Journal of Arid Environments (1987) **13**, 47–52

Winter precipitation and fire in the Sonoran Desert

G. F. Rogers* & M. K. Vint*

Accepted 26 June 1985

Historical fire and climate records from the Arizona Upland portion of the Tonto National Forest were used to test the hypothesis that fires burn larger areas in the Sonoran Desert after two wet winters than after one. We found that many more hectares burn in years following two winters that are wetter than normal, than during any other years. We agree with other ecologists, that desert fire occurrence is probably related to increased production of winter annual plants, and we suggest ways that the relationship may be clarified.

Introduction

Fires in the Sonoran Desert are believed to be widespread only at times when above-normal production of annual herbs provides supplemental fuels (Cave, 1982; Humphrey, 1974; Lotan, Alexander *et al.*, 1981; McLaughlin & Bowers, 1982; O'Leary & Minnich, 1981; Rogers & Steele, 1980; Steenbergh & Lowe, 1983). The germination and growth of desert annuals varies with climate (Franz, 1977; Halvorson & Patten, 1975; Patten, 1978; Shreve, 1964). However, the relationship of climate and fire is complicated by several factors. Important among them is some form of serial dependency between climate and fuel production. U.S. Forest Service fire managers familiar with the desert, claim that this dependency results in highest fire occurrence following two wet years (J. Ewart, personal communication).

Bimodal rainfall in the Sonoran Desert produces two floristically distinct groups of annuals, one appearing in summer and the other in winter (Shreve, 1964; and see Vasek & Barbour, 1977). The total production by each group varies with the amount of precipitation (Shreve, 1964). Fine fuel derived from summer annuals may persist through winter months, but it seems reasonable to expect that winter annuals which complete growth just before the start of the summer fire season—thus remaining mostly unweathered, evenly distributed and, probably, especially flammable at the start of the fire season—serve as the chief source of fine fuel. McLaughlin & Bowers (1982) hypothesized that high fire occurrence follows two consecutive wetter-than-normal winters because increased production during one wet winter will result in above-normal seed reserves. A second consecutive wet winter then results in denser stands of annuals than a single wet winter, thus providing sufficient fuel for fires to spread.

Very little quantitative data on desert fire occurrence is available, and none has been published that tests whether occurrence is higher after two wet winters, or even whether there is any link at all between desert fires and climate. Here we use historical fire and climate records from the desert portion of the Tonto National Forest to determine whether or not fires are actually more common following two wet winters than after one.

* Geography Department, Columbia University, New York, NY 10027, U.S.A.

0140–1963/87/040047+06 $03.00/0

Study area and methods

Tonto National Forest includes approximately 1,194,000 ha, of which 380,000 ha is desert vegetation typical of the Arizona Upland subdivision of the Sonoran Desert (Shreve, 1964; Turner & Brown, 1982). Long-term (1938–77) mean annual precipitation in the desert portion of Tonto National Forest is approximately 33 cm, distributed unevenly, with approximately 60% falling during winter (Brazel & Ziriax, 1979; Hastings & Turner, 1965). Precipitation variability (measured by the coefficient of variation) is highest in June, and it is above the long-term average in April, May, October and January (Brazel & Ziriax, 1979). The southern boundary of the Tonto National Forest desert is 40 km north of the site studied by McLaughlin & Bowers (1982) (Fig. 1).

The Tonto National Forest fire record includes individual fire reports describing the location and size of all fires reported during the 29-year period 1955–83. The record is supplemented with fire history maps showing the boundaries of larger fires. The subset of desert fires was extracted from the record by plotting the location of each fire on vegetation maps of the region by Brown (1973) and Turner (1974). Further details of the methods used to identify desert fires are presented in Vint & Rogers (1987). In this paper we analyze

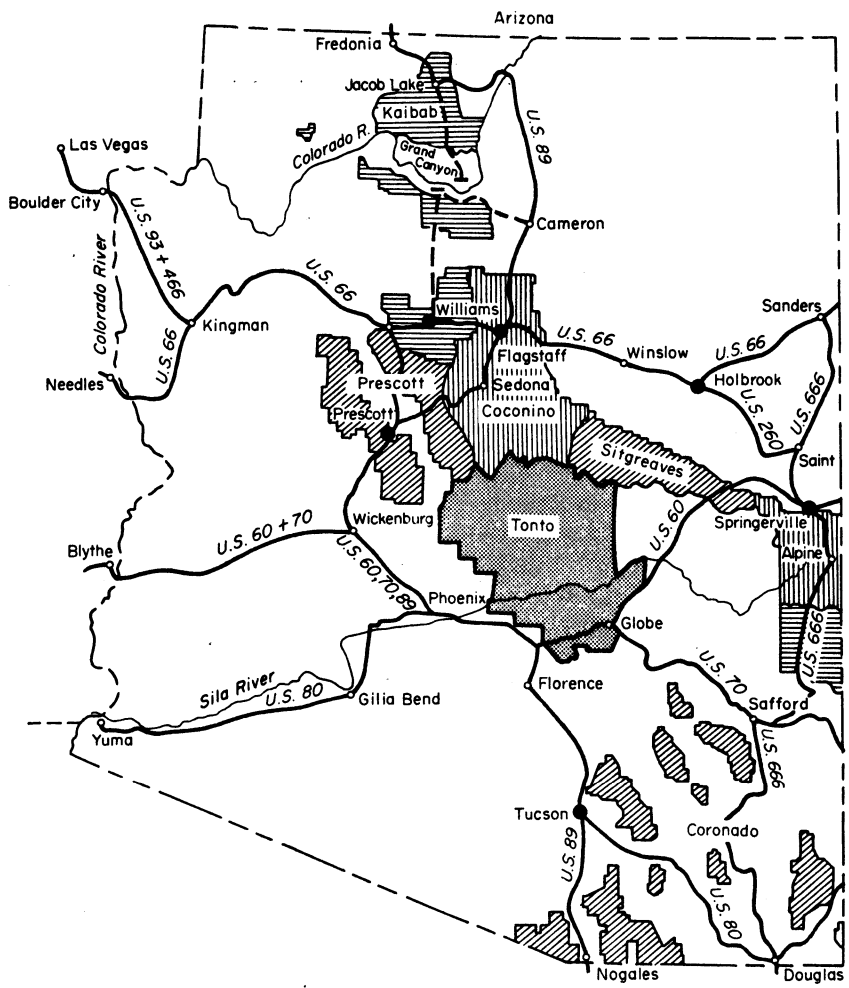

Figure 1. Tonto National Forest, Arizona (U.S. Forest Service, Southwestern Region, 1958).

only the annual total area burned. We do not consider the number of fires because many fires are small, especially accidental human-caused fires, and may occur independently of general fuel levels (Vint & Rogers, 1987).

We performed two separate analyses using first total winter precipitation, and then the moisture index (Thornthwaite, 1948) expressed as

$$Im = 100(P/PE - 1) \quad (1)$$

where P is precipitation and PE is potential evapotranspiration, to identify wet winters. The moisture index incorporates energy as well as moisture, and thus may be a better indicator of wetter-than-normal conditions than precipitation alone. Other indices have been developed (see reviews by Bordne and McGuinnes, 1973; Tuhkanen, 1980; Wallen, 1967), but most require radiation or other data not available to us. The tendency of the Thornthwaite method to underestimate PE in arid regions, because of elevated humidity near areas of irrigated agriculture or near oases (Major, 1977; Sellers, 1964; Shelton, 1978; Wallen, 1967), is unlikely to influence the present study because such areas are uncommon in the Tonto National Forest desert. It is also likely that general inaccuracies associated with the use of PE (and other indices) in arid regions are small when only the moist winter months of the Sonoran Desert are considered.

We used monthly precipitation totals and monthly mean temperatures for the winters 1953–54 through 1982–83 recorded at the Mormon Flat weather station (U.S. Department of Commerce, 1953–83) and the tables provided by Thornthwaite & Mather (1957) to calculate PE for use in Eqn (1). The Mormon Flat station is located approximately in the middle of the range of elevation in the desert area, and we believe that it is the most representative of the three stations within the study area having records for the period under study.

We chose the months November–March to represent 'winter' after reviewing works by Shreve (1964), Hastings & Turner (1965), Franz (1977), Brazel & Ziriax (1979), McLaughlin & Bowers (1982) and Turner & Brown (1982). November is a compromise between October and December, all three of which are suggested as the start of the winter rainy season. In the study area the coefficient of variation of monthly precipitation declines substantially in November (Brazel & Ziriax, 1979) and this, coupled with decreased temperature, supports Franz's (1977) conclusion that the growing season for winter annuals begins in November. We followed Shreve in choosing March as the end of the winter rains, because it provides a reasonable compromise between February and April, which are suggested by other authors as the last month of winter rainfall, and because the coefficient of variation for precipitation increased by over 50% in April (Brazel & Ziriax, 1979).

We estimated missing values of precipitation and temperature by using correlation analysis to determine which of the two other weather stations (Bartlett Dam and Roosevelt 1 WNW) most resembled Mormon Flat, and then used the regression equation formed by regressing Mormon Flat on the most similar station (Bartlett Dam, $r = 0{\cdot}78$) to calculate the missing values.

We defined wet winters for the separate analyses as those in which total Im and those in which total precipitation exceeded the mean for the study period. To evaluate whether or not fires were more common after two wet winters, two groups of yearly fire observations were formed and compared. The two groups were defined as those preceded by two consecutive wet winters, and those that were not. To make the comparisons, we used a one-tailed Mann–Whitney test (Ray, 1982; Zar, 1984) of the null hypothesis that the annual area burned was no greater in the years preceded by two wet winters than in all other years. We used the same test to compare the area burned following the pairs of wet winters, to the area burned following an equal number of the wettest single winters. We also compared area burned following the wettest single winters and for all other years minus the years preceded by two wet winters.

Results and discussion

During the 29-year study period, 1611 fires burned a total area of 41,447·6 ha in the Tonto National Forest desert. Mean winter Im was 268·8 (SD 485·1) and mean winter precipitation was 17·5 cm (SD 10·3). Tests of the hypotheses indicated that many more hectares burn in years following two wet winters than in any other years (Table 1). The test results were almost identical when either precipitation or Im was used to define wet winters. One additional pair of wet winters was identified when precipitation rather than Im was used but, because the level of fire occurrence was near the mean, the addition or subtraction of the single year had little effect. Only the results of the analysis of fire occurrence following two wet winters defined by Im are given in Table 1. Our analysis supports the positive relationship between two wetter-than-normal winters and increased desert fire occurrence that is accepted by Tonto National Forest fire managers, and predicted by the McLaughlin & Bowers hypothesis.

Our results highlight the need for research on the production of fuel by Sonoran Desert annuals. Additional research might evaluate the contribution of individual species to fuel production. In addition to static observations of the quantities of species present in particular cases, research might be directed toward underlying process including (i) measurement of the relative attrition rates of the seeds of various annuals (see Franz, 1977) and (ii) measurement of interspecific variations in relative durability (i.e. weathering resistance) of dead plants. Variable seed attrition rates might be strongly associated with changes in composition and relative abundance among annual species assemblages, and thus control the distribution of fuel quantities produced by each species. Variations in durability would indicate potential for providing carry-over fuels.

Summer annual fuel contributions might also be considered in further research. The abundance of summer annuals may vary from place to place, such that their fuel contribution equals that of winter annuals in some areas. In the Tonto National Forest desert, approximately 60% of annual precipitation falls during the 6 winter months (November–April) (Brazel & Ziriax, 1979; Hastings & Turner, 1965). This value declines

Table 1. *Comparison of annual hectares burned between groups of years defined by moisture index levels. Mann–Whitney t-test approximations were used for one-tailed tests of the hypothesis that fire occurrence was greatest in the first of each pair of groups below*

	n	Mean ± SE (range in parentheses)	p
Pair 1			
Two wet winters	4	4390·2±1116·4 (1956·4–7369·9)	
All others	25	955·5±342·8 (0·2–5811·5)	<0·05
Pair 2			
Two wet winters	4	4390·2±1116·4 (1956·4–7369·9)	
One wet winter	4	178·4±125·7 (12·3–551·0)	<0·05
Pair 3			
One wet winter	4	178·4±125·7 (12·3–551·0)	
All others (except years following two wet winters)	21	1103·5±400·8 (0·2–5811·5)	<0·05

to 45% on the southeast boundary of the Desert, about 180 km south of the study area. In addition, there is virtually no difference in the summer and winter coefficients of variation for precipitation in the study area (Brazel & Ziriax, 1979). Winter precipitation tends to be more variable elsewhere in the Sonoran Desert (Hastings & Turner, 1965). Thus the fuel contribution of summer annuals and the importance of summer precipitation, not considered here, may have a significant influence on desert fire occurrence at other desert locations.

Our study does not evaluate shorter-term (i.e. daily, weekly, monthly) timing of moisture and temperature levels that might be more critical for the germination and growth of annuals than the winter totals we used. Use of shorter intervals might lead to predictive models that account for more of the variability in annual hectares burned than is possible using winter totals. Successful models might be useful as sources of hypotheses about the interactions of annual production and climate, as well as tools for predicting annual fire occurrence potentials.

Fire has a catastrophic effect on desert vegetation. Few plants survive burning, and recovery is a slow process (McLaughlin & Bowers, 1982; O'Leary & Minnich, 1981; Rogers & Steele, 1980; Rogers, 1985). Fifty-six percent of the total hectares burned during the 29-year period studied, burned during the 5 years that followed two winters with above-normal precipitation. The periodic occurrence of pairs of wet winters, like catastrophic freezes (Bowers, 1981), may have had a significant effect on the development of contemporary desert vegetation.

Conclusion

During the period 1955–83, fires burned many more hectares in the 380,000 ha desert portion of the Tonto National Forest after two wet winters than after one. This finding supports the hypothesis of McLaughlin & Bowers (1982) that the production of winter annual plants is greatly enhanced by the occurrence of consecutive wet winters, and it indicates a need for additional research on the role of annual plants in determining desert fire regimes.

Jerry Ewart, Tim Bos and Tom Tillman of Tonto National Forest helped supply the necessary fire records, and Janice Bowers, Steve McLaughlin and John Robertson read and commented on the manuscript.

References

Bordne, E. F. & McGuinnes, J. L. (1973). Some procedures for calculating potential evapotranspiration. *Professional Geographer*, **25**: 22–28.

Bowers, J.E. (1981). Catastrophic freezes in the Sonoran Desert. *Desert Plants*, **2**: 232–236.

Brazel, A. J. & Ziriax, R. D. (1979). Monthly and seasonal variability of precipitation: Phoenix and environs. *Laboratory of Climatology, Arizona State University, Tempe*, AZ, *Climatological Publications, Scientific Paper* No. 10. 109 pp.

Brown, D. E. (1973). *The Natural Vegetative Communities of Arizona* (map). Phoenix, AZ: Arizona Resources Information.

Cave, G. H., III (1982). Ecological effects of fire in the upper Sonoran Desert. M.A. Thesis, Arizona State University, Tempe, AZ, U.S.A.

Franz, C. E. (1977). Seasonal dynamics of selected annuals of the Sonoran Desert. Ph.D. Dissertation, Arizona State University, Tempe, AZ, U.S.A.

Halvorson, W. L. & Patten, D. T. (1975). Productivity and flowering of winter ephemerals in relation to Sonoran Desert shrubs. *American Midland Naturalist*, **93**: 311–319.

Hastings, J. R. & Turner, R. M. (1965). *The Changing Mile; an Ecological Study of Vegetation Change with Time in the Lower Mile of an Arid and Semiarid Region.* Tucson, AZ: University of Arizona Press. 317 pp.

Humphrey, R. R. (1974). Fire in desert and desert grasslands of North America. In: Kozlowski, T. T. & Ahlgren, C. E. (Eds), *Fire and Ecosystems*. pp. 365–400. New York: Academic Press. 542 pp.

Lotan, J. E., Alexander, M. E., Arno, S. E., French, R. E., Langdon, O. G., Loomis, R. M., Norwin, R. A., Rothermel, R. C., Schmidt, W. C. & Von Wagtendonk, J. (1981). Effects of fire on flora: a state-of-the-knowledge review. *U.S. Forest Service, General Technical Report* WO–16. 71 pp.

Major, J. (1977). California climate in relation to vegetation. In: Barbour, M. & Major, J. (Eds), *Terrestrial Vegetation of California*. pp. 11–74. New York: John Wiley. 1002 pp.

McLaughlin, S. P. & Bowers, J. E. (1982). Effects of wildfire on a Sonoran Desert plant community. *Ecology*, **63**: 246–248.

O'Leary, J. F. & Minnich, R. A. (1981). Post fire recovery of creosote bush scrub vegetation in the western Colorado Desert. *Madrono*, **28**: 61–66.

Patten, D. T. (1978). Productivity and production efficiency of an upper Sonoran Desert ephemeral community. *American Journal of Botany*, **65**: 891–895.

Ray, A. A. (Ed.) (1982). *SAS User's Guide: Statistics*. Cary, NC: SAS Institute, Inc. 584 pp.

Rogers, G. F. (1985). Mortality of burned *Cereus giganteus*. *Ecology*, **66**: 630–632.

Rogers, G. F. & Steele, J. (1980). Sonoran Desert fire ecology. In: Stokes, M. A. & Dieterich, J. H. (Technical Coordinators), *Proceedings of the Fire History Workshop*. pp. 15–19. *U.S. Forest Service, General Technical Report* RM–81.

Sellers, W. D. (1964). Potential evapotranspiration in arid regions. *Journal of Applied Meteorology*, **3**:98–104.

Shelton, M. L. (1978). Calibrations for computing Thornthwaite's potential evapotranspiration in California. *Professional Geographer*, **30**: 389–396.

Shreve, F. (1964). Vegetation of the Sonoran Desert. In: Shreve, F. & Wiggins, I. L. (Eds), *Vegetation and Flora of the Sonoran Desert*. pp. 1–186. Stanford, CA: Stanford University Press. 1740 pp.

Steenbergh, W. F. & Lowe, C. H. (1983). Ecology of the saguaro. III. Growth and demography. *U.S. National Park Service, Scientific Monograph Series*, No. 17. 228 pp.

Thornthwaite, C. W. (1948). An approach toward a rational classification of climate. *Geographical Review*, **38**: 55–94.

Thornthwaite, C. W. & Mather, J. R. (1957). Instructions and tables for computing potential evapotranspiration and the water balance. *Publications in Climatology*, **10**: 185–311.

Tuhkanen, S. (1980). Climatic parameters and indices in plant geography. *Acta Phytogeographica Suecica*, **67**: 1–105.

Turner, R. M. (1974). *Map showing the Vegetation in the Phoenix Area, Arizona*. Denver, CO: U.S. Department of the Interior/U.S. Geological Survey.

Turner, R. M. & Brown, D. E. (1982). Sonoran Desert scrub. *Desert Plants*, **4**: 181–221.

U.S. Department of Commerce (1953–83). *Climatological Data, Arizona, Volumes 57–87*. Ashville, NC: National Climatic Data Center.

U.S. Forest Service, Southwestern Region (1958). *Recreation Map, Tonto National Forest, Arizona*. Washington, DC: U.S. Government Printing Office.

Vasek, F. C. & Barbour, M. G. (1977). Mojave desert scrub vegetation. In: Barbour, M. G. & Major J. (Eds), *Terrestrial Vegetation of California*. pp. 835–868. New York: John Wiley.

Vint, M. K. & Rogers, G. F. (1987). Trend in fire occurrence in the Arizona Upland subdivision of the Sonoran Desert, 1955–1983 (in preparation).

Wallen, C. C. (1967). Aridity definitions and their applicability. *Geografiska Annaler*, **49**: 367–384.

Zar, J. H. (1984). *Biostatistical Analysis*. Englewood Cliffs, NJ: Prentice-Hall. 718 pp.