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TRENDS IN FIRE OCCURRENCE IN THE ARIZONA UPLAND SUBDIVISION OF THE SONORAN DESERT, 1955 TO 1983

MARY K. SCHMID AND GARRY F. ROGERS

ABSTRACT—Using U.S. Forest Service fire occurrence records, we found that during the 29-year period 1955 to 1983, 1611 fires burned a total of 41,447 ha in the 391,000-ha desert portion of Tonto National Forest, Arizona (TNF). Lightning-caused fires, though fewer in number, burned approximately twice the area of fires set by people. Fires were numerous from May through August, but area burned was greater during June than all other months combined. Using average annual hectares burned and subtracting areas of overlap between fires, we estimated that 294 years were required for all parts of the TNF desert to burn. Ignoring overlap, estimated time required for an area of equal size to the TNF desert to burn is 274 years. Increasing fire occurrence during the 29-year period studied might be due to wetter-than-normal winters toward the end of the period, fuel provided by exotic annual plants, improved fire detection and reporting, and ignition by people.

Fire is generally considered to be rare in the Sonoran Desert. Except in a few areas where perennial grasses occur or during unusually wet years when ephemeral herbs are abundant, fuel provided by desert plants is too sparse for fires to spread over large areas (Phillips, 1962; Humphrey, 1974; Pase and Granfelt, 1977, Steenbergh and Lowe, 1977, Lotan et al., 1981; McLaughlin and Bowers, 1982). Fires that do occur leave few enduring signs of their passage.

The recurrence interval (the period between fires) is an important key to understanding the ecological role of fire (Vogl, 1977*a*, 1980). Fire-history studies have shown that insome ecosystems the recurrence interval increased during the past century (e.g., Stokes and Dieterich, 1980; Gruell, 1983). Comparable studies of trends in fire occurrence are not available for deserts. Because of the lack of data, the general assumption that desert fires are rare has been tested only once (Rogers, 1986). In contrast to other ecosystems, it has been hypothesized that fires are becoming more frequent in North American deserts because of increased fuel provided by exotic annuals (e.g., West, 1979; Rogers and Steele, 1980; Rogers, 1982, 1986; Zedler et al., 1983) and because of the increase in occurrence of human-caused fires (Vogl, 1977*b*). However, no quantitative evidence has been published to support this hypothesis.

This paper presents an analysis of fire occurrence in the Arizona Upland subdivision of the Sonoran Desert. A 29-year record of fires reported in the 391,000-ha desert portion of Tonto National Forest (TNF), Arizona, was used to study the temporal patterns and probable causes of the desert fire regime evident in annual and monthly numbers and area burned by fires ignited by lighting and people.

MATERIALS AND METHODS—The desert portion of TNF, located about 50 km east of Phoenix, Arizona, contained vegetation representative of the Arizona Upland subdivision of the Sonoran

Desert (Shreve, 1964; Brown, 1982). Dominant plants included shrubs (*Ambrosia deltoidea, Larrea tridentata*), small trees (*Cercidium microphyllum*), and cacti (*Opuntia* sp., *Cereus giganteus*). Detailed descriptions of the vegetation and flora are in Brown (1982) and Shreve (1964). Livestock grazing was continuous during the period studied. The 29-year (1955 to 1983) TNF fire record covered fire occurrence over an extensive desert area. It provided ignition location, date, size, and cause. Because the record did not include size for fires that burn less than 0.11 ha (0.26 acres), we set the size of these fires at 0.05 ha so that their contribution to area burned would be included in our analysis. Fire history maps included in the record showed the areas burned by all fires ≥40 ha. We sorted fires by year, month, and cause and calculated total number, total area burned, mean number, and mean size.

Improved fire reporting after 1970 probably resulted in an increase in the number of small fires recorded. The reporting of hectares burned was probably affected less by reporting changes than number of fires, because large fires, which account for most hectares burned, would have been accurately reported throughout the period. Other errors might be present in the record because of the misassignment of fires to cause. This would be most likely for small fires for which only cursory investigation of causes was made.

Trends in yearly fire occurrence were tested by regressing each of the following variables on year: total number of fires, number of human-caused fires, number of lightning-caused fires, total hectares burned, number of hectares burned by human-caused fires, number of hectares burned by lightning-caused fires. We used logarithmic transformations of the data to maintain constant residual variance (Zar, 1984), and we tested the degree of autocorrelation in the yearly observations using the Durbin-Watson statistic (Ray, 1982).

We estimated the mean fire recurrence interval (I_O) for the TNF desert using the equation $I_O = A/b$, where A is the total desert area, and b is the mean area burned annually. We accounted for area of overlap among fires in the calculation of b by using the equation $b = (B-O)/T$, where B is the total area burned, O is the total area of overlap, and T is the length of the period. Using the fire history maps, we determined that the area of overlap was approximately 7% (0.24%/year) of the total area burned during the study period. Our method of calculating I_O assumed that there is no error associated with b. Annual area burned and annual area of overlap were highly variable. Additionally, the majority of human-caused fires occurred along roadsides, and we personally observed that they frequently overlapped one another. Because most of the fires were too small (<40 ha) to be shown on the fire-history maps, we could not measure their areas of overlap for use in calculating I_O. Fires <40 ha account for 9.4% of the total area burned. Interaction of these error sources makes calculation of the error of b impossible with a record so short as this one. For comparison we calculated the time required for an area equal to the TNF desert to burn using the simpler equation $I = (A/B)/T$, where A, B, and T are as previously defined.

RESULTS—During the 29 years of record, 1,611 fires occurred in the Arizona Upland portion of Tonto National Forest. These fires burned 41,447.4 ha total, averaging 1,429.2 ha/year (range of 0.0 ha/year to 7,946.3 ha/year), and 25.7 ha/fire (range of 0.04 ha/fire to 5180.16 ha/fire). Yearly patterns of occurrence are shown in Fig. 1. Whereas nearly two-thirds of these fires were set by people, lightning-caused fires burned almost twice as much area as did human-caused fires. Mean lightning-caused fire size (44.8 ha) was about three times that of mean human-caused fire size (14.9 ha). This relationship (the occurrence of a higher number of human-caused fires but a greater amount of area burned by lightning-caused fires) was true most years but was more consistent during the latter part of the period (Fig. 1).

The seasonal pattern of fire occurrence corresponds well with general climatic variations and human activity (Fig. 2). All fires during the cooler months of November through March were set by people, and only during July and August were lightning-caused fires more frequent than human-caused fires. The largest number of human-caused fires occurred during May. The largest area was burned during June by fires ignited by lightning.

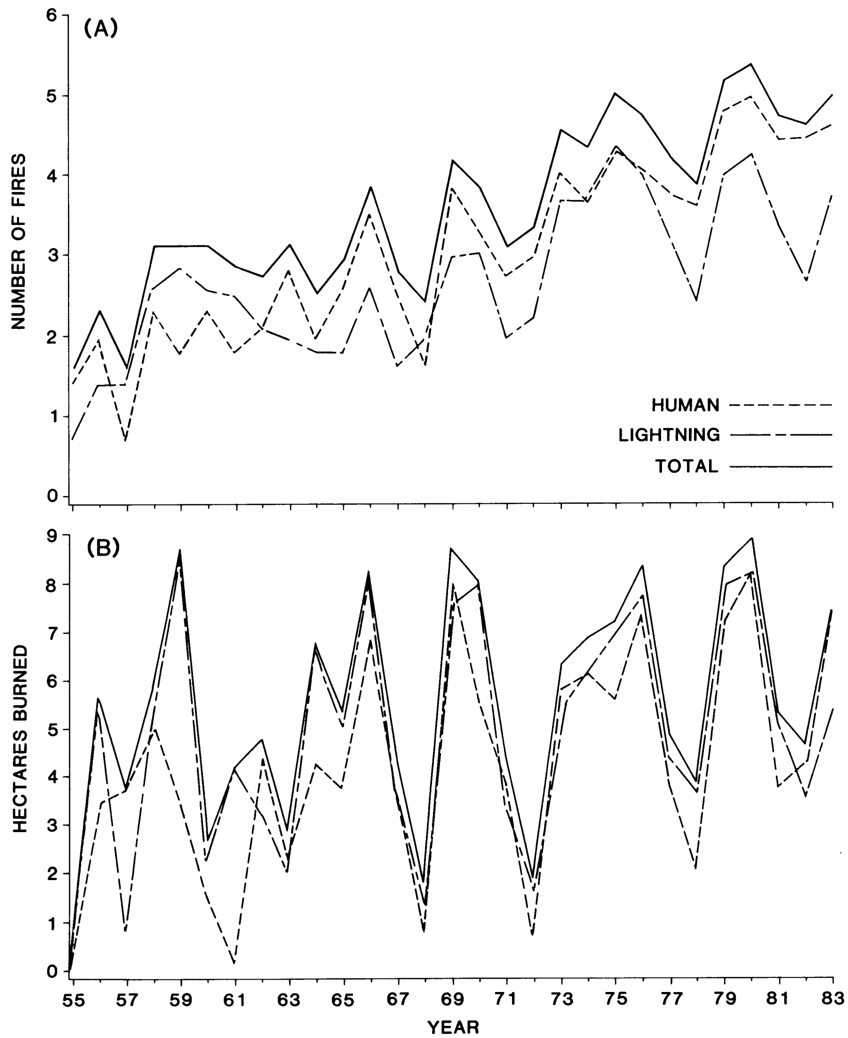

FIG. 1—Total log-transformed number of fires (A) and hectares burned (B) per year during the period 1955 to 1983 in the desert portion of Tonto National Forest, Arizona. Natural logarithms were used for convenience in scaling the graphs. They can be transformed to common logarithms ($\log_{10}$) by multiplying by 0.43429. Regression statistics are given in Table 1.

During the study period the annual number of both human-caused and lightning-caused fires and annual hectares burned by human-caused fires increased (Fig. 1, Table 1). The most striking increase occurred in the number of human-caused fires. Fire recurrence interval (I_O) for the TNF desert was 294 years (where A = 391,000 ha, B = 41,477 ha, O = 2,901 ha, and T = 29 years). The interval I was calculated as 274 years.

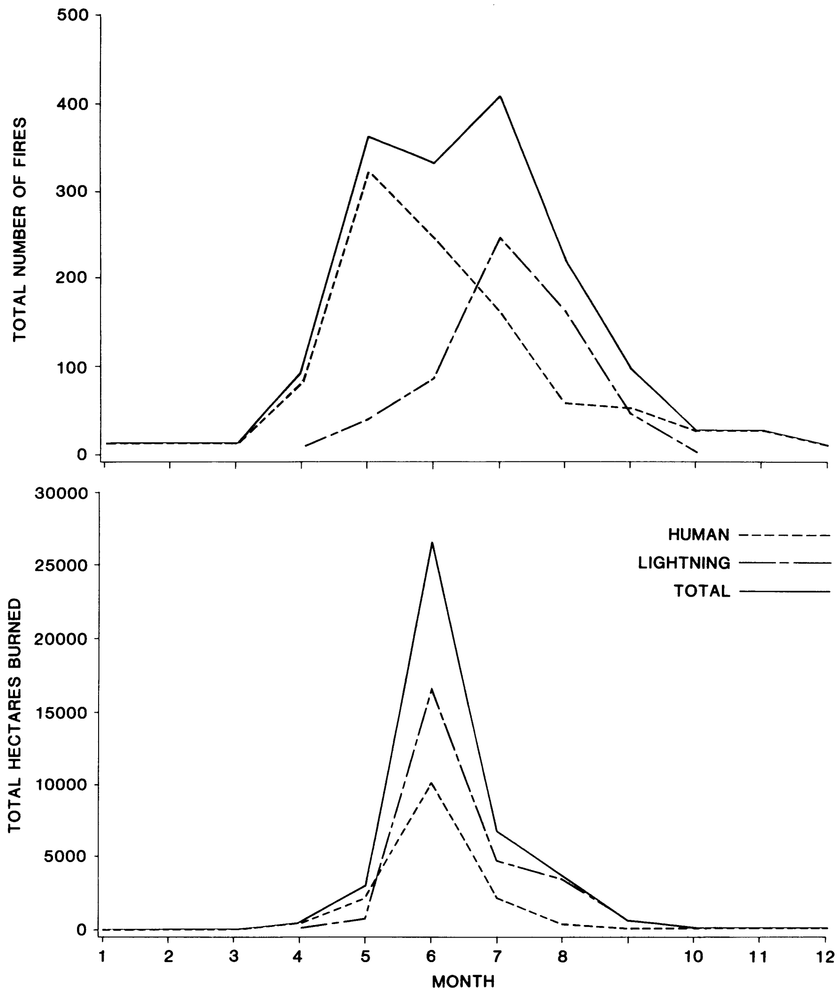

FIG. 2—Total number of fires (A) and hectares burned (B) per month (1 = January, 12 = December) for the period 1955 to 1983 in the desert portion of Tonto National Forest, Arizona.

DISCUSSION—One notable characteristic of fire in the TNF desert is that, although there were many more human-caused fires than lightning-caused fires, the lightning-caused fires were usually larger and burned many more hectares than did human-caused fires. We suggest several explanations for the small size of human-caused fires. They occur in places accessible to people, such as along roads and near campsites, and are therefore easily spotted and suppressed. Runoff from the surfaces of roads supports denser-than-normal vegetation along roadsides (Johnson et al., 1975), which is readily available for ignition by humans, but does not cover extensive areas of the desert. Potential human ignitions might be more numerous than lightning ignitions so that even small, isolated patches of dense fuel can be

TABLE 1—Trend analysis using regression with year as the independent variable. Statistical significance was tested using F for r^2, t for slope, and the Durbin-Watson statistic for autocorrelation. First-order autocorrelations are given.

Dependent variable[1]	n	adjusted r^2	Slope	Autocorrelation
Total number of fires	29	0.74*	0.11	0.05
Number human-caused	29	0.80*	0.12	−0.27
Number lightning-caused	29	0.50*	0.08	0.35*
Total hectares burned	29	0.10	0.10	−0.09
Hectares human-caused	29	0.19*	0.13*	−0.09
Hectares lightning-caused	29	0.08	0.09	−0.08

[1]Analyses were performed on natural logarithms of all variables.
*$P < 0.05$.

ignited by people, whereas such patches would less likely be ignited by lightning. Human-caused fires are ignited throughout the year with many occurring during cooler and wetter periods when the spread of fire is least likely.

The large size of lightning-caused fires might be attributable to dry thunderstorms occurring at the end of the spring drought when vegetation is most flammable, more lightning-caused fires than human-caused fires probably occurring in remote, inaccessible regions where they are not discovered or suppressed quickly, and thunderstorms usually accompanied by strong, gusty winds which spread fires ignited by lightning (e.g., Schroeder and Buck, 1970). Fire size might have been limited during the study period because of increasingly efficient fire detection and suppression by the U.S. Forest Service (Hirsch, 1962; Lindewich, 1972; Latham, 1983).

The temporal distribution of fires (Fig. 2) shows the influence of seasonal climate and human activity. Despite the fact that more fires occurred during both May and July, total area burned was largest during June. Dry conditions and lower, more comfortable, temperatures probably explain why the number of human-caused fires is high during May. Six artificial lakes in the TNF desert serve as foci for human visitors, and, because the desert lies between the large human population located in the lower valleys to the west and the cooler, higher altitude forests to the east, transient populations are large. During the period under study, visitors to TNF increased by more than 300% (Famighetti, 1984). Hot, dry conditions and high flammability of fuels leads to larger fire size during June. The start of the summer rainy season, with its typically dry thunderstorms, is reflected in the occurrence of the highest number of lightning-caused fires during July. The decrease of mean fire size and total area burned from July through September reflects the oneset of wet thunderstorms, increased humidity, and the subsequent decline in fuel flammability. The cooler, damper conditions from October through April, as well as the almost complete absence of lightning, explain the small size and low frequency of fires during this period.

A combination of factors might account for the increase in desert fire occurrence and the greater increase in annual number of fires than in annual area burned. Wetter-than-normal winters were more common toward the end of the period (Rogers and Vint, 1987), resulting in higher production of fine fuel by annual plants and greater fire occurrece. The similarity in trend of both human-caused and lightning-caused fires suggests that climate and fuel influence both. Introduced animals might have increased (Turner and Bowers, 1988), providing greater quantities of fuel than would have been produced by native annuals alone. This seems especially likely on roadsides (Johnson et al., 1975). Increased fire detection and reporting resulted in more small fires being recorded. Increase in number of human visitors resulted in an increase in small human-caused fires.

During the period 1955 to 1983, frequency of fires in the Arizona Upland portion of TNF was sufficiently low to support past impressions that natural fires in the Sonoran Desert are rare. During this period, however, the annual area burned increased. Although the increase in area burned in small (Fig. 1), it nevertheless results in a large decrease in the recurrence interval. This can be illustrated by comparing intervals (I_O) calculated using the first (1955 to 1969) and second (1970 to 1983) halves of the study period. The interval for the first half (340 years) is 50% longer than the interval for the second half (226 years). If this decrease in fire recurrence interval reflects an alteration in the desert fire regime due to changes in fuel and ignition sources, then changes in desert vegetation can be expected (Zedler et al., 1983; Rogers, 1985) unless fire protection increases.

There might be diminishing returns on the effectiveness of fire suppression. Rogers (1986) found that desert fires were as common as nondesert fires in TNF from 1955 to 1983. This might have been true because fire suppression efforts were less effective in the desert because of the greater abundance of fine fuels composed of dry annual plants that supported greater rates of fire spread.

Those portions of the desert that are accessible to humans are subject to greater risk of shortened fire recurrence intervals. Zedler et al. (1983) note that if the time between fires is too short to allow vegetation recovery, burning can result in relatively permanent changes. Rogers (1985) estimated that fire recurrence in the Arizona Upland every 30 years would lead to extinction of saguaro (*Cereus giganteus*), and he noted that areas almost devoid of perennial plants were becoming more common along roadsides in the Sonoran Desert. These changes might be encouraged by increases of annual plants. They might also be a result of fire-induced habitat changes. Potentially detrimental environmental changes that have been observed after single fires include reduced albedo and soil degradation due to reduced permeability, accelerated erosion, and changes in nutrient concentrations (Reynolds and Bohning, 1956; Adams et al., 1970; Wells et al., 1979; Cave, 1982).

Perhaps the most serious problem created by the introduction and spread of exotic annuals in western North America has been the resultant increase in fine fuel and fire frequency, particularly in arid regions (e.g., West, 1979). Exotic annuals have been observed to increase following fires at many desert locations thereby increasing the likelihood of fire recurrence (Beatley, 1966, 1969; Young et al., 1971; Young and Evans, 1973; Vogl, 1977*a*, 1977*b*; West, 1979, 1983; Rogers and Steele, 1980; Cave, 1982; Zedler et al., 1983). This results in a cycle of ecological degradation (Vogl, 1977*b*; West, 1979; Rogers, 1982) that reduces plant species diversity, structural diversity, and productivity. The positive trend in fire occurrence in the desert region of TNF might indicate that a similar cycle is developing in portions of the Sonoran Desert.

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Address of authors: (MKS) *4201 E. Monte Vista, K-107, Tucson, AZ 85721*; (GFR) *2997 South Connor Street, Salt Lake City, UT 84109*.