

Characteristics of Lightning Fires in Southern Appalachian Forests

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INTRODUCTION

THE purpose 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, it 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

used in this 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. This analysis of fire reports is part of a larger study of changes in forest composition following lightning fires.

THE 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 110 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 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

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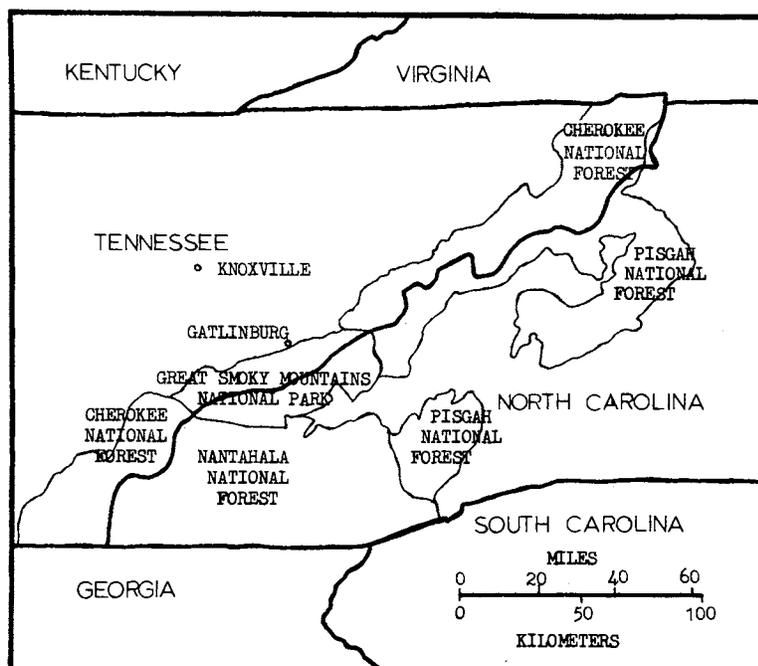


Fig. 1. Authorized boundaries of federal administrative units in the study area.

in stream valleys consist of such mesophytic species as eastern hemlock (*Tsuga canadensis*), Carolina silverbell (*Halesia carolina*), yellow buckeye (*Aesculus otocandra*), 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 a few 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 Frazer 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. *Kalmia latifolia* and *Rhododendron spp.* are the chief taxa of heath balds, and the grass, *Danthonia compressa*, is the most common species of the grassy balds (Whittaker 1956). Nomenclature follows Little (1953) for trees and Fernald (1950) for non-woody species. The comparisons shown in Figures 5-9 are significant at the .01 level using chi-square contingency tests.

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 (Fig. 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 (Fig. 2). The area burned per month by lightning fires is similarly distributed (Fig. 3).

The two seasons for man-caused fires correspond to times when litter is driest: March through May and October through December (Fig. 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 through December, on the other hand, account for only 28 percent of the fires and 16 percent of the area burned (Figs. 2 and 3). Thus, for man-caused fires the spring season is generally much more severe than the fall season. There are notable exceptions to this rule, 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

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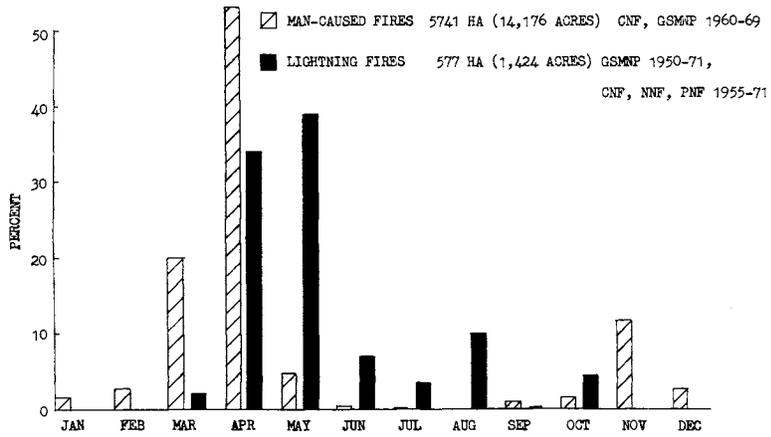


FIG. 2. Incidence of wildfires in the Appalachians of Tennessee and North Carolina.

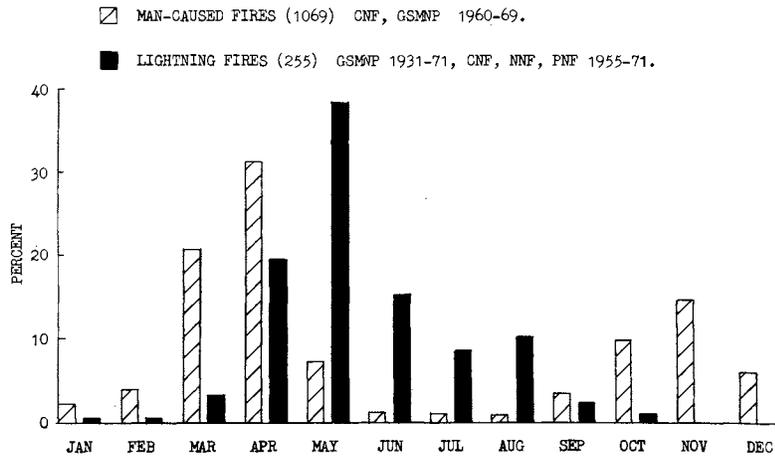


FIG. 3. Area burned by wildfires in the Appalachians of Tennessee and North Carolina.

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).

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 5 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

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

Unit	Percent Total Study Area	Fires		Chi-Square
		Observed	Expected From Percent Area	
<i>Name</i>	<i>%</i>	<i>No.</i>	<i>No.</i>	<i>Value</i>
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 < .001

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per year per 400,000 ha (1 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 (Fig. 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 record in the study area burned 33 ha (81 acres). In contrast, during 1960–1969 there were 23 man-caused fires in CNF and 2 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).

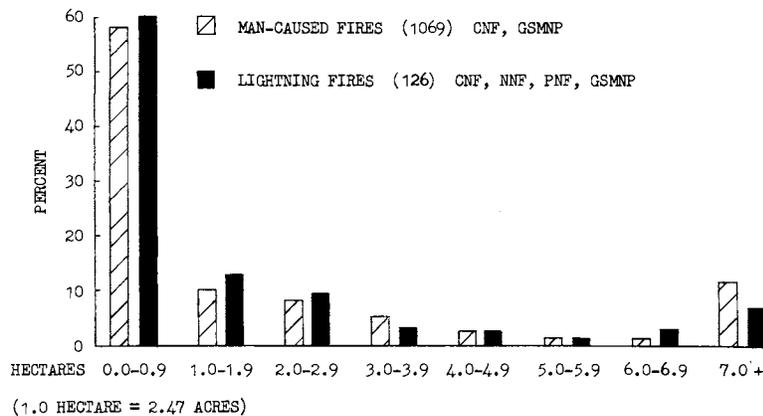


FIG. 4. Incidence by size class of wildfires in the Appalachians of Tennessee and North Carolina.

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 were 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 7 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 4 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 3 years 93 man-caused fires burned at least 25 km² (10 square miles) within the park boundary. In contrast, during 1960–1969 there was an average of 9 fires and 0.33 km² (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, one might expect lightning fires to be more frequent at higher ele-

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variations 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).

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

Elevation	Percent Total Park Area	Fires		Chi-Square
		Observed	Expected From Percent Area	
meters (feet)	%	No.	No.	Value
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 < .01

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 since human activity centers at lower elevations, lightning fires were proportionally more common at higher elevations than man-caused fires (Fig. 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 (Fig. 6). A possible reason is that hardwood forests

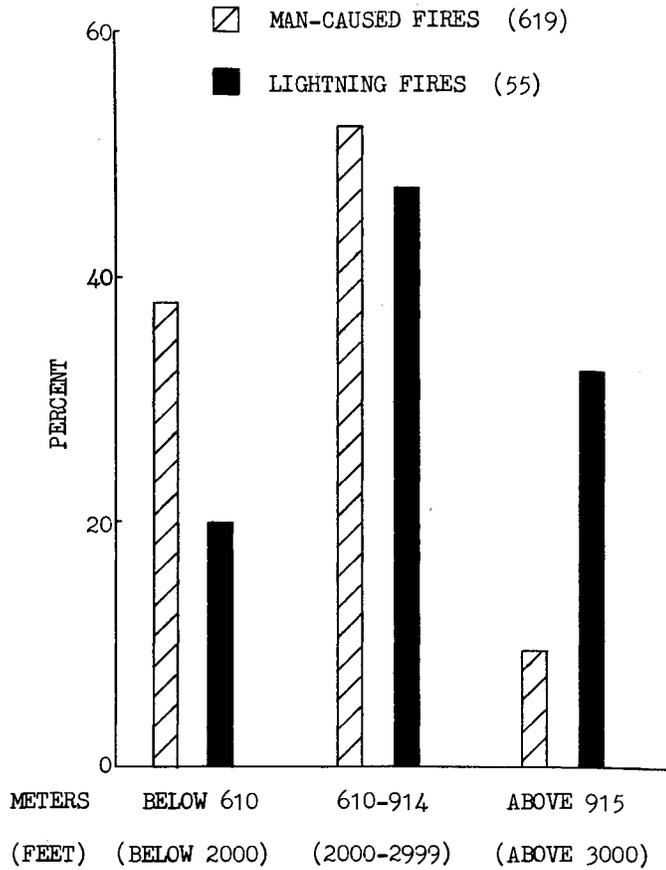


FIG. 5. Elevation of wildfires in Cherokee National Forest, March-August, 1960-1969.

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

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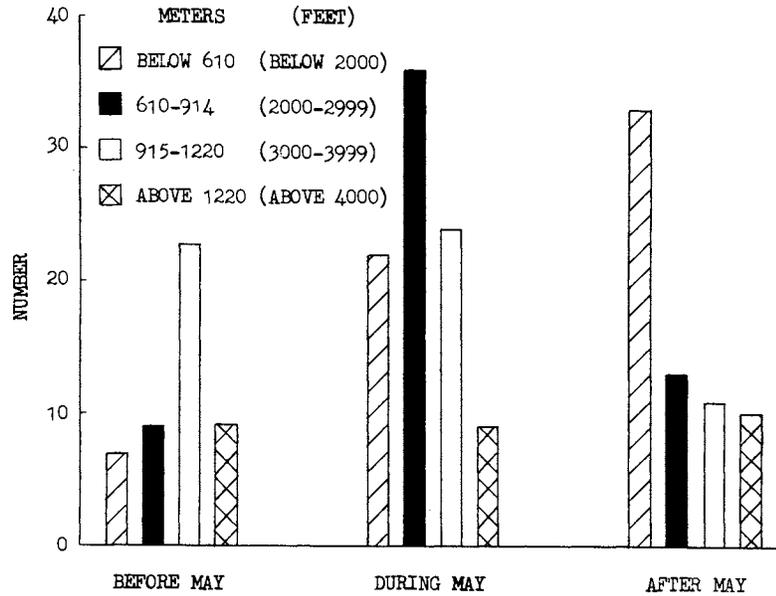


FIG. 6. Elevation of lightning fires before, during and after May in the Appalachians of Tennessee and North Carolina.

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 flammability of hardwood litter at lower elevations where hardwoods leaf-out

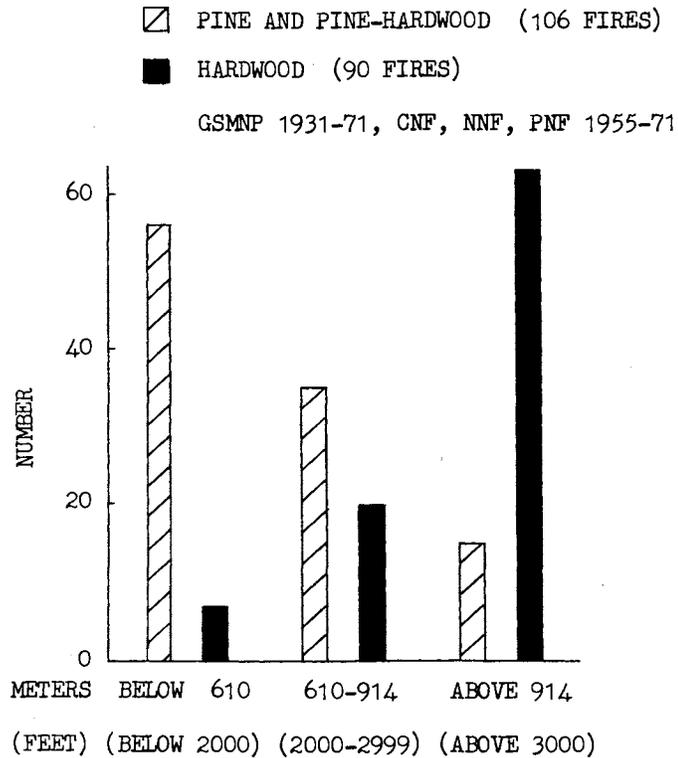


FIG. 7. Elevation of lightning fires in hardwood and pine stands in the Appalachians of Tennessee and North Carolina.

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 OF FIRES

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

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- ▨ PINE AND PINE-HARDWOOD (103 FIRES)
- HARDWOOD (75 FIRES)

GSMNP 1931-71, CNF, NNF, PNF 1955-71

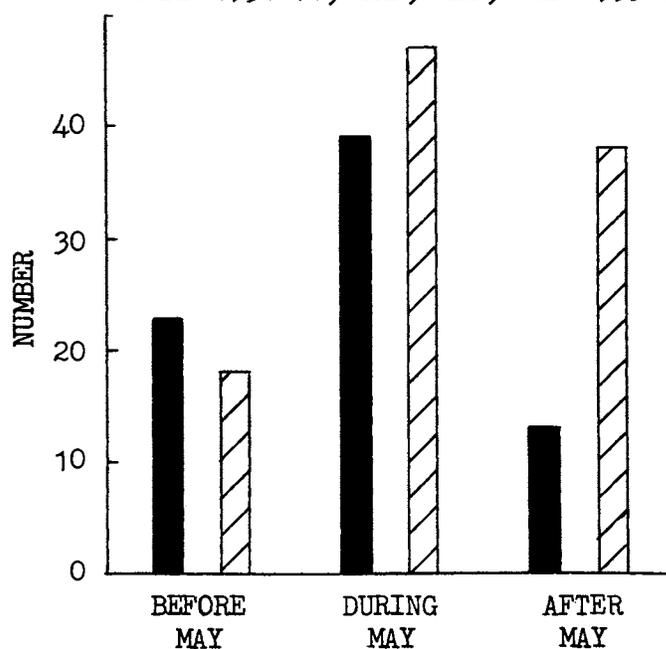


FIG. 8. Lightning fires in hardwood and pine stands before, during and after May in the Appalachians of Tennessee and North Carolina.

lightning fires with man-caused fires. None of the lightning fires on record (185 fires) was described as crowning or spotting. In contrast, 7 percent of man-caused fires on CNF during the lightning fire season were crowning or spotting when the fire crew arrived (Fig. 9). Omitting the crowning or spotting classification from comparison, man-caused fires still tended to be much more severe than lightning fires. One reason for this difference, as Show and Kotok (1923) suggest, is that lightning fires tend to spread slowly at first because rain usually wets the litter.

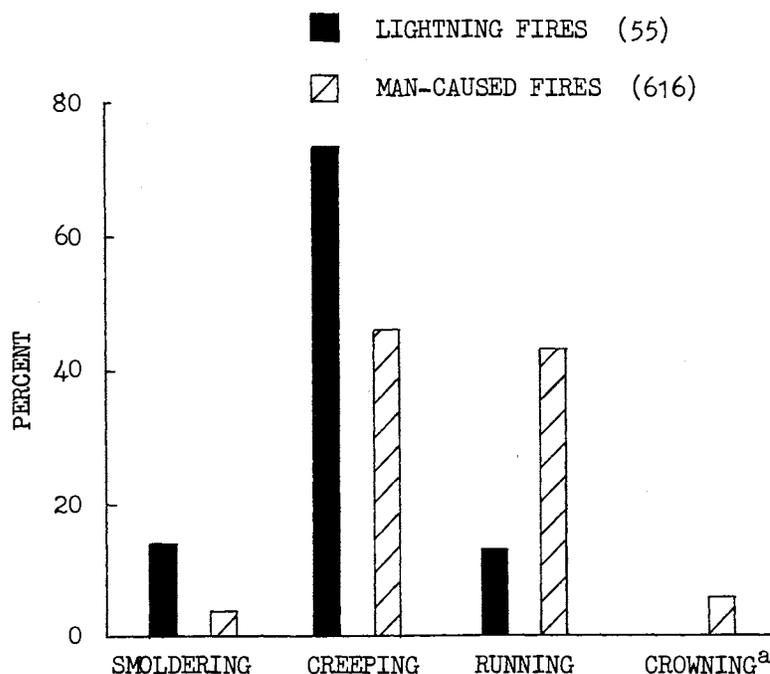


FIG. 9. Severity of wildfires in Cherokee National Forest March-August, 1960-1969.

^a Includes spotting.

WEATHER ASSOCIATED WITH FIRES

To compare weather associated with man-caused and lightning fires, we 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 periods," totaling 210 days, when 235 man-caused fires burned 3200 ha (7920 acres). In contrast, during these

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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 ($P < .02$). On days when large man-caused fires started, the median maximum and median minimum relative humidity at Knoxville were 74 and 29 percent, respectively. On days when large lightning fires started, the median maximum and minimum were 86 and 37 percent.

CONCLUSIONS

An analysis of fire reports from Great Smoky Mountain National Park and from Cherokee, Nantahala and Pisgah National Forests

which cover 800,000 ha (2 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 December. 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 (1 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.

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