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MORTALITY OF BURNED ***CEREUS GIGANTEUS***[1]

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Wildfire causes high rates of mortality in desert plant species (Rogers and Steele 1980, Wright 1980, McLaughlin and Bowers 1982). Some species partially recover by sprouting, but the immediate effect of fire is complete topkill (aboveground epidermal scorch) for most plants (Rogers and Steele 1980, O'Leary and Minnich 1981, Cave 1982, McLaughlin and Bowers 1982). High mortality is not surprising, because the small size (height) of most desert plants places them in the reach of the flames of even low-intensity fires (Alexander 1982). Moreover, many desert plants are highly flammable, and, once ignited, burn without additional fuel (Rogers and Steele 1980, Cave 1982). Recovery is largely dependent on seedling establishment. For species such as saguaro (*Cereus giganteus* Engelm.) that do not sprout or maintain seed reserves (Steenbergh and Lowe 1977), recovery is dependent on individual plant survival and seed dispersal from unburned plants.

At several locations in the Arizona Upland subdivision of the Sonoran Desert (Shreve 1964), fires accidently ignited by motorists have eliminated saguaro and many other desert perennials over large tracts adjacent to major roads. The decrease in diversity of form and quantity of plants is striking. An example of the effect of repeated fires over an extensive area of former desert scrub can be seen for several kilometres along Interstate Highway 17, south of the intersection with State Highway 74, north of Phoenix, Arizona. Saguaro appears to suffer high mortality from fire, and, if fire has increased in frequency, saguaro may have become endangered over portions of its range.

In a study of mortality resulting from the 11,500-ha Granite fire that occurred 29 June 1979 south of Florence, Arizona, McLaughlin and Bowers (1982) counted living and dead plants in two surveys conducted 7 mo and 19 mo after the fire. In the first survey they found total mortality (all size-classes combined) to be 57%. In the second survey they found total mortality to be 31% (McLaughlin and Bowers 1982). The observed decline seems to have been due to the disappearance of smaller plants observed to be dead at the time of the first survey. Limited published information (Steenbergh and Lowe 1977; 180; Rogers and Steele 1980, Cave 1982), and my personal observations suggest that saguaro mortality was underestimated by McLaughlin and Bowers because of the lag between injury and death. Saguaro is capable of flowering and producing seed for 9 yr or longer after a freeze that leads to death (Steenbergh and Lowe 1977), and it is likely that plants also remain standing after being mortally injured by fire. Thus, the low mortality rates observed by McLaughlin and Bowers are probably due to the relatively short time intervals (7 and 19 mo) between the fire and their observations.

I resurveyed saguaro mortality at the Granite fire site studied by McLaughlin and Bowers (1982). By comparing my observations, obtained 54 mo after the fire, with those of McLaughlin and Bowers, I confirmed that percent mortality determined 7 or 19 mo following fire underestimates true mortality, because deaths (as evidenced by plant collapse) continue for several years after burning. In a study of survival of individual plants, I found that topkill and mortality are related; this suggests that immediate postfire predictions of saguaro mortality based on observations of topkill are possible.

Methods

In January 1984, I estimated saguaro mortality at the Granite fire site by counting standing and collapsed plants in 40 2500-m^2 plots arranged in 10 contiguous 1-ha blocks of 4 plots each. I chose a location near the center of the burn that contained no unburned plants, and I recorded the location of the sample using compass heading and measured distance from a highway survey marker. Because small plants are easily overlooked (McLaughlin and Bowers 1982), I searched each plot carefully, paying special attention to brush piles beneath paloverde (*Cercidium microphyllum*) and other shrubs. It is possible that a few small saguaro were overlooked, and it is likely that some small plants killed by the fire had been removed by herbivores or had been weathered beyond recognition. I attempted to control for nonfire causes of mortality by noting excessively weathered saguaro skeletons that might have fallen before the fire. Two were observed. Plants that were mortally damaged before the fire and collapsed afterward could not be identified. When collapsed plants retained epidermis and spines I inspected them for fire scars. No unscarred plants were found.

To obtain information on the relationship between mortality and amount of topkill I conducted a survival study in which I made two observations of 52 individual plants in permanently marked plots. In November 1979, I recorded the location, height, and percent scorch of 38 saguaro growing on a rocky ridge north of the Granite site. The fire at this site occurred 27 July 1979, and burned 20 ha. In April 1980, I recorded the same information for 14 plants at the Granite fire site. In January 1984 I relocated these plants and recorded whether or not they were still standing. All tests of statistical significance were performed at the .05 level.

Results and Discussion

My observations suggest that saguaro mortality (plant collapse) continued beyond the 19 mo period of McLaughlin and Bowers (1982). Of 163 plants I located in the 10-ha sample taken 54 mo after the fire, 68% had collapsed. I constructed a contingency table for survivors and nonsurvivors 19 mo after fire (McLaughlin and Bowers 1982) and 54 mo after fire; the chi-square statistic indicates that mortality was not independent of observation time, and increased after the 19-mo survey. Similar tests indicate that the two surveys of McLaughlin and Bowers differed from each other in results, and that my 54-mo results did not differ from those of the 7-mo McLaughlin and Bowers survey.

Because of the likely disappearance of small plants, both my mortality estimates and those from the McLaughlin and Bowers 19-mo survey are probably low. In addition, many of the plants that still stand are badly burned and do not appear likely to survive. Although actual consumption of saguaro by fire is low, the survival of badly scorched plants may be questionable because of reduced vigor due to loss of photosynthetic surface area.

Fire is strongly implicated as the principal cause of saguaro mortality in this study. Of the 52 plants included in the survival study, all but 4 of the 28 that were <60% topkilled survived, yet only 6 of the 24 plants ≥60% topkilled survived; a chi-square test indicates that the probability that this occurred by chance is <.005. Cattle may have greater physical contact with plants from which spines have been removed by fire, and may contribute to plant collapse. Thus, collapse might only be indirectly linked to fire, and might vary with the presence of cattle.

Wilcoxon two-sample tests in three separate analyses indicated that in all cases survivors were less scorched than nonsurvivors. The analyses were performed on three groupings of the data: all plants ($N = 52$), plants >0% scorched ($N = 46$), and plants >0% and <100% scorched ($N = 36$).

Flame height is directly related to fire intensity (Byram 1959, Alexander 1982), and thus to mortality. Consequently, small plants may suffer greater mortality simply by virtue of their size. I evaluated the relationship between plant size and survival by testing the hypothesis that plant size was greater for suvivors than for nonsurvivors (Wilcoxon two-sample tests). The data were again organized in three sets as described above. I found that survivors were taller in the first two analyses, but the difference in height was not significant in the third analysis. I then measured the correlation between plant height and percent scorch using the same data groupings. In all cases the relationship was negative, but it was significant (Spearman rank-order correlation) only for nonsurvivors in the first two analyses ($r_s = -0.83$ for both). A larger sample is required for more complete testing.

I conclude that saguaro mortality, judged on the basis of plant consumption or collapse, cannot be accurately determined soon after fire because of delayed mortality, nor can it be accurately determined several years later because of attrition of small plants. At the Granite fire site, mortality after 7 mo was measured as 57%, and after 19 mo as 31% (McLaughlin and Bowers 1982), and after 54 mo I found it to be 68%. It is likely that the actual final value will exceed 85%. Reexamination of 52 plants disclosed a strong relationship between amount of topkill (epidermal scorch) and mortality. Both mortality and proportion of topkill are logically related to fire intensity (Byram 1959, Alexander 1982). I suggest that the proportion of topkill, or perhaps the amount of unscorched epidermis, might be used to predict saguaro mortality from observations made immediately following a fire.

The results of my study suggest that saguaro could be virtually eliminated by a sequence of fires that occur at intervals of <30 yr, because saguaro requires 30 yr to reach reproductive maturity (Steenbergh and Lowe 1977). Although mortally injured plants may continue to produce seed for several years after fire, the short fire interval would eliminate most newly established plants. Steenbergh and Lowe (1977) reported that plants growing on barren rock outcrops suffer little damage. However, it should be noted that although such sites may never produce much fine fuel from ephemeral herbs, some flammable shrub species are often present and may provide sufficient fuel to kill saguaro. The threat of local extinction is highest in areas of smooth topography such as the Granite fire site, where patches of unburned plants are not assured of protection from successive fires and where growing human access and use increases the possibility of human-caused fires.

Zedler et al. (1983) argue that arid succession is influenced more strongly by extreme environmental events than is mesic succession. Certainly this appears to be true for saguaro populations, for which death and establishment are controlled by climatic fluctuations in the form of catastrophic freezes, lightning strikes, periods of above- and below-average precipitation, and fires (Steenbergh and Lowe 1977, 1983). Zedler et al. (1983) further point out that traditional successional research has been more concerned with species interactions during periods between extreme events than with the changes caused by the events themselves. They suggest a greater focus on the spatiotemporal patterns of disturbances in arid lands, and emphasize the importance of sequences of events. A pair of fires, separated by an interval of a few years, can result in the local extinction of many desert species, including saguaro (Rogers and Steele 1980; G. F. Rogers, *personal observation*). Increased fire occurrence may permanently alter desert vegetation. Learning the nature of this alteration before it becomes too widespread is an immediate need for the management of fire and the conservation of desert vegetation.

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