) also found very little new pine reproduction after beetles attacked pine stands.

If most pine stands at lower elevations (below 900 m) in the southern Appalachians are the product of severe crown fires which occurred during the century of settlement and farming (1800-1900), then

southern pine beetles may be regarded as opportunists which take advantage of the abundance of food and egg-laying sites. With three to five generations each year and a potential increase of 1000 percent per generation, their population may increase dramatically, particularly after mild winters (Beal 1933) and during dry periods (Craighead 1925). Assuming that no severe crown fires initiate new pine stands, the importance of southern pine beetles in Great Smoky Mountains National Park will diminish as they remove their food supply and hasten succession toward hardwoods.

Whittaker (1956) suggested that in the southern Appalachians, an area of summer thunderstorms, the time necessary for oak to replace pine stands on dry southerly slopes exceeds the normal expectation of fire. However, the results of my study indicate that lightning fires, which are nearly all surface fires, would not maintain the widespread pine forests which now clothe southern slopes in Great Smoky Mountains National Park. If efficient fire control eliminates severe crown fires, pines will gradually be replaced by hardwoods, except possibly on very dry ridges (Racine 1966). On these ridges occasional lightning fires, if allowed to burn, may permit enough new pine reproduction to maintain Table-Mountain, pitch, shortleaf and Virginia pine as fugitive (Hutchinson 1951) species. The shift in forest composition from pine toward hardwoods may return the forests to a closer approximation of the composition of pre-settlement forests, a change which is in accordance with the policy of the National Park Service (Houston 1971).

LITERATURE CITED

LITERATURE CITED

- Alexander, W. H. 1935. The distribution of thunderstorms in the United States, 1904-1933. *Monthly Weather Rev.* 63: 157-158.
- Barrows, J. S. 1951. Lightning fires in the northern Rocky Mountains. *Fire Control Notes* 12: 24-28.
- Beal, J. A. 1933. Temperature extremes as a factor in the ecology of the southern pine beetle. *J. Forestry* 31: 329-336.
- Beers, T. W. and C. I. Miller. 1964. Point sampling: research results, theory and applications. *Purdue Univ. Ag. Exp. Sta. Res. Bull. No. 786.* 54 p.
- Bentley, J. R., D. W. Seegrist and D. A. Blakeman. 1970. A technique for sampling low shrub vegetation by crown volume classes. *U. S. F. S. Res. Note PSW-215.* 11 p.
- Craighead, F. C. 1925. Bark-beetle epidemics and rainfall deficiency. *J. Econ. Entomol.* 18: 577-586.
- Fahnestock, G. R. 1965. Texas forest fires in relation to weather and other factors. *U. S. F. S. Res. Pap. SO-16.* 19 p.
- Fenneman, N. M. 1938. *Physiography of eastern United States.* McGraw-Hill Book Co., New York. 714 p.
- Geiger, R. 1965. *The climate near the ground.* Harvard Univ. Press, Cambridge, Mass. 611 p.
- Gisborne, H. T. 1926. Lightning and forest fires in the northern Rocky Mountain region. *Monthly Weather Rev.* 54: 281-286.
- _____. 1931. A five-year record of lightning storms and forest fires. *Monthly Weather Rev.* 59: 139-149.
- Hardy, C. E. and J. W. Franks. 1963. Forest fires in Alaska. *U. S. F. S. Res. Pap. INT-5.* 163 p.
- Hoffman, C. H. and R. F. Anderson. 1945. Effect of southern pine beetle on timber losses and natural restocking. *J. Forestry* 43: 436-439.
- Hutchinson, G. C. 1951. Copepodology for the ornithologist. *Ecology* 32: 571-577.
- Houston, D. 1971. Ecosystems of national parks. *Science* 172: 648-651.
- _____. 1973. Wildfires in northern Yellowstone National Park. *Ecology* 54: 1111-1117.

- Kilgore, B. M. and G. S. Briggs. 1972. Restoring fire to high elevation forests in California. *J. Forestry* 70: 266-271.
- Komarek, E. V. 1964. The natural history of lightning. *Proc. Third Annual Tall Timbers Fire Ecol. Conf.* 3: 139-183.
- Kruger, D. W. 1961. Threshold values of relative humidity for large fires in Georgia. *Georgia Forest Res. Council Res. Pap.* 3. 5 p.
- Little, E. L. 1953. Check list of native and naturalized trees of the United States (including Alaska). *U. S. D. A. Agr. Handbook No.* 41. 472 p.
- Loope, L. L. and G. E. Gruell. 1973. The ecological role of fire in the Jackson Hole Area, Northwest Wyoming. *Quat. Res.* 3: 425-443.
- McCarthy, E. F. 1923. Forest fire weather in the southern Appalachians. *Monthly Weather Rev.* 51: 182-185.
- McCarthy, E. F. and I. H. Sims. 1935. The relation between tree size and mortality caused by fire on southern Appalachian hardwoods. *J. Forestry* 33: 155-157.
- Oosting, H. J. 1944. The comparative effect of surface and crown fire on the composition of a loblolly pine community. *Ecology* 25: 61-69.
- Oosting, H. J. and R. B. Livingston. 1964. A resurvey of a loblolly pine community twenty-nine years after ground and crown fire. *Bull. Torrey Bot. Club* 91: 387-395.
- Racine, C. H. 1966. Pine communities and their site characteristics in the Blue Ridge escarpment. *J. Elisha Mitchell Soc.* 82: 172-181.
- St. George, R. A. 1930. Drought-affected and injured trees attractive to bark beetles. *J. Econ. Entomol.* 23: 825-828.
- Schnur, G. L. 1937. Yield, stand, and volume tables for even-aged upland oak forests. *U. S. D. A. Tech. Bull. No.* 560. 87 p.
- Schroeder, M. J. and C. C. Buck. 1970. Fire weather. *U. S. D. A. Agr. Handbook No.* 360. 229 p.
- Schumacher, F. X. and T. S. Coile. 1960. Growth and yield of natural stands of the southern pines. *T. S. Coile, Inc., Durham, N. C.* 115 p.
- Shanks, R. E. 1954. Climates of the Great Smoky Mountains. *Ecology* 35: 354-361.
- Show, S. B. and E. I. Kotok. 1923. The occurrence of lightning storms in relation to forest fires in California. *Monthly Weather Rev.* 51: 175-180.

- Siegel, S. 1956. Nonparametric statistics for the behavioral sciences. McGraw-Hill Book Co. New York. 312 p.
- Slocum, G. K. and W. D. Miller. 1953. Virginia pine: reproduction, growth, and management on the Hill Demonstration Forest, Durham County, North Carolina. North Carolina Ag. Exp. Sta. Tech. Bull. No. 100. 52 p.
- Tennessee Valley Authority. 1941. Areas characterized by principal forest types in the Tennessee Valley. [Map]. Dept. Forest Relations. Norris, Tenn.
- Thorntwaite, C. W. 1948. An approach toward a rational classification of climate. Geog. Rev. 38: 55-94.
- Trewartha, G. T. 1968. An introduction to climate. 4th ed. McGraw-Hill Book Co. New York. 408 p.
- Van Doren, M., ed. 1928. Travels of William Bartram. Macy-Masius, Pub. New York. 414 p.
- Wenger, K. F. 1955. Growth and prospective development of hardwoods and loblolly pine seedlings on clearcut areas. U. S. F. S. Southeastern Forest Exp. Sta. Pap. 55. 19 p.
- Whittaker, R. H. 1956. Vegetation of the Great Smoky Mountains. Ecol. Monogr. 26: 1-80.

APPENDIX

TABLE 4

BASAL AREA AND CHANGE IN PERCENT PINE AT EACH PLOT

Fire	Plot	Pk ^a	Ps ^b	Pr ^c	Hk ^d	Hs ^e	Hr ^f	T ^g	So ^h	T-So ⁱ
#	#	m ² /ha						%	%	%
1	1	0.3	7.2	0	0.2	3.8	.0	65.8	65.6	0.2
1	2	0.0	20.2	0	0.5	0.4	.0	98.2	95.7	2.5
1	3	0.5	31.7	0	0.0	2.4	.0	93.1	93.2	-0.1
1	4	1.4	53.7	0	0.4	0.9	.0	98.4	97.8	0.6
1	5	0.0	19.1	0	0.7	5.8	.0	76.6	74.6	2.0
1	6	0.0	10.6	0	0.8	5.7	.0	65.0	61.9	3.1
1	7	0.0	16.4	0	0.4	5.5	.0	74.8	73.4	1.4
1	8	0.1	31.6	0	0.0	1.9	.0	94.2	94.2	0.0
1	9	1.3	22.1	0	0.0	0.4	.0	98.2	98.3	-0.1
1	10	0.4	20.4	0	1.1	2.1	.0	90.7	86.7	4.0
1	11	0.6	17.7	0	1.0	8.4	.0	67.9	66.1	1.8
1	12	0.8	39.7	0	0.3	0.8	.0	97.9	97.2	0.7
1	13	0.6	22.5	0	0.4	1.7	.0	92.8	91.6	1.2
1	14	0.0	25.0	0	0.2	1.0	.0	96.0	95.1	0.9
1	15	1.2	29.9	0	0.7	0.6	.0	98.2	96.0	2.2
1	16	0.0	0.0	0	0.3	5.1	.0	0.0	0.0	0.0
1	17	0.0	22.9	0	0.0	2.3	.0	90.9	90.9	0.0
1	18	0.0	9.7	0	0.0	3.6	.0	72.7	72.7	0.0
2	1	13.5	0.9	0	0.6	9.9	.0	8.2	57.6	-49.4
2	2	1.6	0.6	0	0.0	8.8	.0	6.3	20.0	-13.7
2	3	34.5	0.4	0	0.4	9.1	.0	3.8	78.5	-74.7
2	4	3.1	5.3	0	0.4	2.6	.0	67.4	74.0	-6.6
2	5	4.4	2.6	0	1.2	4.6	.3	35.0	54.7	-19.7
2	6	3.4	5.8	0	0.5	5.0	.1	53.4	62.6	-9.2
2	7	7.1	0.8	0	0.7	4.0	.0	17.3	62.9	-45.6
2	8	1.2	0.3	0	0.5	6.1	.0	4.5	18.9	-14.4
2	9	27.0	0.8	0	0.2	3.5	.0	18.1	88.1	-70.0
2	10	34.5	0.5	0	0.4	4.6	.0	10.1	87.5	-77.4
2	11	33.1	0.5	0	0.5	4.1	.1	10.1	88.0	-77.9
2	12	11.7	0.5	0	0.8	10.1	.3	4.8	53.0	-48.2
2	13	29.8	0.1	0	0.7	9.7	.0	0.6	74.1	-73.5
2	14	12.6	1.1	0	0.2	9.6	.1	10.5	58.4	-47.9
2	15	9.6	1.5	0	0.0	17.1	.0	8.0	39.3	-31.3
2	16	19.8	0.7	0	0.0	0.9	.0	45.1	95.9	-50.8
2	17	9.5	1.4	0	0.1	1.2	.1	52.5	88.9	-36.4
2	18	11.8	0.0	0	0.6	5.8	.1	0.3	64.9	-64.6
2	19	11.4	1.7	0	0.0	9.8	.0	14.8	57.2	-42.4
3	1	2.8	9.2	0	0.2	2.3	.0	79.8	82.7	-2.9
3	2	0.2	1.8	0	0.6	12.5	.0	12.8	13.6	-0.8
3	3	0.9	4.4	0	0.7	27.3	.0	13.8	15.9	-2.1

TABLE 4 (continued)

Fire	Plot	Pk ^a	Ps ^b	Pr ^c	Hk ^d	Hs ^e	Hr ^f	T ^g	So ^h	T-So ⁱ
#	#	m ² /ha						%	%	%
3	4	2.9	3.7	0	0.0	9.1	.0	29.1	42.1	-13.0
3	5	0.9	1.7	0	1.1	4.5	.0	27.7	31.6	-3.9
3	6	0.8	7.5	0	1.0	13.9	.0	35.3	36.0	-0.7
3	7	4.5	12.0	0	0.0	12.9	.0	48.3	56.1	-7.8
3	8	1.4	21.4	0	0.2	4.7	.0	82.0	82.2	-0.2
3	9	2.3	4.0	0	0.1	6.9	.0	36.9	47.7	-10.8
3	10	0.1	4.2	0	0.2	10.6	.0	28.6	28.8	-0.2
3	11	0.1	0.0	0	0.3	14.8	.0	0.0	0.8	-0.8
3	12	1.2	4.4	0	0.5	6.3	.0	40.9	44.8	-3.9
3	13	0.5	5.0	0	0.1	7.6	.0	39.8	42.0	-2.2
3	14	0.7	1.6	0	1.2	17.4	.0	8.4	11.0	-2.6
3	15	0.8	6.6	0	1.6	7.9	.0	45.6	43.8	1.8
3	16	0.8	1.2	0	1.1	11.3	.0	9.6	13.9	-4.3
3	17	0.7	3.4	0	0.2	21.6	.0	13.7	16.0	-2.3
3	18	0.7	8.5	0	1.1	10.5	.0	44.8	44.2	0.6
3	19	0.6	5.6	0	0.9	26.6	.0	17.4	18.3	-0.9
3	20	0.0	0.5	0	1.6	20.3	.0	2.5	2.4	0.1
3	21	1.0	13.0	0	1.0	17.6	.0	42.5	43.0	-0.5
4	1	0.0	0.0	0	1.0	16.9	.0	0.0	0.0	0.0
4	2	0.0	0.0	0	1.4	33.4	.0	0.0	0.0	0.0
4	3	0.0	0.0	0	1.5	29.0	.0	0.0	0.0	0.0
4	4	0.0	0.0	0	5.1	18.5	.0	0.0	0.0	0.0
4	5	0.0	0.0	0	1.7	20.5	.1	0.0	0.0	0.0
4	6	0.0	0.0	0	4.2	15.7	.0	0.0	0.0	0.0
4	7	0.0	0.0	0	3.0	38.2	.0	0.0	0.0	0.0
4	8	0.0	0.0	0	2.9	5.8	.0	0.0	0.0	0.0
4	9	0.0	0.0	0	0.9	18.6	.0	0.0	0.0	0.0
4	10	0.0	0.0	0	1.8	13.7	.0	0.0	0.0	0.0
4	11	0.0	0.0	0	0.8	25.3	.0	0.0	0.0	0.0
4	12	0.0	8.5	0	0.6	28.2	.0	23.2	22.8	0.4
4	13	0.0	4.0	0	0.6	14.9	.0	21.3	20.7	0.6
4	14	0.0	3.9	0	2.7	10.7	.0	26.5	22.4	4.1
4	15	0.0	0.0	0	2.4	14.5	.0	0.0	0.0	0.0
4	16	0.0	1.8	0	2.4	11.9	.0	13.1	11.1	2.0
4	17	0.0	0.0	0	3.9	12.8	.0	0.0	0.0	0.0
4	18	0.0	10.2	0	1.2	19.3	.0	34.6	33.3	1.3
4	19	0.0	9.7	0	0.6	10.9	.0	47.0	45.6	1.4
4	20	0.0	22.6	0	0.9	6.2	.0	78.4	76.0	2.4
4	21	0.0	22.1	0	3.1	15.5	.0	58.8	54.3	4.5
4	22	0.6	3.1	0	2.8	12.2	.0	20.3	19.8	0.5
4	23	0.1	15.5	0	1.6	8.0	.1	65.8	62.1	3.7

TABLE 4 (continued)

Fire	Plot	Pk ^a	Ps ^b	Pr ^c	Hk ^d	Hs ^e	Hr ^f	T ^g	So ^h	T-So ⁱ
#	#	m ² /ha						%	%	%
4	24	0.0	17.4	0	6.4	7.3	.0	70.3	55.9	14.4
4	25	0.6	18.9	0	1.2	8.1	.0	70.1	67.9	2.2
5	1	0.0	29.6	0	1.9	4.6	.0	86.7	82.1	4.6
5	2	0.0	9.6	0	0.6	13.7	.1	40.9	40.1	0.8
5	3	0.2	10.1	0	0.8	3.1	.2	75.8	72.7	3.1
5	4	0.0	20.0	0	1.0	4.6	.0	81.4	78.1	3.3
5	5	0.2	5.9	0	1.3	5.1	.0	53.8	49.2	4.6
5	6	5.5	15.5	0	3.3	9.2	.0	62.7	62.7	0.0
5	7	2.7	10.9	0	0.5	0.6	.0	94.8	92.7	2.1
5	8	3.6	5.9	0	2.0	2.0	.1	74.3	70.6	3.7
5	9	0.2	20.7	0	2.7	2.3	.0	90.1	80.7	9.4
5	10	0.0	20.0	0	0.5	5.5	.0	78.3	76.8	1.5
5	11	3.2	28.7	0	1.4	4.1	.0	87.5	85.4	2.1
5	12	2.0	24.4	0	2.3	6.6	.0	78.7	74.9	3.8
5	13	7.0	21.2	0	0.9	0.5	.0	97.5	95.1	2.4
5	14	0.0	14.8	0	1.7	7.1	.0	67.4	62.7	4.7
5	15	3.4	15.3	0	0.2	8.6	.0	63.9	67.9	-4.0
5	16	2.5	14.1	0	1.5	15.6	.0	47.6	49.4	-1.8
5	17	0.0	25.1	0	0.9	1.1	.0	95.7	92.5	3.2
5	18	1.4	5.5	0	1.1	15.0	.0	26.6	29.7	-3.1
5J	1	29.2	0.5	0	0.0	4.6	.0	9.1	86.7	-77.6
5J	2	8.4	1.1	0	0.0	13.8	.0	7.6	40.9	-33.3
5J	3	9.0	1.4	0	0.0	3.2	.0	29.8	76.2	-46.4
5J	4	15.6	0.4	0	0.0	4.6	.0	7.5	81.4	-73.9
5J	5	0.2	5.9	0	0.0	5.1	.0	53.8	54.8	-1.0
5J	6	5.5	15.5	0	0.0	9.2	.0	62.7	69.6	-6.9
5J	7	11.9	1.7	0	0.0	0.6	.0	73.7	95.7	-22.0
5J	8	3.6	5.9	0	0.0	2.0	.0	74.3	82.3	-8.0
5J	9	19.2	1.8	0	0.0	2.3	.0	44.5	90.2	-45.7
5J	10	17.5	2.4	0	0.0	5.5	.0	30.4	78.3	-47.9
5J	11	28.9	3.0	0	0.0	4.1	.0	42.0	88.6	-46.6
5J	12	24.6	1.8	0	0.0	6.6	.0	21.6	80.0	-58.4
5J	13	25.3	3.0	0	0.0	0.5	.0	84.6	98.1	-13.5
5J	14	13.9	0.9	0	0.0	7.1	.0	11.3	67.5	-56.2
5J	15	18.7	0.0	0	0.0	8.6	.0	0.0	68.5	-68.5
5J	16	15.7	0.9	0	0.0	15.6	.0	5.5	51.6	-46.1
5J	17	22.1	3.0	0	0.0	1.1	.0	72.2	95.7	-23.5
5J	18	6.6	0.2	0	0.0	15.0	.0	1.5	31.2	-29.7
6	1	7.8	16.3	0	0.3	0.8	.0	95.1	95.7	-0.6

TABLE 4 (continued)

Fire	Plot	Pk ^a	Ps ^b	Pr ^c	Hk ^d	Hs ^e	Hr ^f	T ^g	So ^h	T-So ⁱ
#	#	m ² /ha						%	%	%
6	2	5.0	23.0	0	1.2	2.6	0	89.8	87.9	1.9
6	3	3.4	18.6	0	0.8	3.5	0	84.1	83.6	0.5
6	4	1.9	19.3	0	0.4	4.0	0	82.9	82.8	0.1
6	5	3.4	28.9	0	1.1	2.6	0	91.8	89.9	1.9
6	6	4.2	24.5	0	0.9	1.7	0	93.7	91.8	1.9
6	7	0.4	26.9	0	0.3	1.8	0	93.9	93.1	0.8
6	8	0.2	21.7	0	4.6	2.1	0	91.0	76.4	14.6
6	9	0.7	13.4	0	1.3	6.5	0	67.3	64.4	2.9
6	10	0.0	0.4	0	4.0	16.7	0	2.4	1.9	0.5
6	11	0.0	0.0	0	2.4	13.3	0	0.0	0.0	0.0
6	12	0.0	0.0	0	2.6	17.9	0	0.0	0.0	0.0
6	13	7.7	11.9	0	3.6	0.6	0	95.3	82.5	12.8
6	14	2.6	23.3	0	6.7	2.8	0	89.3	73.1	16.2
6	15	0.0	2.4	0	3.3	11.3	0	17.7	14.3	3.4
6	16	0.0	0.0	0	0.9	15.7	0	0.0	0.0	0.0
6	17	0.0	0.0	0	5.3	13.3	0	0.0	0.0	0.0
6	18	0.0	0.0	0	5.2	14.1	0	0.0	0.0	0.0
6	19	0.3	0.0	0	0.9	8.9	0	0.0	2.6	-2.6
6	20	0.0	0.0	0	5.9	12.5	0	0.0	0.0	0.0
6	21	0.0	0.0	0	9.0	8.8	0	0.0	0.0	0.0
6	22	0.0	23.6	0	2.6	7.7	0	75.5	69.6	5.9
6	23	0.0	3.4	0	6.7	14.7	0	18.7	13.6	5.1
6	24	0.0	0.4	0	6.8	8.8	0	4.4	2.5	1.9
7	1	3.0	6.0	0	1.0	6.2	0	49.3	55.8	-6.5
7	2	3.2	5.1	0	1.4	9.1	0	36.1	44.3	-8.2
7	3	14.1	14.4	0	1.1	0.9	0	94.1	93.5	0.6
7	4	4.1	0.2	0	1.7	0.6	0	23.3	65.5	-42.2
7	5	5.1	0.7	0	2.3	7.4	0	8.9	37.3	-28.4
7	6	6.5	9.8	0	3.1	0.0	0	100.0	83.9	16.1
7	7	7.1	0.0	0	1.7	0.9	0	0.0	72.9	-72.9
7	8	4.3	0.1	0	1.9	1.9	0	6.6	53.6	-47.0
7	9	3.2	4.4	0	1.3	9.2	0	32.0	41.8	-9.8
7	10	5.7	8.7	0	0.6	4.2	0	67.5	75.0	-7.5
7	11	2.8	11.4	0	1.1	10.8	0	51.4	54.4	-3.0
7	12	2.1	1.8	0	2.0	4.6	0	28.4	37.5	-9.1
7	13	5.2	15.2	0	0.7	14.0	0	52.2	58.2	-6.0
7	14	10.5	5.6	0	0.9	4.7	0	54.1	74.1	-20.0
7	15	6.8	7.4	0	1.3	2.4	0	75.9	79.8	-3.9
7	16	3.5	10.2	0	0.2	2.9	0	77.9	85.9	-8.0
7	17	4.5	0.0	0	0.9	5.1	0	0.0	42.9	-42.9
7	18	6.6	4.3	0	1.8	12.0	0	26.4	44.1	-17.7

TABLE 4 (continued)

Fire	Plot	Pk ^a	Ps ^b	Pr ^c	Hk ^d	Hs ^e	Hr ^f	T ^g	So ^h	T-So ⁱ
#	#	m ² /ha						%	%	%
8	1	21.6	6.3	0	0.2	0.0	.0	100.0	99.2	0.8
8	2	12.4	21.1	0	1.1	0.2	.0	98.9	96.1	2.8
8	3	13.5	26.8	0	0.9	0.0	.0	100.0	97.7	2.3
8	4	10.0	20.3	0	0.8	0.0	.0	100.0	97.4	2.6
8	5	11.7	18.0	0	0.9	0.5	.0	97.2	95.5	1.7
8	6	16.3	11.1	0	0.2	0.0	.0	100.0	99.2	0.8
8	7	3.4	28.4	0	0.5	0.7	.0	97.6	96.5	1.1
8	8	21.0	8.6	0	0.7	0.2	.0	97.4	97.0	0.4
8	9	10.1	24.2	0	0.4	0.0	.0	100.0	99.0	1.0
8	10	3.1	25.7	0	0.9	0.8	.0	96.9	94.3	2.6
8	11	18.4	23.6	0	0.1	0.0	.0	100.0	99.7	0.3
8	12	7.2	17.9	0	3.2	0.2	.0	98.7	88.0	10.7
8	13	17.6	7.2	0	0.7	0.4	.0	95.3	95.9	-0.6
8	14	2.3	28.1	0	0.7	0.0	.0	100.0	97.8	2.2
8	15	17.5	3.4	0	1.6	0.0	.0	100.0	92.9	7.1
8	16	4.1	35.1	0	0.1	0.0	.0	100.0	99.7	0.3
8	17	11.9	20.2	0	0.6	0.0	.0	100.0	98.2	1.8
8	18	4.0	24.0	0	1.5	1.4	.0	94.4	90.6	3.8
8	19	1.2	19.3	0	3.5	1.2	.0	94.1	81.2	12.9
8	20	11.5	20.7	0	1.1	0.0	.0	100.0	96.7	3.3
8	21	13.3	16.4	0	5.5	0.7	.0	95.9	82.8	13.1
8	22	11.6	24.5	0	1.9	2.1	.0	92.0	90.0	2.0
9	1	3.7	0.9	0	0.6	0.0	.1	90.1	88.3	1.8
9	2	0.1	5.4	0	1.1	0.0	.1	98.2	82.7	15.5
9	3	2.4	5.0	0	2.1	0.0	.0	100.0	77.6	22.4
9	4	6.0	3.7	0	4.9	0.0	.0	100.0	66.4	33.6
9	5	0.0	2.5	0	2.0	0.0	.0	100.0	55.9	44.1
9	6	1.2	21.3	0	3.2	0.0	.1	99.5	87.7	11.8
9	7	0.1	7.4	0	8.0	1.2	.0	86.0	45.0	41.0
9	8	0.8	0.0	0	2.0	0.0	.0		29.5	
9	9	6.0	3.4	0	3.5	5.4	.0	38.6	51.3	-12.7
9	10	0.9	8.1	0	2.3	8.1	.0	50.0	46.5	3.5
9	11	1.1	2.5	0	1.2	0.0	.0	100.0	74.3	25.7
9	12	0.1	12.4	0	1.7	0.0	.0	100.0	88.1	11.9
9	13	0.1	2.5	0	3.1	0.0	.0	100.0	45.8	54.2
9	14	0.0	5.0	0	1.2	4.3	.0	53.5	47.2	6.3
9	15	0.8	0.8	0	4.0	0.6	.0	57.7	26.2	31.5
9	16	0.4	2.1	0	4.5	0.6	.0	77.4	33.3	44.1
9	17	0.0	0.9	0	1.9	0.0	.0	100.0	32.5	67.5
9	18	1.2	0.6	0	3.7	1.2	.0	33.7	27.4	6.3

TABLE 4 (continued)

Fire	Plot	Pk ^a	Ps ^b	Pr ^c	Hk ^d	Hs ^e	Hr ^f	T ^g	So ^h	T-So ⁱ
#	#	m ² /ha						%	%	%
9	19	1.1	2.9	0.0	3.6	0.0	0.0	100.0	52.1	47.9
9	20	1.0	5.4	0.0	4.8	0.4	0.0	93.2	55.0	38.2
9	21	0.0	5.6	0.0	3.1	0.9	0.0	86.2	58.3	27.9
9	22	2.5	4.0	0.0	5.2	0.0	0.0	100.0	55.8	44.2
9	23	1.7	9.6	0.0	3.1	4.4	0.0	68.5	60.0	8.5
9	24	1.0	3.3	0.0	2.1	0.0	0.0	100.0	67.4	32.6
9	25	0.8	0.0	0.0	5.5	0.0	0.0		12.7	
10	1	11.3	8.2	4.0	2.1	0.0	1.5	88.8	90.5	-1.7
10	2	0.0	12.8	4.8	4.6	0.0	0.5	97.2	73.5	23.7
10	3	17.4	1.0	4.4	0.0	8.2	1.6	35.3	69.2	-33.9
10	4	4.6	8.2	3.8	0.0	0.0	0.2	98.1	100.0	-1.9
10	5	19.5	4.6	5.9	14.9	0.0	1.5	87.5	61.8	25.7
10	6	8.2	4.6	4.7	2.1	0.0	0.3	97.0	86.2	10.8
10	7	12.8	4.1	4.0	0.0	0.0	0.7	92.1	100.0	-7.9
10	8	9.7	0.0	1.1	0.0	1.0	0.8	37.6	90.6	-53.0
10	9	6.7	0.0	6.3	0.0	0.0	0.6	90.8	100.0	-9.2
10	10	21.0	0.0	6.4	4.8	0.0	2.1	75.7	81.4	-5.7
10	11	4.6	0.0	5.8	4.6	8.5	2.4	34.6	26.0	8.6
10	12	16.4	0.0	3.4	0.9	0.0	1.0	78.0	94.7	-16.7
10	13	4.6	8.2	6.5	0.0	0.0	0.3	98.2	100.0	-1.8
10	14	8.5	0.0	5.5	5.1	0.0	3.0	64.9	62.5	2.4
10	15	4.6	0.0	2.7	0.0	0.0	5.6	32.6	100.0	-67.4
11	1	13.1	1.6	0.0	15.3	0.0	0.2	87.7	49.0	38.7
11	2	24.0	3.8	0.0	16.5	1.1	0.3	72.7	61.3	11.4
11	3	1.6	4.9	0.0	23.2	0.0	1.2	80.2	22.0	58.2
11	4	3.9	1.4	0.0	11.9	0.0	0.7	67.3	30.8	36.5
11	5	0.0	0.0	0.0	9.5	8.1	0.7	0.0	0.0	0.0
11	6	19.7	0.0	0.0	11.6	0.0	1.1	2.2	62.8	-60.6
11	7	0.5	0.0	0.0	13.3	2.4	0.2	0.0	3.3	-3.3
11	8	19.7	0.0	0.0	11.5	0.0	0.3	0.0	63.2	-63.2
11	9	4.9	0.0	0.0	23.3	0.0	1.4	0.0	17.4	-17.4
11	10	21.9	0.0	0.0	10.4	0.0	0.5	0.0	67.8	-67.8
11	11	0.7	0.8	0.0	12.6	3.0	1.1	16.1	8.7	7.4
11	12	3.3	0.0	0.0	6.0	0.0	0.7	0.0	35.2	-35.2
11	13	5.7	0.0	0.0	15.1	0.0	0.3	0.0	27.4	-27.4
11	14	15.9	0.0	0.0	5.7	0.0	0.4	0.0	73.5	-73.5
11	15	30.3	0.0	0.0	1.3	0.0	0.0	0.0	95.8	-95.8
11	16	29.2	0.0	0.0	0.8	0.0	0.0	0.0	97.4	-97.4
11	17	7.7	0.0	0.0	0.7	0.0	0.1	0.0	91.6	-91.6
11	18	15.9	0.0	0.0	0.0	0.0	0.0		100.0	

TABLE 4 (continued)

Fire	Plot	Pk ^a	Ps ^b	Pr ^c	Hk ^d	Hs ^e	Hr ^f	T ^g	So ^h	T-So ⁱ
#	#	m ² /ha						%	%	%
11	19	45.4	0.8	0.0	1.7	0.0	2.7	22.4	96.5	-74.1
11	20	38.8	0.0	0.0	5.7	0.0	0.0		87.2	
11	21	26.2	0.0	0.0	6.6	0.0	0.2	0.0	80.0	-80.0
11	22	23.5	0.0	0.0	10.7	0.0	0.1	0.0	68.7	-68.7
11	23	34.0	0.5	0.0	1.3	0.0	0.1	80.2	96.4	-16.2
12	1	3.7	0.0	0.0	1.5	0.0	2.2	0.0	70.9	-70.9
12	2	4.8	0.0	0.0	0.0	0.0	0.0		99.5	
12	3	5.2	0.0	0.5	0.1	0.0	0.2	74.4	98.3	-23.9
12	4	1.6	0.0	0.4	0.8	0.0	0.4	50.0	67.6	-17.6
12	5	2.6	0.0	1.4	0.0	0.0	0.0	100.0	100.0	0.0
12	6	2.5	0.0	0.9	0.1	0.0	0.1	88.3	96.5	-8.2
12	7	7.3	1.4	0.5	0.0	0.0	0.0	98.7	99.7	-1.0
12	8	1.8	0.6	0.2	0.9	0.0	0.7	52.3	72.8	-20.5
12	9	2.3	0.0	1.3	0.5	0.0	0.2	86.6	83.2	3.4
12	10	3.9	0.8	0.4	0.0	0.0	0.0	100.0	100.0	0.0
12	11	3.3	1.2	1.4	0.4	0.0	0.2	93.3	92.5	0.8
12	12	1.6	4.2	0.0	0.4	0.0	0.2	95.3	93.7	1.6
12	13	3.0	0.0	2.7	0.0	0.0	0.1	96.8	100.0	-3.2
12	14	7.0	0.0	1.9	0.0	0.0	0.0	100.0	100.0	0.0
12	15	2.4	0.0	0.9	0.2	0.0	0.3	76.6	93.0	-16.4
13	1	0.0	0.0	0.0	7.3	0.0	2.6	0.0	0.0	0.0
13	2	0.0	0.0	0.0	17.3	0.0	5.3	0.0	0.0	0.0
13	3	0.6	0.0	0.2	9.6	6.2	4.1	2.3	3.9	-1.6
13	4	3.0	0.0	0.0	21.1	0.0	2.6	0.8	12.6	-11.8
13	5	0.0	0.0	0.0	9.7	0.0	5.9	0.0	0.0	0.0
13	6	9.5	0.0	0.6	9.6	0.0	5.2	9.7	49.6	-39.9
13	7	6.2	0.0	0.5	7.6	0.0	2.7	15.4	45.0	-29.6
13	8	7.7	0.0	0.9	3.6	0.0	3.3	21.0	68.3	-47.3
13	9	0.6	0.0	1.8	0.4	0.0	0.3	86.8	59.6	27.2
13	10	0.0	0.0	0.0	27.3	0.0	5.9	0.3	0.0	0.3
13	11	0.0	0.0	0.0	7.5	0.0	8.0	0.0	0.0	0.0
13	12	13.4	0.0	0.7	2.0	0.0	1.1	38.3	86.8	-48.5
13	13	4.3	0.0	4.4	10.0	0.0	2.4	64.5	30.3	34.2
13	14	46.6	0.0	1.5	1.5	0.0	0.2	88.9	96.8	-7.9
13	15	0.0	0.0	0.0	3.8	0.0	4.2	0.0	0.0	0.0
13	16	0.0	0.0	0.0	29.5	0.0	9.4	0.0	0.0	0.0
13	17	5.0	0.0	0.0	5.9	0.0	3.4	0.0	46.0	-46.0
13	18	8.4	0.0	5.3	2.4	0.0	1.4	78.9	78.0	0.9
13	19	40.3	0.0	3.7	0.9	0.0	1.2	75.5	97.9	-22.4
13	20	23.9	26.3	0.1	2.5	0.0	0.9	96.6	95.2	1.4

TABLE 4 (continued)

Fire	Plot	Pk ^a	Ps ^b	Pr ^c	Hk ^d	Hs ^e	Hr ^f	T ^g	So ^h	T-So ⁱ
#	#	m ² /ha						%	%	%
13	21	18.4	0	1.3	1.4	0	1.4	48.7	93.1	-44.4
13	22	8.9	0	1.5	3.7	0	1.9	45.2	70.8	-25.6
13	23	20.2	0	2.0	6.2	0	0.8	72.4	76.5	-4.1
13	24	13.9	0	2.1	0.2	0	0.2	93.0	98.3	-5.3
13	25	23.1	0	5.8	0.2	0	1.1	84.6	98.9	-14.3

^aPk = basal area of top-killed pines.

^bPs = present basal area of pines which survived the fire.

^cPr = present basal area of post-fire pine reproduction.

^dHk = basal area of top-killed hardwoods.

^eHs = present basal area of hardwoods which survived the fire.

^fHr = present basal area of post-fire hardwood regeneration.

^gT = $100(Ps + Pr)/(Ps + Pr + Hs + Hr)$, the percent of pine in the total basal area of presently living trees.

^hSo = $100(Ps + Pk)/(Ps + Pk + Hs + Hk)$, an approximation of the hypothetical percent of pine basal area in the absence of fire (see text).

ⁱT-So = the approximate shift in percent pine.

^j Effect of beetle-kill only.

VITA

Lawrence Samuel Barden was born November 12, 1942, in Little Rock, Arkansas, where he attended public schools. He received the B. A. Degree in 1964 from Hendrix College, Conway, Arkansas, and the M. S. Degree in 1968 from the University of Maine at Orono.

After two years employment as a park ranger with the National Park Service, he entered the University of Tennessee Graduate Program in Ecology. Mr. Barden completed the requirements for the Ph.D. Degree in 1974.