

Burned Saguaro: Will They Live or Die?

Marcia G. Narog and Bonni M. Corcoran

USDA, Forest Service, Pacific Southwest Research Station, Riverside, California

Ruth C. Wilson

Department of Biology, California State University, San Bernardino, California

Abstract—Thousands of acres of giant saguaro (*Carnegiea gigantea*) habitat in the Sonoran Desert have been scorched by fire in recent decades. Resource managers struggle to maintain scenic landscapes featuring majestic saguaro faced with the challenges of fire, non-native species invasion, and recreational needs of millions of annual visitors. Successfully managing this iconic plant community requires understanding its fire resilience or intolerance. We compared survival of 162 saguaro 10 years after two wildfires on the Mesa Ranger District, Tonto National Forest, Arizona. Six 350-m point-quarter transects were randomly placed among burned and unburned areas. Four individual saguaro were measured at each of 8 points spaced 5 m apart along each transect. Ten years post-fire, high saguaro mortality and stunted growth were observed in both burns. Average saguaro mortality was 32% with apical height growth of 0.9 m after the Vista View fire compared to 51% and 0.6 m after the higher severity River fire. Unburned areas had 7% saguaro mortality and apical growth of 1.13 m. High compared to low fire severity burned areas nearly doubled saguaro mortality and stunted the growth of surviving saguaro by 30%. Our results suggest that maintaining strict fire prevention and suppression measures in high value saguaro habitat may be necessary to ensure that expansive vistas will continue to include this iconic cactus.

Introduction

Annually, about six million visitors travel to the Sonoran Desert on the Tonto National Forest, Arizona, to view a tourism favorite, the giant saguaro cactus (*Carnegiea gigantea*). Sadly, thousands of acres of this cactus's thorn-shrub vegetation community have been scorched by fire during the last 4 decades (Narog and others 1995). Because of its slow growth and great size at maturity, the saguaro and its habitat will take a century or more to return to their previous grandeur after fire. Presently, maintaining and restoring this ecosystem poses a multidimensional problem. Resource managers of the saguaro thorn-shrub habitat face challenges managing this ecosystem such as recurrent fire, uncertain saguaro retention and regeneration, invasion of non-native species (Cave and Patten 1984; D'Antonio and Vitousek 1992; Tellman 2002) and the recreational needs for millions of annual visitors.

Natural saguaro attrition and recruitment can be highly variable. Turner (1990) followed two different saguaro populations over 29 years that had 26 and 80% mortality; recruitment was correspondingly 11% vs. 76%. He found that episodic recruitment corresponded to heavy precipitation years. Humphrey (1984), and more recently Brooks and Pyke (2002), noted how effects of human activities, such as grazing, shortened fire return intervals, and increases in invasive plants, have reduced biodiversity in all North American deserts. High fire mortality and difficulties predicting future fire and climatic events

further complicate saguaro conservation. Comprehensive studies of the ecology and natural history of saguaro have been done (Pierson and Turner 1998; Robichaux 1999; Steenbergh and Lowe 1971, 1977, 1983; Turner and others 1995). However, long-term post-fire quantitative work using measures of fire injury, mortality and recovery for saguaro and other Sonoran Desert plants are poorly documented (Wilson and others 1995, 1996, 1998). Reasons why some fire-injured saguaro persist over time and survive while others perish still need to be determined. Recent research has included studies on the impacts of fire and invasive species on soil ecology (Steers and Allen 2011) and the use of GIS relational database management systems for fire history analysis (Swantek and others 1997). Broadening the knowledge and scope of environmental changes with an expanded database and increasing the resource tools available for measuring change in this thorn-shrub desert habitat will facilitate the understanding of fire impacts on saguaro and its ecosystem's response to burning.

We've been studying the long-term effects of fire on saguaro populations following two fires that burned thousands of hectares on the Mesa District, Tonto National Forest, Arizona (Narog and others 1995). During May 1993, the Vista View fire burned 1,200 ha (3,000 ac), including scenic vistas of saguaro along Highway 87. Nearby, during July 1995, about 4,047 ha (10,000 ac) of saguaro habitat burned in the high intensity River fire. Post-fire saguaro injury and mortality were apparent in both areas. However, why some burned saguaro lived and others died was not always clear (fig. 1). In this paper we present data on the growth and mortality of individual saguaro from the first 10 years after these two wildfires.

Methods

The 1993 Vista View and 1995 River wildfires charred saguaro habitat in an area known as The Rolls, near Four Peaks Road on the

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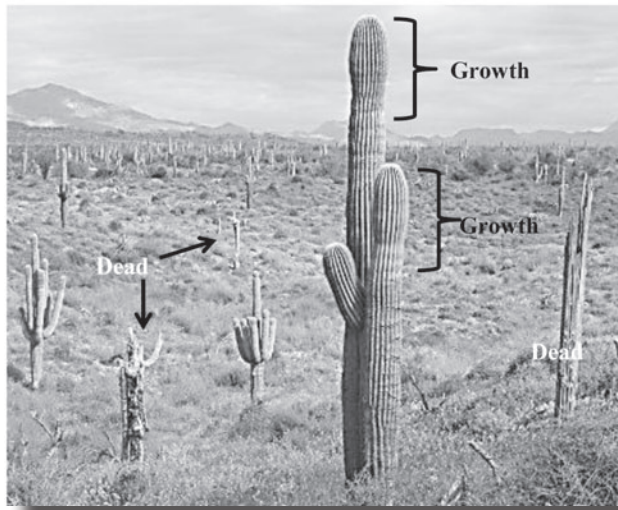


Figure 1—Some post-fire saguaro survived and grew while others nearby died. Photo was taken 10 years after the 1995 River Fire, Tonto National Forest, Arizona.

Tonto National Forest, Arizona (Wilson and others 1995). Saguaro measurement data were collected along six 350-m point-quarter line transects randomly placed in and near the two adjacent wildfires (one control and five within fire perimeters; fig. 2a). Transects were oriented north to south, and both burned and unburned saguaro plants were represented in the study population. Eight points, located at 50 m intervals, were sampled along each transect. At each point, the nearest saguaro in each quarter was chosen for measurement (fig. 2b). Saguaro dimensions, fire exposure, and mortality were documented over time for 162 individual saguaro. The saguaro is highly variable in the number of branching arms each plant has and the contributions that the arms give to the total biomass of each cactus. Therefore, to estimate how growth differed among the burned and unburned saguaro individuals, we simply used maximum height gain or loss for comparisons. Transects had different numbers of saguaro due to overlap from previous 50 m sample points, variable topography, irregular burn perimeters, and roads. Fire severity was defined after personal communications with fire fighters who fought the fires and the Tonto National Forest Resource Officer as well as personal observations made of fuel reduction on our post-fire study.

Individual cacti were remeasured at each successive visit to the study area. Unburned transects were measured in 1994, 1997, 2000, 2003 and 2005. Transects in the Vista View fire perimeter were visited in 1994, 1998, and 2003 (1, 5, and 10 years post-fire). The River fire transects were measured in 1997, 2000, and 2005 (2, 5, and 10 years post-fire).

Results

Data from unburned saguaro sampled from 1994 through 2005 are presented in table 1. Tables 2 and 3 show data from each saguaro exposed to fire over 10 years later. Transect 2 (fig. 2b) was unburned and had no recorded fire history. Some saguaro on Transect 3 escaped burning, but others were subjected to varying fire severity by the River fire. The River fire was less intense at its perimeter, which included part of Transect 3. More intense fire behavior was observed by fire personnel in Transect 4.5 (Kerr, personal communication).

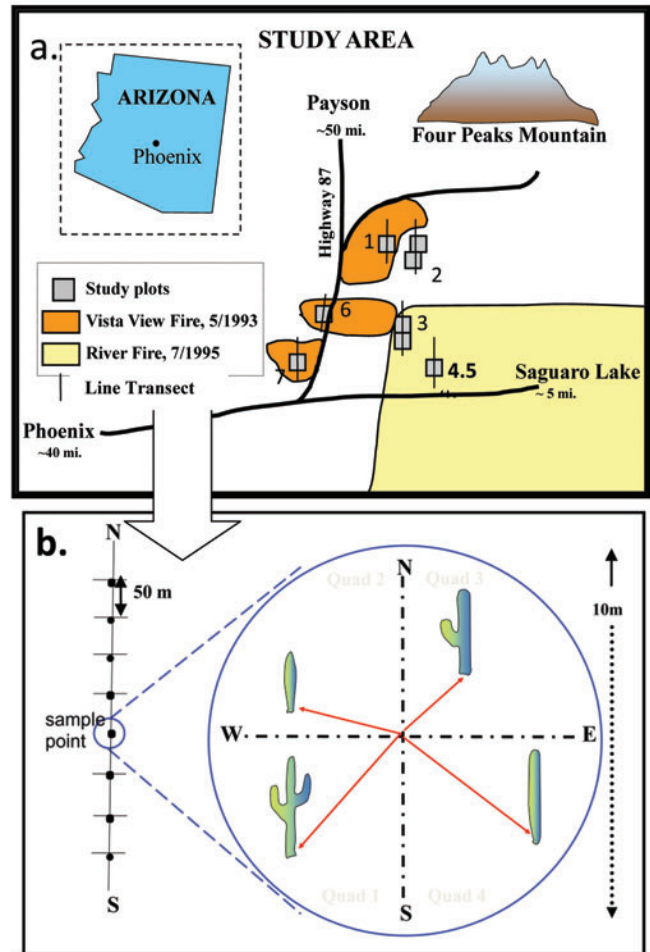


Figure 2—(a) Location of study and fire perimeters on the Mesa District, Tonto National Forest near Phoenix, Arizona. (b) Saguaro were sampled every 50 m along randomly placed 350-m transects in burned and unburned areas.

Observational assessment of fire intensity correlated well with the amount of fuel reduction found during our post-fire measurements. Transect 6 showed the greatest fire severity among the three transects burned in the Vista View fire (fig. 2a). Burn scar measurements on individual saguaro (Narog and Wilson unpublished data), in addition to the presence of abundant shrub and cactus skeletons, illustrated the lower intensity of the Vista View fire compared to most of the River fire.

Saguaro mortality and growth during the first 10 years after fire differed among the unburned, low fire severity, and high fire severity areas. We observed 7% mortality after 10 years of saguaro growing in unburned areas (table 4). Saguaro mortality was 5 to 10 times greater in burned than in unburned areas. Saguaro mortality for the three transects on the lower severity Vista View fire averaged 32%. Saguaro mortality varied on the River fire from 22% along Transect 3 (low severity area) to 77% for Transect 4.5 (high severity area) (table 4). Smaller saguaro had greater mortality than larger; most individuals less than 4 m in height did not survive either fire.

Height measurements of individual saguaro ranged from less than 1 m to over 10 m. Saguaro height growth averaged 1.1 m per plant over 10 years in the unburned area (table 1) compared to 0.9 m for saguaro burned in the Vista View fire (table 2) and 0.6 m for the River

Table 1—Ten year point-quarter data for unburned Transect 2 and the unburned portion of Transect 3 showing saguaro live and dead heights (m) measured between 1994 and 2005, Tonto National Forest, Arizona (N = 30).

Saguaro	1994		1997		2000		2003		2005	
	Live	Dead	Live	Dead	Live	Dead	Live	Dead	Live	Dead
2	6.5	--	7.0	--	7.1	--	7.2	--	7.4	--
23	6.5	--	5.8	--	6.2	--	6.4	--	6.4	--
24	2.4	--	2.9	--	3.5	--	3.8	--	4.2	--
25	3.2	--	3.4	--	4.2	--	4.5	--	4.8	--
26	3.8	--	4.0	--	4.4	--	4.6	--	4.8	--
27	6.5	--	7.5	--	8.7	--	9.0	--	9.2	--
28	5.4	--	6.1	--	6.3	--	6.7	--	7.3	--
29	8.5	--	9.0	--	9.5	--	10.1	--	10.4	--
212	7.0	--	8.0	--	8.2	--	8.5	--	8.6	--
213	4.8	--	3.5	--	3.5	--	3.5	--	3.7	--
216	7.0	--	7.7	--	7.8	--	8.1	--	8.3	--
217	6.5	--	7.3	--	7.5	--	8.0	--	8.2	--
220	5.0	--	5.6	--	5.8	--	6.0	--	6.0	--
222	4.5	--	4.8	--	5.1	--	5.1	--	5.4	--
223	4.0	--	4.7	--	5.2	--	6.2	--	6.0	--
224	0.8	--	1.1	--	1.5	--	1.8	--	2.2	--
225	7.0	--	7.7	--	7.6	--	7.8	--	8.1	--
227	6.0	--	6.1	--	6.5	--	6.4	--	3.7	--
228	3.8	--	4.1	--	4.8	--	5.2	--	5.8	--
229	2.4	--	3.3	--	4.2	--	4.6	--	5.0	--
230	5.0	--	5.7	--	6.0	--	6.2	--	6.6	--
232	5.5	--	6.3	--	6.1	--	6.4	--	6.7	--
221	3.6	--	3.6	--	--	3.2	--	3.3	--	3.1
21	--	2.5	--	2.5	--	--	--	--	--	--
333	5.5	--	6.0	--	6.2	--	--	--	7.4	--
335	2.0	--	2.3	--	2.9	--	--	--	3.6	--
336	2.1	--	3.4	--	3.4	--	--	--	4.2	--
342	4.5	--	4.7	--	5.1	--	--	--	5.5	--
350	3.7	--	4.2	--	4.9	--	--	--	6.1	--
358	7.7	--	7.3	--	7.7	--	--	--	8.1	--
Sum	141.2	2.5	153.1	2.5	159.9	3.2	136.1	3.3	173.7	3.1
Average	4.9		5.3		5.7		6.2		6.2	
Std dev	1.9		1.9		1.9		1.9		1.9	

fire (table 3). By 2005, only six saguaro on Transect 4.5 survived from the 1995 River fire. Based on remnants of burned saguaro found along Transect 4.5 immediately after the River fire, we determined that saguaro had an initial loss in height. They measured approximately 92 m in dead height compared with the 25 m of height of surviving saguaro. By 2005, the six remaining live saguaro had accumulated 6 m of additional height. After 10 years, about 80 m of remnant saguaro skeletons were no longer evident and had decomposed. Only 12 m of dead saguaro remained.

In the Vista View fire, saguaro final total live height (286 m) was less than initial cumulative live saguaro height (343 m). Wind toppled or blew tops off some damaged saguaro in the Vista View area. The cumulative height of dead saguaro at 1 and 5 years post-fire was similar, about 20 m.

Discussion

Our long-term post-fire study has followed individual saguaro for a decade. Some surviving saguaro cacti and associated plants still appear to be suffering adverse effects from fire, even after 10 years. Unlike other studies tracking saguaro longevity and growth, we focused on

fire-injured saguaro and associated vegetation in our observations. The desert thorn-shrub habitat had no recent documentation of fire effects on saguaro survival or mortality. Huge areas on the Tonto National Forest had recently burned when we initiated our study (Narog and others 1995). Subsequently, increasing public appreciation for desert vistas and early results from our study led to improved fire management. A change was made in policies at the national forest, state, and local levels that recognized the fire sensitivity of saguaro and its associated ecosystem (Hunt 1997; Narog and others 1999; Wilson and others 1995).

Short term saguaro mortality is only part of the story. After 10 years we discovered that saguaro were still dying from delayed effects of fire injury. Both short- and long-term saguaro mortality was higher in burned than in unburned areas of our study. Natural attrition in unburned sites was minimal; therefore, environmental anomalies and variable weather conditions would not account for the higher loss of saguaro or their reduced growth in burned areas. While saguaro showed long-term adverse effects from both low and high severity fires, they survived low fire severity better than high severity. Not all fire-injured saguaro died immediately after the fire (Narog and Wilson 2004): some persisted for longer periods of time, and others

Table 2—Ten year point-quarter data for Vista View fire burned Transects 1, 6 and 7 showing live and dead saguaro heights (m) measured between 1994 and 2003, Tonto National Forest, Arizona.

Saguaro	1994						1998						2003							
	Live		Dead		Live		Dead		Live		Dead		Live		Dead					
	T1	T6	T7	T1	T6	T7	T1	T6	T7	T1	T6	T7	T1	T6	T7	T1	T6	T7		
64	12	44	1.9	2.6	6.0	--	--	--	2.6	6.2	6.2	--	--	--	3.7	3.2	6.4	--		
11	32	83	6.5	4.0	3.3	--	--	--	6.5	5.8	3.3	--	--	--	3.2	4.6	3.8	--		
14	34	73	7.5	1.3	2.4	--	--	--	6.5	1.6	2.5	--	--	8.0	2.0	2.8	--			
44	41	11	5.5	6.3	3.1	--	--	--	6.2	6.1	3.5	--	--	6.4	3.6	4.0	--			
71	43	12	3.6	5.0	1.6	--	--	--	4.5	6.0	1.7	--	--	6.8	5.2	2.1	--			
13	52	13	8.5	5.0	5.8	--	--	--	7.0	5.2	7.3	--	--	8.0	6.4	8.0	--			
41	53	14	5.5	9.0	4.1	--	--	--	6.2	9.5	4.8	--	--	7.4	6.4	3.4	--			
51	61	22	8.5	1.4	8.0	--	--	--	8.5	1.4	7.5	--	--	8.7	1.4	6.2	--			
61	64	24	1.2	2.0	2.3	--	--	--	1.6	2.2	2.3	--	--	2.0	2.3	2.6	--			
12	71	34	8.0	2.3	4.0	--	--	--	7.2	2.5	4.2	--	--	8.3	3.1	5.7	--			
23	72	41	3.5	3.0	7.0	--	--	--	3.9	3.3	7.2	--	--	4.3	3.6	4.8	--			
24	73	51	4.5	3.8	4.2	--	--	--	5.1	4.0	4.3	--	--	5.7	4.6	5.4	--			
31	81	62	4.5	3.5	5.0	--	--	--	4.7	3.5	5.3	--	--	4.9	5.5	5.7	--			
33	22	63	4.5	5.5	5.9	--	--	--	5.1	6.9	5.8	--	--	6.6	--	4.2	6.9			
42	44	71	6.0	8.5	2.5	--	--	--	7.4	8.3	2.9	--	--	7.9	--	3.5	8.1			
52	51	72	6.5	8.5	8.0	--	--	--	7.1	5.9	8.0	--	--	7.8	--	3.8	5.1			
53	54	74	4.5	2.5	2.9	--	--	--	6.6	--	3.0	--	0.2	5.1	--	3.5	1.2			
54	11	81	6.5	--	4.0	--	2.5	--	7.2	--	4.2	--	2.3	7.5	--	4.8	3.9			
73	13	84	6.0	--	3.0	--	1.3	--	6.2	--	3.1	--	1.1	7.2	--	3.0	9.4			
81	14	31	7.0	--	5.3	--	0.5	--	5.2	--	5.5	--	0.5	8.9	--	--	2.5			
83	21	61	6.0	--	8.5	--	2.0	--	5.3	--	9.0	--	1.9	6.8	--	--	5.4			
84	23	33	4.3	--	6.5	--	0.8	--	3.6	--	6.4	--	0.4	5.4	--	--	2.5			
82	31	52	4.0	--	7.8	--	2.0	--	6.3	--	7.8	--	2.0	5.6	--	--	2.0			
34	82	53	3.1	--	13.0	--	0.5	--	3.6	--	13.0	--	0.6	4.1	--	--	12.5			
62	84	64	4.3	--	5.3	--	0.2	--	4.5	--	7.0	--	0.1	--	--	--	0.7			
22	83	21	2.5	--	4.8	--	0.3	--	2.5	--	--	--	0.7	--	--	--	--			
62	74	54	0.5	--	--	--	1.5	5.0	--	--	--	--	5.5	--	--	--	3.3			
21	--	--	--	--	--	2.6	--	--	--	--	--	--	3.0	--	--	--	0.4			
32	--	--	--	--	--	1.5	--	--	--	--	--	--	1.0	--	--	--	--			
Sum			134.9	74.1	134.2	4.1	11.6	5.0	141.1	74.8	135.8	4.7	9.0	6.2	150.3	51.9	83.7	4.8	60.2	40.8
Average			5.0	4.4	5.2	2.1	1.2	5.0	5.4	4.7	5.4	1.6	1.0	3.1	6.3	4.0	4.4	1.6	5.0	6.8
Std dev			2.1	2.5	2.5	0.8	0.8	0.0	1.7	2.4	2.6	1.3	0.8	3.4	1.9	1.6	1.5	1.7	3.6	2.1

*Transect 1: N = 29; Transect 6: N = 27; Transect 7: N = 27. Total N = 83.

Table 3—Ten year point-quarter data for River Fire burned Transects 3 and 4.5 showing live and dead saguaro heights (m) measured between 1997 and 2005, Tonto National Forest, Arizona (N = 26).

Saguaro	1997				2000				2005				
	Live		Dead		Live		Dead		Live		Dead		
	T3	T4.5	T3	T4.5	T3	T4.5	T3	T4.5	T3	T4.5	T3	T4.5	
34	2	4.1	5.8	--	--	4.6	6.5	--	--	5.3	6.7	--	--
38	3	1.8	4.5	--	--	2.2	5.2	--	--	2.8	5.6	--	--
39	5	6.8	4.0	--	--	7.2	4.4	--	--	7.9	5.1	--	--
43	21	4.0	2.3	--	--	4.4	3	--	--	4.7	3.5	--	--
44	28	6.2	4.5	--	--	6.3	5.2	--	--	6.5	6.0	--	--
45	32	7.4	3.9	--	--	7.5	4.2	--	--	7.8	4.5	--	--
46	1	6.3	3.2	--	--	6.8	3.4	--	--	7.1	--	--	0.8
47	11	4.4	6.2	--	--	5.1	6.5	--	--	5.8	--	--	2.0
48	7	6.0	3.7	--	--	5.2	--	--	1.7	6.6	--	--	1.5
49	10	4.4	3.9	--	--	5.1	--	--	1.1	5.8	--	--	1.2
52	17	3.8	4.6	--	--	4.1	--	--	--	4.8	--	--	1.2
54	22	9.8	4.2	--	--	10	--	--	1.5	10.2	--	--	1.5
55	9	8.0	3.3	--	--	8.4	--	--	1.5	8.8	--	--	--
56	13	5.2	8.3	--	--	5.3	--	--	4.1	5.9	--	--	--
57	16	2.3	8.3	--	--	2.4	--	--	3.5	2.8	--	--	--
59	24	3.4	7.5	--	--	3.5	--	--	7.5	3.8	--	--	--
62	4	5.5	--	--	2.4	5.9	--	--	2.3	6.5	--	--	2.3
64	8	5.5	--	--	1.7	5.9	--	--	1.6	6.4	--	--	1.6
63	12	5.0	--	--	0.6	--	--	1.5	0.6	--	--	1.5	--
51	25	--	--	0.6	2.9	--	--	0.6	2.7	--	--	--	--
60	26	--	--	0.4	4.1	--	--	0.4	2.9	--	--	--	--
40	15	--	--	1.5	3.9	--	--	--	--	--	--	--	--
41	20	--	--	0.3	0	--	--	--	--	--	--	--	--
	23	--	--	--	2.4	--	--	--	--	--	--	--	--
	27	--	--	--	1.9	--	--	--	--	--	--	--	--
	29	--	--	--	4.6	--	--	--	--	--	--	--	--
Sum		99.9	78.2	6.4	24.5	99.9	38.4	2.5	31.0	109.5	31.4	1.5	12.1
Average		5.3	4.9	1.6	2.5	5.6	4.8	0.8	2.6	6.1	5.2	1.5	1.5
Std dev		2.0	1.8	1.7	1.4	2.0	0.2	0.6	2	1.9	1.1	0.5	0.5

Table 4—Percent mortality among all saguaro plots unburned and burned after the River and Vista View wildfires, Tonto National Forest, Arizona. Note: Six unburned saguaro are from Transect (T) 3.

Transect	Live	Dead	% Dead
Unburned			
T2 & T3	28	2	7
Burned			
River T3	18	5	22
River T4.5	6	20	77
Vista View T1	24	5	17
Vista View T6	13	14	52
Vista View T7	19	8	30
Sum	80	52	
Average			39

ultimately perished. Our data show that 5 years after fire was not sufficient time to evaluate the impact of fire on the growth increments in fire-damaged plants or the ultimate fate of individuals from the burned saguaro populations. We hope to reassess the saguaro in this study at 20 years post-fire to determine whether further mortality has occurred and to see if height growth trends have changed since our last measurements.

Our results showed a loss and decomposition of nearly 80% of a healthy pre-burn saguaro population on one transect during the first 10 years following a wildfire. Narog and Wilson (2005) documented persistent loss of associated vegetation that can serve as nurse plants in all the burned areas on our study sites 10 years after the fires.

Turner and others (1966) found poor saguaro seedling establishment and survival when appropriate environmental conditions and nurse plants are lacking. Proactive restoration efforts for burned saguaro ecosystems may be needed particularly after high severity or short-interval repeated fire. Maintaining strict fire prevention and suppression measures in high value saguaro habitat may be necessary to ensure that expansive vistas continue to include these iconic cacti.

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