Saguaros Under Siege: Invasive Species and Fire

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Abstract

Wildfires in the Arizona Upland subdivision of the Sonoran Desert, historically rare, are now expected after single or successive winters of above average precipitation. On May 8, 1994, a vehicle fire ignited the 1200 acre-Mother's Day Fire in Saguaro National Park. This moderate-intensity fire attracted not only public interest but also researchers interested in examining the effects of the fire on saguaros. Abundant winter rains can lead to prolific growth by the alien annual grass, red brome (*Bromus madritensis* ssp. *rubens*), which has been the cause of many serious fires in the northern Sonoran Desert. Red brome is currently the most widespread fuel source for desert wildfires, but buffelgrass (*Pennisetum ciliare* = *Cenchrus ciliaris*), a perennial African grass that was imported and developed to increase livestock forage, is rapidly increasing in abundance and represents a serious future threat. Buffelgrass is rapidly increasing its aerial extent, can produce standing fuel loads orders of magnitude greater than red brome in most years, and may burn in any season. In 1994, 436 saguaros were randomly located on transects on the Mother's Day Fire burn area and monitored for fire effects. In 1996, an additional 496 saguaros were permanently tagged in an adjacent unburned area with similar slope and aspect to the burned site. We established these plots to monitor the effect of fire on saguaros and other native vegetation at Saguaro National Park. We collected data on percent scorching, saguaro height, and mortality of saguaros in burned and unburned areas. We also re-located plots from a previous vegetation monitoring study that was burned in the Mother's Day Fire to determine mortality of four perennial plant species. Six percent of the saguaros sampled in the burned area were dead within 6 weeks of the fire and all of them were less than 1 m tall. The greatest losses were recorded in 1995, one year after the fire. Annual saguaro mortality in the burned area gradually dropped until it matched that of the unburned area. Saguaros in both burned and unburned areas showed a parallel increase in mortality during two years, coincident with a regional drought. We observed measurable losses of the saguaros due to fire and also due to inter-annual drought responses, indicating that fire has a negative effect on saguaro stands that is cumulative over the course of several years.

Introduction

Wildfire occurrence in the Arizona Upland subdivision of the Sonoran Desert has increased in recent decades, having been relatively uncommon prior to the late 1970s (Humphrey 1974, Rogers and Steele 1980, McLaughlin and Bowers 1982, Rogers and Vint 1987, Schmid and Rogers 1988, Swantek 1997, Brooks et al. 2000, Alford 2001). These fires are often associated with abundant alien annual grasses such as *Bromus madritensis* ssp. *rubens*. Alien annual grasses can have prolific production in years of average to above average precipitation (Steenbergh and Lowe 1977, Rogers and Steele 1980, Rogers and Vint 1987, Schmid and Rogers 1988, Esque and Schwalbe 2002, Alford 2001, Salo 2002, Esque et al. 2003). Increased fuels in the Arizona Upland of the Sonoran Desert also occur because of the alien perennial, buffelgrass (*Pennisetum ciliare*); Búrquez-Montijo et al. 2002, Haines et al. *In Review*). If buffelgrass distributions increase in backcountry areas, the risk of wildfire will increase substantially, as these grasses have much greater fuel loads than the alien annual grasses and they may burn in any month of the year (Hamilton and Scifres 1982, Hamilton 1985, McAuliffe 1995, Williams and Baruch 2000, Búrquez-Montijo et al. 2002, Haines et al. *In Review*). Once established, the annual or perennial alien grasses may contribute to a positive feedback system known as the grass/fire cycle (D'Antonio and Vitousek 1992) that can cause impoverishment in desert shrub lands of North America (Billings 1990).

The distribution of fires in the northern Sonoran Desert is mostly anthropogenic, occurring near highways, or in association with lightning strikes. Major conflagrations have occurred in the Arizona Upland of the Sonoran Desert near Florence, Arizona in 1979 (McLaughlin and Bowers 1982), on the south sides of the Santa Catalina Mountains in 1986 and the San Tan Mountains in 1987 (Esque et al. 2003), in the Rincon Mountains in 1993 (Esque and Schwalbe 2003), in the McDowell Mountains and Mazatzal Mountains in 1994, in the Harcuvar Mountains 1999, and again in parts of the Santa Catalina Mountains in 2003. In Mexico, fires are also frequent along major roadways, either by accidental ignition, or where people ignite fires to maintain roadside stands of buffelgrass for harvest of vegetation and seed. These fires tend to creep away from roadsides and into desertscrub and thornscrub plant communities, with deleterious effects to those biomes. Increased fire frequency can have a negative effect on saguaro populations because saguaros are easily damaged by fire (Steenburgh and Lowe 1977, McLaughlin

and Bowers 1982, Cave and Patten 1984, Rogers 1985, Thomas and Goodson 1992, Wilson et al. 1994, McAuliffe 1995, Esque and Schwalbe 2002, Narog and Wilson 2003). Previously, it was noted that there was a positive relationship between the amount of fire damage and saguaro mortality, and was suggested that accurately recording scorch damage to saguaros could be used to predict saguaro mortality (Rogers 1985). Indirect effects of increased fire frequency may reduce the density of shrubs and trees (Patton and Cave 1984) that provide favorable microsites for saguaro germination and establishment known as nurse plants (Turner et al. 1966, Despain 1974, Steenbergh and Lowe 1976, Nobel 1980, McAuliffe 1984, McAuliffe 1996).

On May 8, 1994, a vehicle fire ignited the 1200-acre Mother's Day Fire in the Rincon Mountains District of Saguaro National Park. That fire burned approximately 340 acres of Arizona Upland desertscrub. This fire was of moderate intensity due to the amount of fuel available and weather conditions. Following the Mother's Day Fire we established study plots to evaluate the effects of fire on mortality of saguaros in particular and of vegetation in the Arizona Upland subdivision of the Sonoran Desert in general. In this report we characterized the mortality rates of burned saguaros, compared rates of mortality for burned versus unburned saguaros, and report mortality for some other common desert plants.

Methods and Materials

Study Site

The study site was in the Rincon Mountain District of Saguaro National Park in Pima County, Arizona. The Mother's Day Fire occurred on the easternmost part of the Loop Road east of the visitor's center. The elevation of the study plots ranged between 840 and 1160 m. Soils are mostly very shallow decomposed granite interspersed by bedrock outcrops. An intermittent stream separates the burned study plot from the unburned study plot to the north. The vegetation community is Arizona Upland desert scrub characterized by a *Cercidium microphyllum-Carnegiea gigantea* community.

Saguaros

To examine the mortality of saguaros following a moderate intensity fire, we established transects in June 1994 one month after the Mother's Day Fire. The point-centered quarter method of transecting was used for most of our study plants (Cottam and Curtis 1956). Transects were placed in the burned area to the east of the Loop Road, running east to west and spaced at least 200 m apart, with transect lengths from 200 to 1800 m long. At every 200 m interval on these transects the closest saguaro within each of four directional quadrants (NE, SE, SW, and NW) was selected. Each saguaro was permanently marked with a uniquely numbered aluminum tag secured to a 30 cm spike that was hammered into the soil on the south side of the plant. Nine transects with a total of 208 saguaros were established using this method. Additional belt transects were established in the burned area from July 1994 through February 1995 by National Park Service personnel and volunteers. These transects were 10 m wide belts running parallel to the point-centered quarter transects at lengths from 95 to 1304 m, with a total of 5 transects and 228 additional tagged saguaros. With permission of the National Park Service, we incorporated these saguaros into our study to increase sample size, to a total of 436 saguaros. It should be noted that the goal of setting up transects was primarily to identify saguaros to monitor their survival over time, throughout the burned and unburned areas. Saguaro data on either transect type was used individually when the question or analysis required that the data be collected using one method. However, when possible we merged the data to increase the sample size. In February to May 1996, 13 point-centered quarter transects (496 saguaros on transects that were established using the same methods as described for the previous point-centered quarter transects) were established in an unburned area north of the Mother's Day Fire location to determine the mortality of saguaros in undisturbed habitat. The burned saguaros on point-centered quarter transects were also re-surveyed in 1995. After establishment, all transects were re-surveyed in 1996-1998 and 2000. Saguaro surveys were conducted June through August of each year.

For all saguaros we recorded: location, whether live or dead, evidence of re-growth and size class (≤1 m, >1m to 5 m, and >5 m). Only saguaros completely devoid of chlorophyll, or broken off at the base were considered to be dead. Saguaros that were identified as such were assumed to have died as a result of fire in 1994 because we observed that individuals that were apparently dead prior to 1994 (and thus severely dessicated) were all reduced to white ash. Saguaro locations were recorded with a geographic positioning system (GPS) unit (recorded using the NAD 1927 geodetic datum), distances were determined with transect tapes, and saguaro heights were measured using telescoping fiberglass poles. On burned transects we recorded the height and percent area of scorch damage, and height to which each saguaro was charred. We defined scorch damage as physical change in the color, surface texture or subsurface of the plant tissue. Charring was defined as incineration of plant material resulting in and characterized by black carbonized plant material, indicating a more intense level of damage to the saguaro than when they were scorched and usually only occurring on previously scarred surfaces (by prior fire damage or advanced age). Information on scorch and char damage was only recorded in the initial survey. If the saguaros survived, these signs of damage diminished with time.

Associated Vegetation

Five 30 by 30 m study plots were established by National Park Service personnel in 1994 to examine the effects of fire on perennial plants. All of these plots were burned in the Mother's Day Fire. The corners of these plots were marked by 30-cm spikes with brass identification tags. Data were collected on all *Carnegiea gigantea*, *Cercidium microphyllum*, *Ferocactus wislizeni*, and *Prosopis velutina* within these plots, including whether living or dead, percent area scorched, and height to which they were scorched or charred. We resurveyed these plots in 1997 and 2000 to record any change in status of each of the plants.

Design and Statistical Analysis

Study plots (burned versus unburned) were selected such that saguaro density, soil, slope and aspect were comparable. Because only one large fire occurred at Saguaro National Park in 1994, replication of the fire treatment was not possible. We used individual transects within the burned and unburned areas as replicates. Saguaro mortality was analyzed in analyses of variance (ANOVA) with a two-factor (fire, and size class) repeated measures (year) model (Littel et al. 1996). Mortality data for perennial plant species other than saguaros were also analyzed using a repeated measures ANOVA. Annual mortality was defined as, the number of saguaros that died in year t / the number of saguaros that survived as of year t-1. The assumptions for ANOVA were tested using the D'Agostino-Pearson Omnibus K2 Normality test (D'Agostino et al. 1990) and Levene's test for equal variance. Heteroscedastic data were log10-transformed to meet the assumption of equal variance (Box and Cox 1964).

To maximize the use of data generated from transects we used subsets of the data that were most suited to the analysis objective. For example, the most continuous data set about the mortality of burned saguaros was from point-quarter transects that were measured continuously from 1994 through 1998, and the belt transect data were not available in 1995, so they were not used in this analysis. In another instance we maximized the sample size of saguaros used with relatively equal numbers of saguaros in the burned versus unburned treatments, and we combined the data for point-quarter and belt-transects and excluded data from 1994 and 1995. Because subsets were used, simply tallying data from either of these graphs does not result in similar total values.

Results

One hundred and eight of the 436 saguaros we sampled (cumulative mortality 24.8%) were dead within six years of being exposed to the Mother's Day Fire in 1994. Annual mortality (1994 to 1998 and 2000) of saguaros burned in 1994 differed among years ($F_{5,35} = 12.56$, $P<0.0001$; Figure 1), with significantly greater mortality occurring within one year after the fire than any other year (Tukey's HSD with $\alpha = 0.05$). Averaging mortality of 1999 and 2000 does not affect the result because the total mortality of the two years combined was not statistically significant. There were also significant differences in saguaro mortality by size class ($F_{2,14} = 3.67$, $P = 0.052$), primarily because of higher mortalities among the smallest and largest saguaros. We did not observe any saguaros resprouting in the years following the fire, but some severely scarred terminal buds on saguaros continued to grow (Figure 2).

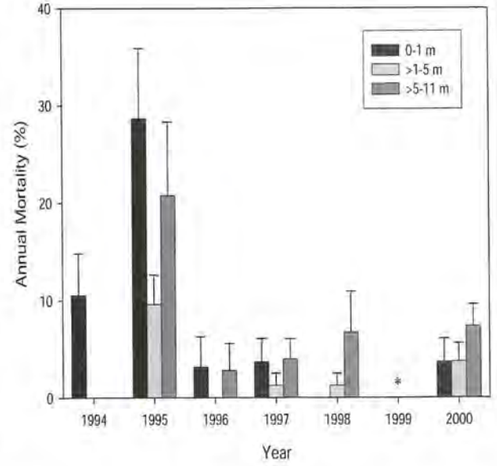

Figure 1. Annual mortality of burned saguaros in three size classes from 1994-2000. Asterisk (*) denotes an unsampled year. Bar height is mean across all transects, whiskers are one standard error.

Figure 2. Six years of recovery from fire on a medium-sized saguaro (< 2 m tall) that was damaged in the Mother's Day Fire on 8 May 1993. Note that the fire removed the spines from the lower portion of the plant, but several centimeters of vigorous new growth have occurred since the fire. (T. C. Esque)

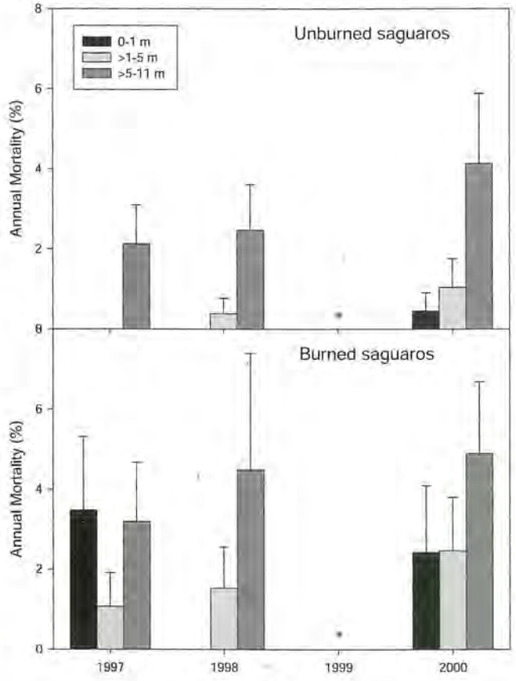

Figure 3. Comparison of annual saguaro mortality on unburned and burned areas beginning three years after the Mother's Day Fire. Mortality data are provided for saguaro size classes for 1997 through 2000. Asterisk (*) denotes an unsampled year. Bar heights are means across all transects; whiskers are one standard error.

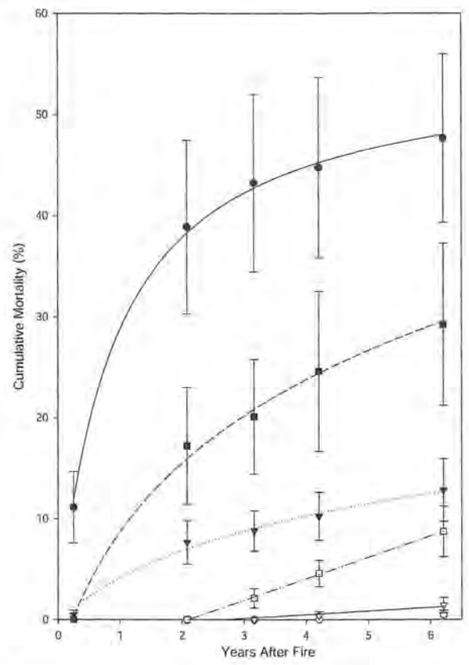

Figure 4. Cumulative mortality of saguaros subsequent to the Mother's Day Fire at Saguaro National Park in 1994. Regressions were made for each size class for each year. Open symbols represent saguaros on unburned transects; closed symbols, burned transects. Circles represent saguaros 0-1 m tall; triangles >1-5 m; squares, >5-11 m. Time '0' represents date of the fire and unburned transects were established 2 years post fire. No data were collected in year 5 (1999). No regression is completed for saguaros on unburned transects in the 0-1 m class, as none in that size class died in the first 2 years subsequent to unburned transects being established.

Saguaros burned in 1994 suffered significantly higher mortality in 1997, 1998, and 2000 than saguaros not exposed to fire ($F_{1,23} = 4.83$, $P = 0.038$; Figure 3). When annual mortality was compared for all size classes of saguaros on burned and unburned areas for 1997 through 2000, saguaros greater than 5 m tall had significantly greater mortality than those in the smaller size classes ($F_{2,46} = 8.89$, $P < 0.001$, Tukey's HSD at $\alpha = 0.05$).

Cumulative mortality of saguaros was very high initially, with the majority of saguaro mortality occurring within two years of the fire for all three size classes, after which annual mortality was similar between burned and unburned areas (Figure 4). The cumulative mortality of saguaros in all size classes in the burned area was logarithmic, with the cumulative rate slowing after two years. By comparison, the cumulative mortality rate of unburned saguaros in the middle and large size classes had a linear relationship with respect to year, indicating that annual mortality was relatively constant over the four years that unburned transects were studied. None of the unburned saguaros less than or equal to one meter tall died in the first two years after the unburned transects were established.

Damage by scorching was positively correlated with greater mortality of saguaros ($R^2 = 0.786$, $F_{1,8} = 34.1$, $P < 0.001$, Figure 5). Mortality of saguaros remained close to 20% when scorched up to about 60% but rose to 81% with 90-100% scorching.

Cumulative mortality of perennial plants on the vegetation plots was significantly different between species ($F_{3,48} = 21.72$, $P < 0.0001$, Figure 6). Mortality of the trees (*Cercidium microphyllum* and *Prosopis velutina*) was higher than the cacti (*Carnegiea gigantea* and *Ferocactus wislizeni*), but mortality did not differ between tree species or cactus species.

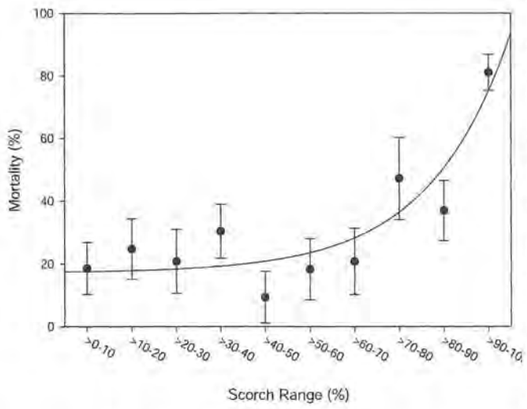

Figure 5. The relationship between percent area schorched and cumulative mortality of saguaros on burned transects six years after the 1994 Mother's Day Fire at Saguaro National Park. Circles are means of all burned transects; whiskers are ± one standard error.

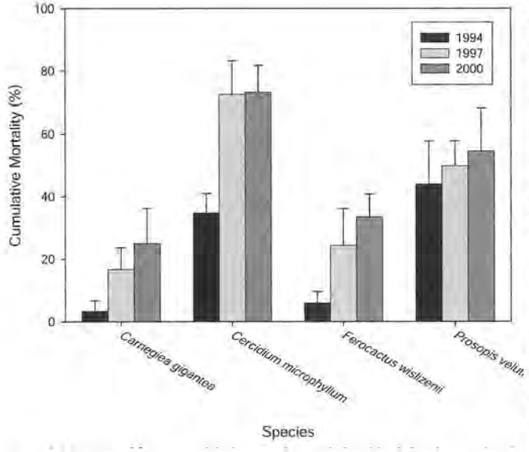

Figure 6. Mortality of four perennial plant species on National Park Service density plots in the Mother's Day Fire from 1994 to 2000. Bar heights are means of transects in the burned area; whiskers are one standard error.

Discussion

Fire and saguaro mortality: Our cumulative saguaro mortality following the Mother's Day Fire (24.8%) was not as high as that reported in other studies. On the Granite Burn near Florence, Arizona, 31% of the saguaros sampled were dead 19 months after the fire (McLaughlin and Bowers 1982), increasing to 68% 54 months post fire (Rogers 1985). Thirty-two per cent mortality was recorded in saguaros at South Mountain Park in Phoenix, Arizona, which had burned four times over the six-year period from 1981-1987 (Thomas and Goodson 1992). A ten-year study of the Vista View Fire in Tonto National Forest, Arizona also indicated a saguaro mortality of 32% (Narog and Wilson 2003). Reasons for these differences in saguaro mortality are unknown, but varying fire intensity likely plays a role, as well as, varying sizes of saguaros at the different fires, and length of post-fire follow-up. A short fire return interval, such as that seen at South Mountain Park, can cause local extinctions of saguaros (Rogers and Steele 1980, Rogers 1985).

Height in relation to saguaro mortality: It was difficult to compare mortality we observed in saguaros by height class, because we used different height classes than what was reported in previous work (McLaughlin and Bowers 1982). In their study, 19 months after a fire the mortality was the highest for short saguaros (58% for saguaros 0-40 cm tall), lowest for the tall saguaros (11% for saguaros >200 cm tall), and intermediate for mid-height saguaros (33% for saguaros 41-200 cm tall). Other observations indicate that saguaros less than 4 m tall do not survive when burned extensively, while larger saguaros are more likely to survive the same kind of damage (Cave and Patten 1984). We observed the highest mortality for saguaros less than 1 m tall, but the lowest mortality for mid-height saguaros (Figure 3). The saguaro mortality that we observed among size classes was similar to mortality observed in other, unburned populations, but the magnitude of mortality was greater in burned populations. In unburned populations of saguaros, Steenburgh and Lowe (1983) found that there was a high mortality for saguaros until they were at least 1 cm tall, then the mortality declined until the saguaros reached about 7 m tall, and above 7 m tall the mortality again increased. Pierson and Turner (1998) noticed a similar pattern. Our results are similar for both our burned and unburned saguaros. Minor differences in the mortality rates that we observed, compared to other research, may be because we defined mortality more strictly than other investigators and we left no room for doubt that plants were irrecoverably dead.

Drought and saguaro mortality: Our study reveals the importance of making a comparison of mortality in burned and adjacent unburned areas. As an example, the similar annual mortality of saguaros >5 m tall in burned and unburned areas in 2000 indicates that the mortality within this size class may be due to other factors, such as the extreme drought that the area was under at the time. Saguaros damaged or killed by high winds were observed in both burned and unburned study plots in Tonto National Forest (Narog and Wilson 2003), another indication of the importance of comparisons with unburned saguaros.

Scorch damage in relation to saguaro mortality: Consistent with our results, Rogers (1985) found that 4 of 28 saguaros with <60% scorching died, and 18 of 24 saguaros with ⊕ 60% scorching died. Our study determined that mortality could

be predicted based upon amount of scorching, as initially predicted by Rogers (1985).

The observations described here indicate that a moderate fire can have a substantial negative effect on stands of saguaros. During the relatively brief time that we have monitored burned and unburned saguaros, we observed large losses of saguaros against the background of drought. Invasive species, such as red brome, increase fuel loads, resulting in higher fire frequency and intensity. If active control methods are not successful at stopping the spread of the invasive exotic buffelgrass, that can provide an order of magnitude more fuel per area (Haines et al. *In Review*), it will likely increase losses of saguaros and other native plant species, to the detriment of the Arizona Upland of the Sonoran Desert.

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