Effects of fire on Agave palmeri

EFFECTS OF FIRE ON *AGAVE PALMERI*

by

Roxane Jeannette Johnson

A Thesis Submitted to the Faculty of the

Department of Biochemistry and Molecular Biophysics

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE

WITH A MAJOR IN GENERAL BIOLOGY

In the Graduate College

THE UNIVERSITY OF ARIZONA

2001

UMI Number: 1407828

ProQuest Information and Learning Company
300 North Zeeb Road
P.O. Box 1346
Ann Arbor, MI 48106-1346

Statement by Author

This thesis has been submitted in partial fulfillment of requirements for an advanced degree at The University of Arizona and is deposited in the University Library to be made available to borrowers under the rules of the Library.

Breif quotations from this thesis are allowable without special permission, provided that accurate acknowledgment of source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the Graduate College when in his or her judgement the proposed use of the material is in the interest of scholarship. In all other instances, however, permission must be obtained from the author.

SIGNED: Roxanne J. Jack

16 November 2001
Guy R. McPherson — Date
Professor of Renewable Natural Resources

William A Calder — 16 Nov. 2001
William A. Calder — Date
Professor of Ecology and Evolutionary Biology

Katrina Mangin — 11/16/01
Katrina Mangin — Date
Outreach Coordinator for Ecology and Evolutionary Biology

David Gori — 16 Nov 2001
Dave Gori — Date
Director of Stewardship, The Nature Conservancy

Acknowledgments

I like to express my sincere gratitude to all of those that supported me on this journey. Thanks to The Nature Conservancy, especially Dave Gori, who trusted me with this research project, introduced me to the Muleshoe staff, gave me the gift of time and made me laugh. Thank you Dr. McPherson for your time, expertise, patience, humor, and encouragement. Thanks to Dr. Bill Calder and Dr. Katrina Mangin for your suggestions and ideas.

I am so appreciative of the volunteers who went out to the field with me: Jeff Brooks who the biting flies adored; Carolyn "Hot Tub" Harris; and Dana Backer and her side kick, Jasper. You guys made getting poked and jabbed by agaves something to laugh about.

Thanks to the Muleshoe staff, Bob, Susan, Wes and Mimi, for arranging for my transportation and accommodations while I was out in the field. Thanks Wes, for cleaning the hot tubs! Thanks also go out to Ed and Bob for black-lining my "no burn" plots.

Finally, thanks V. Your patience, understanding, and home-cooked meals during the writing stage were invaluable.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

I investigated the effects of prescribed fire on *Agave palmeri*, an important seasonal food source of the federally Endangered bat, *Leptonycteris curasoae yerbabuenae*. Three different treatments were randomly assigned to plots containing agaves within a burn unit: plots were burned with extant fuel, plots were left unburned, and plots were burned with an augmentation of fuel. Agaves were surveyed before the fires, immediately after the fires, and one and two years after the fires. Mortality and survivorship with the fuel load, agave size and the type of clusters in which the agaves grew. Agaves near mesquite and acacia trees or dead, dried agaves experienced higher mortality than agaves growing elsewhere. Agaves in plots with added fine fuels also had higher rates of mortality. One year post-fire, mortality was low in all treatments and recruitment was higher on augmented and burned plots than on unburned plots. Two years post-fire, mortality of small *Agave palmeri* was associated more strongly with rainfall than with fire treatment, while mortality of larger height classes of agaves exhibited a delayed response to fires.

CHAPTER I: INTRODUCTION

Agave palmeri Engelmann is a North American leaf succulent and one of the agaves commonly called the century plant. From the subgenus *Agave* and the group *Ditepalae*, *A. palmeri* is representative of species with candelabra-like inflorescence and clusters of flowers borne at the end of branches. Once in its life each plant sends a reproductive stalk many feet skyward, then dies. This stalk flowers in late summer and early fall in southeastern Arizona when bats of the genus *Leptonycteris* (subfamily *Glossophaginae*), who are anatomically structured for nectar lapping and pollen feeding, visit the chiropterophilous ("bat") flowers. Because the anatomical structures and behavioral adaptations of nectar-feeding bats and *Ditapalae* agave point to adaptive co-evolution and mutualism (Howell 1972, Gentry 1982, Fleming et. al. 1993), it was thought by ecologists that these bats were persistent specialized pollinators of the *Agave palmeri*. There has been some controversy in recent years about the level of dependency of these two species on each other. Several recent studies have more precisely defined the actual relationship between *A. palmeri* and these nectar-feeding bats.

A recent *A. palmeri* exclusion study found that a variety of animals are able to pollinate the agave through the "mess and soil" method, pollination that seems to occur randomly and is a less precise method of pollination. *Leptonycteris curasoae yerbabuenae* (*L. curasoae*) had a one to one ratio of pollen to stigma contact ensuring pollination with every contact (Slauson 2000). This same investigation found that *A. palmeri* was visited more often by diurnal pollinators such as honey bees, bumble bees, butterflies, and hummingbirds, than nocturnal pollinators such as bats and moths. Day-pollinated treatments had higher mean values in fruit set then night-pollinated treatments (Slauson 2000). This suggests that the relationship between *A. palmeri* and nectar-feeding bats is not a strictly "monogamous" one but rather that bats rely on the agaves for energy to a greater extent than the agaves rely on the bats for pollination (Slauson 2000). Because a single *A. palmeri* plant produces enough nectar to support approximately 1.5 bats throughout the summer season, and because the bats rely on it as a food source in southeastern Arizona, a reduction or fragmentation in *A. palmeri* populations could have a negative effect on the ability of *L. curasoae* to forage as bats would need to commute longer distances and/or compete with more bats for food (Ober 2000).

Since the listing of the nectarivorous and frugivorous lesser long-nosed bat, *L. curasoae* as an endangered species by the United States Fish and Wildlife Service (USFWS 1995) in September of 1988, there has been much controversy and scientific research surrounding this bat and one of its food sources, *A. palmeri* (Fleming et.al. 1993, Slauson 2000, Ober 2000). Because it eats pollen, nectar, and fruit of several species of paniculate agave and columnar cactus, and is involved to some extent in the reproduction of these unique desert plants, *L. curasoae* is considered a "keystone mutualist" in the southwestern deserts of the United States and Mexico (USFWS 1995). Furthermore, *Agave palmeri* is known to be *L. curasoae's* primary food source in the months it blooms, primarily late July through September in southeastern Arizona, so that the preservation of these plants and bat roosts associated with populations of these plants (along the "nectar corridor") have become a "Priority 1 Task" for the USFWS (USFWS 1995).

The Endangered Species Act directs federal agencies to carry out conservation programs for the benefit of threatened and endangered species. In response, the Lesser long-nosed bat Recovery Plan was written by the USFWS (USFWS 1995). Since *Agave palmeri* is a primary forage plant of the *L. curasoae* and its close relative, the Mexican long-nosed bat, *L. nivalis*, also listed as Endangered in September of 1988 and also in southeastern Arizona, *A. palmeri* is subject to Federal, State and Tribal land management activities (USFS 2000). Any land management practices that could fragment or destroy populations of *A. palmeri* must be considered by the United States Fish and Wildlife Service through the use of biological opinion statements and consultations. Relevant land use activities include livestock grazing, ammunition training (or other proposed actions) on military bases, and prescribed fires. While Section 9 of the Endangered Species Act prohibits taking or harming Endangered or Threatened species, the U.S. Forest Service goes further and defines harm to "include significant habitat modification or degradation that results in the death or injury to listed species by significantly impairing essential behavior patterns, including breeding, feeding, or sheltering" (USFS 2000). Because little is known about these land management activities and their effects on the reproduction, mortality, recruitment, and establishment of these plants in association with these activities, several federal agencies have identified the need for research that would better define the relationships of these activities to the ecology of *A. palmeri*.

Two studies in this region have attempted to answer some of the questions about agave mortality, survivorship, and recruitment after fire. Howell (1996) investigated fire effects on *A. palmeri* on Ft. Huachuca, an Army base in southeastern Arizona. Fire frequency of three to six fires per decade constrained sexual reproduction of agave and repeated fires biased agave demographics toward older age classes, suggesting younger (smaller) agave were less tolerant of fire than older (larger) agave. Effects of fire on agave recruitment were not studied.

Thomas and Goodson (1992) evaluated two predictions: 1) Succulents are intolerant of fire but avoid it by growing in refugia (rocky or sandy areas where little grass or other fine fuels grow), and 2) succulents can tolerate fire and have adapted to fire as a natural occurrence in the landscape. Meristems of succulent species are well protected and allow for post-burn growth from the apical meristem or from underground rhizomes. To evaluate their predictions, Thomas and Goodson recorded the percentage of living and dead succulents on burned sites and unburned sites and classified living plants on burned sites as surviving through apical growth, offshoot growth, both, or by evading the fire in refugia. Seven of fifty (14%) *A. palmeri* died on burnt sites, and none died on unburnt sites. Thirty-four of 41 (83%) *A. palmeri* living on the burnt site survived via regeneration of the apical meristem. Survivorship by evasion was 17%. In a greenhouse experiment with *Agave gigantensis*, leaf succulents were slightly more tolerant of simulated grassland fires than cacti and regrowth of these well-watered agaves took place from the apical meristem.

There are unpublished post-fire survivorship estimates for agave. Ongoing field research by the The Nature Conservancy (TNC) and U.S. Forest Service in the Pelloncillo mountains and the Canelo Hills of southeastern Arizona suggest mortality of agave after fire is about 10% (P.Warren, pers. comm.; D. Gori, pers. comm.). These studies are post-burn studies and assume visible leaf damage to agave is caused by fire. Health of the agaves or estimated fuel loads had not been established prior to the fires .

The use of fire as a restoration tool in semidesert grasslands of the southwestern U.S. has been explored for several decades (Griffith 1919, Humphrey 1951, Cable 1965,1967, White 1969, Martin 1975, Bock 1976, Wright 1980, Thomas 1992, Robinett 1994). Land managers in this region have begun widespread application of prescribed fire, in part because evidence indicates that wildfires occurred at least every ten years in the semi-desert grasslands before cattle were introduced (Wright & Bailey 1982, Bahre 1985, McPherson 1995), which would have constrained the encroachment of shrubs (Clark 1975, Wright 1980, Humphrey 1987, Bahre 1991).

Because of the importance of *A. palmeri* as a forage plant to the bats on the Endangered Species list and the questions land managers have about land-use practices and their effects on *A. palmeri*, this investigation was initiated to better understand the response of *Agave palmeri* to fire. Specific objectives were to (1) investigate effects of fire on *Agave palmeri* mortality and recruitment rates, (2) determine if this relationship is mediated by fuel abundance, (3) investigate mortality and survivorship relationships between agave size and fire treatment, and (4) investigate the relationship between agave mortality and neighboring vegetation.

CHAPTER II: PRESENT STUDY

METHODS

Study Area

The Muleshoe Ranch Cooperative Management Area (CMA) is part of a semi-desert grassland ecosystem straddling Cochise and Graham counties in the Galiuro Mountains of southeastern Arizona, about 45 kilometers northwest of Willcox, Arizona (32 15' N, 109 50' W). It contains approximately 20,235 hectares which comprise major portions of the Redfield, Hot Springs, and Cherry watersheds. It is jointly managed by the Bureau of Land Management (BLM), USDA Forest Service (USFS) and The Nature Conservancy (TNC). Before The Nature Conservancy purchased the Muleshoe Ranch in 1984 it was grazed by cattle. Livestock grazing has since been suspended on all portions of the CMA to allow recovery of perennial grasses. Large-scale prescribed burns have been implemented there since 1995 to reduce shrubs and increase grass cover, thereby improving watershed condition (BLM 1998, Brunson et al. 2001).

The Muleshoe Ranch CMA is located in the transition zone of the Sonoran and Chihuahuan deserts. The vegetation of the area consists of perennial grasses such as sideoat grama (*Bouteloua curtipendula*), black grama (*Bouteloua eriopoda*), purple grama (*Bouteloua radicosa.*), curly mesquite (*Hilaria belangeri*), bush muhly (*Muhlenburgia porteri*), plains lovegrass (*Eragrostis intermedia*), cane beardgrass (*Bothriochloa barbinodis*), and various threeawns (*Aristida longiseta, Aristida purpurea, Aristida ternipes*). There is some intermixing of succulent species such as amole (*Agave shottii*), century plant (*Agave palmeri*), and beargrass (*Nolina microcarpa*). Woody shrubs such as mesquite (*Prosopis velutina*), juniper (*Juniperus erythrocarpa*), white thorn acacia (*Acacia constricta*), cat-claw acacia (*A. greggii*), wait-a-minute bush (*Mimosa biuncifera*), and smaller shrubs such as snakeweed (*Gutierrezia sarothrae*), Wright's buckwheat (*Eriogonum wrightii*), and burro bush (*Isocoma tenuisecta*) are common on the CMA as they are on other shrub-invaded grassland sites in southern Arizona (Humphrey 1987, Bahre 1991), giving the appearance of a desert scrub aspect rather than a grassland aspect.

Two nectar feeding bats, the lesser long-nosed bat, and the sympatric Mexican long-tongued bat (*Choeronycteris mexicana* Tschudi), were captured in July of 2000 on the Muleshoe Ranch CMA. Radio transmitter collars were placed on the two male bats. The bats were then followed to a roost on in Redfield Canyon within a mile of the agave sites in this study. No population counts were obtained (T. Snow, pers. comm.), but the captures suggests that there is a population of these bats that feed from these agaves.

Pre-burn Agave Inventory

In May of 1998, four sites were established each containing at least 75 agaves. Three of these sites, Redfield Canyon Road (32°25' N, 110°16' W; 1382 m elevation), Redfield Canyon Upslope (32°25' N, 110°16' W; 1400 m elevation), and Bearscat (32°24' N, 110°16' W; 1405 m elevation) were measured and flagged, creating a grid with 25, 100- m^2 plots. The fourth site, Pride (32°25' N, 110°16' W; 1413 m elevation) is a 50 m by 25 m site divided into ten, 100- m^2 plots and 5, 10 m by 5 m plots. Once plots were measured and flagged, height and diameter of all agaves in each plot were recorded. Pre-burn condition of each agave was categorized as 0 (no damage to any leaf), 1 (slight damage to some leaves, but no leaves are dead), 2 (fewer than 50% leaves were dead and other leaves were damaged), 3 (more than 50% of the leaves were dead and other leaves were damaged), 4 (all leaves were dead although the apical meristem remained green), 5 (all leaves were dead, dry and tan and the apical meristem, if green, could be lifted out due to rot, but the plant still maintained its form), or 6 (the agave was currently flowering or had flowered and a stalk was still attached).

Once all plants were inventoried, I categorized them into three different size classes to determine which plots would receive which treatment. To determine if agave survivorship after fire was due to the size of the agaves it was important that nearly 50 of each height class fell into each of the three treatment categories (burn, no burn, burn with augmentation). The height class divisions prior to the burn were: 1 = 1-20 cm; 2 = 21-42 cm; and 3 > 42 cm. I then determined how many agave plants of each height class were on each plot for each site. Plots with fewer than 5 plants were excluded from the experiment but were monitored. Site by site, ranked lists of the plots were made based on the number of agave in each plot. The numbers of the plots that qualified for the experiment were arranged in descending order and placed into consecutive triplets based on the number of agaves in each plot. The plots were then drawn randomly from triplets and assigned a treatment: the first drawn from each triplet was a plot to be burned with added fine fuel;

the second drawn was a plot to be burned with extant fine fuel; the third drawn was a plot to be left unburned. Thirty-six plots from the 4 different sites were included in the experiment (Table 1.1). The remaining plots were all burned with extant fuel and monitored.

One week prior to ignition 20, 1-m^2 quadrats were clipped from each site to determine their fuel load. Each bag of fine fuel was oven-dried for 2 days at 21 °C, then weighed. For the fuel augmentation treatment, fine fuel was clipped from outside the burn unit, bagged, weighed and added to plots assigned to this treatment (Table 1.2). On-site inspection by a range conservationist from the Cochise County, Arizona office of the National Resources Conservation Service (NRCS) confirmed Redfield Canyon Road (RCR) and Redfield Canyon Upland (RUP) sites as loamy upland ecological sites and the Bearscat (Bear) and Big Pride Slope (Pride) sites as volcanic hills ecological sites. The quantity of the fine fuel added in the augmented plots was based on United States Department of Agriculture (USDA) soil survey range site descriptions that predict in years with very high productivity, approximately 1500 lbs/acre of fine fuel will grow on loamy upland sites (SCS site # 041xc313AZ) and 1800 lbs/acre of fine fuel on volcanic hills sites (SCS site# 041xc323AZ) that receive 30.48-40.64 cm of annual precipitation at 1370-1830 m elevation (USDA 1988). This corresponds to 16.8 kg of fine fuel in a 100-m^2 plot on loamy upland sites and 20.2 kg of fine fuel in a 100-m^2 plot on volcanic hills sites. On the augmented fuel plots, original fuel quantity (determined using the comparative yield method) plus added fuel equaled total fuel amounts (Ruyle 1987).

Augmentation was done June 21, one day before ignition. Remaining plots were neither clipped nor augmented.

All plots were burned 22-24 June 1998. Immediately prior to the burning of each site, approximately 50 g - 100 g of fine fuel was clipped from inside the plots that would remained unburned and weighed. These samples were later oven-dried and re-weighed to determine fine fuel moisture content. Temperature, relative humidity and wind speed were recorded at the time of burning (Table 1.3).

Post-burn Agave Demography

All agaves on all sites were inventoried again for height, diameter, condition, and cluster type two weeks post-fire, one year post-fire and two years post-fire. After the agaves had been inventoried for the third time, one year post-burn (July 1999), a distribution analysis was performed to determine the height of agave that had recruited within one year of the burn. To do this, I used data from only plots that had been burned (from both experimental and monitored plots) and that had only living agaves > 22 cm tall two weeks after the burn (July 1998). I then counted all agaves < 21 cm in height in these plots in July 1999 assuming they had germinated or been reproduced vegetatively since July 1998. There were 125 of these plants ranging from 1-12 cm in height; the mean height was 5.3 cm + 2.3 (S.D) with 75% < 7 cm. Based on this analysis, I operationally defined post-burn recruits in July 1999 (time 3) as agaves < 7 cm tall, and in April 2000 (time 4), as agaves < 14 cm tall. This allows for a conservative estimate of the number of recruits in July 1999 and April 2000. To distinguish recruits from other agaves, and to determine the differential effects of fire on agaves of different height classes, the height-class category was further divided into five levels for post-burn surveys: 1-7 cm = 1; 8-21 cm = 2; 22-44 cm = 3; 45-79 cm = 4; and 80 cm and above = 5.

The cluster-type category acknowledges that fuel load and fire intensity are elevated in the proximity of agaves growing near shrubs such as mesquite and acacia, or other dead or living agaves. If an agave was within 50 cm of the base of a mesquite trunk, then it was classified as a mesquite cluster (cluster type 1). If the agave was within 20 cm of another living agave it was classified as an agave cluster (cluster type 4). If the agave was within 20 cm of a dried, dead agave carcass it was classified as a dead agave cluster (cluster type 2). If an agave was growing with both mesquite and dried, dead agave it was classified as a mesquite/agave cluster (cluster type 3). If the agave was not near any other shrub or agaves, it was not considered part of a cluster (cluster type 0). If, post-burn, there was evidence of dried, agave carcass ashes, they were noted and the agave was assigned to cluster type 2. (The signature of ashes of dead, dried agave are very distinct; they are a bright, white/grey, in a circle, found at the base of other living, but burned, agave. The ashes retain the shape of the leaves.)

I noted the flowering condition of the agaves during July 1999, one-year post-fire. Categories included flowering current year, flowered previous year, not flowering, and terminated by herbivory on the inflorescence. Some agave stalks were browsed as they bolted, before they bloomed, probably by deer (Widmer and McClaran 2001).

Statistical Analyses

All statistical analyses were conducted using JMP IN 3.2 for Windows (SAS Institute, 1996). Mortality, survivorship and recruitment data were tested for normality using the Shapiro-Wilk W statistic. Data were often non-normal and heteroscedastic even after arcsine and log transformations. Thus data were ranked before subsequent analysis (Zar 1984). To test the effect of treatment on the number of agave living, and the mortality and recruitment of agave after the fires, data were analyzed separately after each of the three surveys; treatment was treated as a fixed effect, and site was nested within treatment as a random effect in ANOVA models. To test the effect of treatment throughout successive surveys, repeated-measures MANOVA models were performed with the same fixed, nested, and random effects. Wilcoxon Kruskal/Wallis (rank sums) test were used to determine differences in mortality between size classes and between treatments for each of the 3 post-burn surveys (Sall and Lehman 1996).

To test the effect of cluster type on mortality, analyses were preformed on just those plots that were burned or augmented. Data were analyzed separately after each of the three surveys; cluster type was treated as a fixed effect in ANOVA models. Wilcoxon Kruskal/Wallis tests were used as non parametric paired t-tests to determine differences in mortality between cluster types, between height classes, and between treatments for each of the 3 post-burn surveys.

Since the Muleshoe Ranch Remote Automated Weather Station (RAWS) was not functioning one year post-burn, a comparative analysis was done between precipitation at

Muleshoe Ranch and Willcox, Arizona using eleven years of data (1988-2000, excluding 1999). Pearson product-moment correlation coefficients were calculated to determine the association between precipitation at the two locations. Linear fit equations were calculated for each month using regression analysis to derive precipitation amounts for each month of the missing year (1999). These amounts were then included in a 12-year seasonal analysis of rainfall on the Muleshoe Ranch where average rainfall was calculated using the three months of that season from 1988-2000. Taking into account regional rainfall patterns, winter included the months of December (of the previous year), January, and February; spring included the months of March, April and May; summer included the months of June, July, and August; fall included the months of September, October, and November. The long-term average rainfall was found for each season and compared to the four seasons of the year of the burn and for the two years following the burn. The percent deviation was calculated from this comparison (Figure 1).

RESULTS

Pre-burn Agave Inventory

Before the fires, over 650 agaves were inventoried on all four sites. Of a total of 85 possible plots (3 sites X 25, 100-m^2 plots; 1 site X 10, 100-m^2 plots), 36 plots had enough agaves to be selected for the experiment. Although the sites were rich with agave, the agave tended to cluster in groups so that some 100-m^2 plots had a high number of agave (max. 49 plants) ranging among all size classes while many other 100-m^2 plots had no agave or fewer than 5 individuals with only one or two size classes represented (Table 1.1). Two replicates of each treatment (6 plots) were located at Bear site, four replicates of each treatment were located at the RUP site (12 plots), three replicates of at the RCR site (9 plots) and three replicates (9 plots) at Pride. Together, this gives 12 plots of each treatment within all four sites (Table 1.1).

Prior to the burn, unburned plots contained 47 agaves in height class 1 (26%), 69 agaves in height class 2 (38%), and 64 agaves in height class 3 (35.5%) for a total of 180 agaves, all of which were alive. Burned plots contained 80 agave in height class 1 (44%), 53 agave in height class 2 (29%), and 49 agave in height class 3 (27%) for a total of 182 agaves. Three of these agaves (1.6 %) were dead before the fires, one each of each height class 2 (21-42 cm) and height class 3 (>42 cm) in Bear plot 3, and one in height class 2 in plot RUP 7. In the twelve plots slated for augmentation, 190 agave were surveyed: 78 in height class 1 (41%); 68 in height class 2 (36%); and 44 in height class 3 (23%). One agave in height class 3 agave was recorded as dead in Bear plot 9. There were no significant differences between treatments in the number of plants of different height classes before the fires ($p > .404$). An analysis using a MANOVA model showed that the proportion of living agaves to the number of total counted did not differ by treatments ($p = .410$) or between sites ($p = .107$).

In all treatments, the number of agaves in the five different cluster types varied but the number of agave found in the different cluster types was consistent across treatments (Table 1.4). In burned plots most agaves were found in either no cluster, cluster type 0 (34%) or cluster type 4, within 20 cm of another living agave (46%). Burned plots had the most agave associated with mesquite trees before treatments were applied (8%) with the same percentage associated with dead agaves, cluster type 2. Four percent of the agaves in burned plots were found in a mesquite agave cluster, cluster type 3.

Before the fires were applied, most agaves were in condition category 1 (43%, n = 552), where some leaves showed some damage but none were dead, or in condition category 2 (38%), where fewer than 50% of the leaves were dead. Thirteen percent were in condition category 0, where no damage or death to the leaves was evident. Fourteen agaves were found at condition 3 (2.5%) before the burn, where 50% or more of the leaves were dead.

Post-burn Agave Demography

Time 2, two weeks post-burn

Two weeks post-fire, July 1998, the plots were inventoried again. Sixty-six percent more agaves < 7 cm (height class 1) were found in the augmented plots and 60% more of the same height class were found in the burned plots than in May 1998 due to the removal of fine fuels and litter by fire. More small agaves (< 7 cm) were also observed in monitored, burned plots with 31 height class 1 agaves counted immediately after the burn compared to only 2 height class 1 agaves counted in those plots before the burn. There were also some discrepancies between the counts of agaves in May 1998 and July 1998 in all treatments and size classes due to both the inexperience of the researcher at vegetation monitoring, and due to the occasional instance of an agave located on the border of two plots, being counted in one plot in May 1998 and the adjacent plot in July 1998. However, as the height class increased, approximately the same number of *Agave palmeri* were missed regardless of the treatment (Table 1.5). There was a relatively small change in the number of agave counted between May 1998 and July 1998 in the unburned plots since abundance of fine fuels remained static. Due to this discrepancy in counts of small agave in the burned and augmented plots, between May 1998 (pre-burn) and July 1998 (post-burn), future comparisons between pre-burn and post-burn counts will use the July 1998 data as the pre-burn values, assuming all those plants counted were alive before the fire.

In July 1998, two weeks after the burn, 181 agaves (1508 plants/ha) were counted in the unburned plots, 222 agaves (1850 plants/ha) were counted in the burned plots and 238 agaves (1983 plants/ha) were counted in the augmented fuel plots. Most agaves in unburned plots were in condition category 2 (69%), where some leaves were damaged, but fewer than 50% of the leaves were dead. There were no dead agaves or agaves in condition category 4, (only the apical meristem was green) in the unburned plots.

In both the burned and fuel-augmented plots, many more agaves were in condition category 4 than were actually dead. In burned plots there were 3 times as many condition 4 plants then there were dead plants at that time and thus condition category 4 plants account for 27% of the population (n=222). In plots that were augmented with fuel, the highest percentage of agaves were of condition 4 (n = 238, 31%) whereas 18% were dead in July 1998. Seventy-five percent of those agaves in condition 4 were in height classes 1 and 2 (< 21 cm).

There were significant differences in overall agave mortality between treatments in July 1998 (Table 1.6). In a MANOVA model, the main effect of treatment significantly affected the proportion of dead agave in plots (total number dead/total number counted) (df = 2, p = .01), while site showed no effect (df = 9, p = .55). Using Wilcox Kruskal/Wallis tests, the overall proportion dead in fuel-augmented plots was greater than on unburned plots (p < .001) but did not differ from burned plots (p = .62). Overall mortality was also significantly greater on burned plots than unburned plots (p < .001). There was no difference in mortality between burned experimental plots and burned monitored plots (p = .57).

When the agaves were divided into 5 height classes, significant differences in mortality were evident, especially in the smaller height classes; the smaller the agave, the higher the chance of mortality in both burned and augmented plots (Table 1.6). Burned and augmented plots had greater mortality in the smaller height classes 1 and 2, and had similar mortality rates to one another ($p = .62$ and $p = .48$ respectively). Augmenting plots with fine fuels increased the proportion dead 8-fold for agaves < 7 cm, while the proportion dead in plots burned without augmentation increased 5-fold in the same height class of agave compared to unburned plots. Mortality of plants > 45 cm did not differ between any treatment ($p = 1.0$). There were no dead agaves in height classes 4 or 5 in either augmented or unburned plots, and only 2 plants in height-class 4 (> 45 cm and < 80 cm) were dead in burned plots two weeks post-fire (Figure 2).

There was no significant difference between burned and augmented treatments in the proportion of agaves that died or were severely burned (condition 4) in the different cluster types (Table 1.7). Mortality of and severe damage to agaves occurred in nearly equal proportions in cluster types 0 and 4 in augmented and burned treatments ($p = .94$, and $p = .72$, respectively). In burned plots, there was no significant difference in mortality of and severe damage to agaves between cluster types. However, in monitored, burned plots, 5 out of 6 agaves associated with a mesquite tree and a dried, dead agave (cluster type 3) in Pride plot 11, died. Within augmented plots, a significantly greater proportion of *A. palmeri* died or were severely damaged in cluster type 2, with dead, dried agaves ($\bar{x}$ = .85) than in cluster type 0 ($p = .01$) or cluster type 4 ($p = .01$), but not significantly greater than in mesquite clusters, cluster type 1 ($p = .12$).

Only agaves taller than 45 cm attempted to bloom or did successfully bloom in this study. In burned plots, of a possible 45 agaves taller than 45 cm, 4 (9%) bloomed in July 1998 (33 plants/ha). Two bolting inflorescence (4%) had been aborted by herbivory. Four of possible 69 agave (6%) bloomed in the unburned plots (33 plants/ha) and one bolting inflorescence was terminated by herbivory. One *A. palmeri* (2%) (8 plants/ha) bloomed in augmented plots; it was not browsed.

Time 3, one year post-burn

On June 30 and July 1 of 1999, the *A. palmeri* plots were surveyed for a third time. One year post-burn, virtually no dead agaves were found in any of the treatments (Table 1.8). This suggests that dead agave from the previous year disappeared. In addition, no height class 1 agave were found dead in any of the treatment plots or monitored, burned plots, indicating that these were probably recruits and not present at the time of the fires. Based on this and the size distribution analysis discussed earlier, agaves in height class 1 (< 7 cm) were considered recruits.

Of 173 agaves counted in the unburned plots, 11 (6%) were new recruits (92 plants/ha). One height class 4 agave was dead in the unburned plots and 4 more agaves were found in condition 4. In the burned plots, 46 recruits (383 plants/ha) were found (22%) out of the total 208 agave counted. The number of living agaves, including the recruits, is just one more agave than the year before (1675 living plants/ha). Three percent of the agaves in the burned plots were dead, one each in height classes 3, 4 and 5, and four in height class 2. Another 3% of the burned agaves were condition 4. In the monitored, burned plots, All dead agaves were larger plants, in height classes 3-5 (n = 9). Six dead plants in the monitored plots were also recorded as dead in July, 1998 in plot Pride 11 and presumably failed to disappear. In augmented fuel plots, 193 agaves were counted, 6% of them dead and another 5% at condition 4 (1516 living plants/ha). Recruits account for 19% of those that were counted (300 living plants/ha). The number of living agaves in the augmented plots, including the recruits, was 15 fewer agaves than the number living at time 2.

With the decrease in the number of dead and condition 4 agave, in the burned and augmented plots, a simple equation was devised to describe the fate of those agaves that were severely damaged at the time of the burn and were classified as condition 4 in July 1998 assuming dead and dying agaves disappeared between surveys: 1) I summed the number of agave counted at time 2 in all burned and augmented plots, 2) I counted the total dead at time 2 in both treatments, and 3) added that to the total agaves of condition 4 in July 1998 in both treatments. I then compared this number to the number calculated in the following manner: 1) I summed the total number counted in all burned and augmented plots at time 3, 2) I subtracted the total number of recruits at time 3 in both treatments, 3) I subtracted the total number dead at time 3 in both treatments, and 4) added that to the total agaves of condition 4 at time 3 in both treatments. From the first equation [460 - (62 + 135)], a total of 263 agaves would have remained alive if all condition 4 agaves had died between time 2 and time 3. From the second equation [401 - 82 - (18 + 8)], a total of 293 living agaves at time 3 was calculated. The difference in the numbers of living agaves between time 2 and time 3 suggests that some agaves that are condition 4 immediately after the fire do recover and survive for at least another year. In July 1998, 135 agaves were condition 4. Thirty more agaves than expected were living in July 1999. Thus, approximately 20% of agaves that are severely burned recovered via the apical meristem. This analysis assumes that all height class 1 agaves are new recruits.

In a MANOVA linear model, with treatment as a fixed effect, and site nested inside of treatment as a random effect, there was no effect of treatment ($df = 2$, $p = .24$) or site ($df = 9$, $p = .20$) on the number of recruits in each of the treatments in July 1999, one year post-fire. Comparing the mean number of recruits between augmented and unburned plots, there was a greater number of recruits in the augmented plots than the unburned ($p = .03$), and augmented plots also had a greater proportion of agave recruits to the total number of all living agaves in that treatment than unburned plots ($p < .01$) (Table 1.9). There were no other significant differences between the number of recruits in July 1999 in unburned and augmented plots or burned and unburned plots (Table 1.9).

In July 1999, recruitment occurred primarily in cluster type 4 in all treatments. In unburned plots, 63% of height class 1 agaves ($n = 11$) occurred in clusters with other agaves. In burned and augmented plots, 70% ($n = 46$) and 81% ($n = 36$) of the recruits occurred in cluster type 4, respectively. In burned plots, 17% of height class 1 recruited under mesquite trees ($n = 8$) that were re-sprouting after the fire. This is 10% fewer than before the burn, when 17 out of 65 height class 1 agaves were living in cluster type 1.

Of 5 bolting inflorescence (42 plants/ha) in July 1999 in the unburned plots, 3 were terminated by herbivory. Of the 3 agaves that flowered (25 plants/ha) at time 3 in the burned plots, none were terminated by herbivory. In the augmented plots at time 3, four agaves had bolting inflorescence (33 plants/ha) Three flowered, while one was terminated by herbivory before it had reached the flowering stage.

Time 4, 2 years post burn

On 9 and 10 April of 2000, two years after the fires, the fourth and final survey was completed. New recruits two years after the burns were defined as height class 1 agaves (< 7 cm) and those height class 2 agaves < 14 cm. At this time, 219 agaves (1725 living plants/ha) were counted on the unburned plots, of those agaves, 12 plants were dead (6%), 9 in height class 1 and 2, (8 new recruits), and 3 agaves in height class 4 (> 45 cm). On burned plots, 251 A. palmeri were counted (1775 living plants/ha), 39 agaves were dead (16%). Of the 39% dead in the burned plots in April 2000 62% were primarily new recruits. Twenty-eight percent of the remaining dead were in the largest height classes 3-5.

On the plots that had been augmented with fuel, 200 *A. palmeri* were counted (1516 living plants/ha), 27 of them dead (14%). Of those dead, 67% were new recruits, 5 agaves were of size class 3 (or 11% of that height class population), 2 agaves were height class 4, > 45 cm, and 2 (out of 6 living in the augmented plots) were > 80 cm in height (Figure 3). A MANOVA linear model with treatment as a fixed effect and site nested inside of treatment as a random effect indicated no overall effect of treatment on the proportion dead in April 2000 (df = 2, p = .35), but there was a significant effect from site nested inside of treatment (df = 9, p = .01). Further analysis using the Wilcoxon/Kruskal-Wallis test indicated Bear site had a significantly smaller proportion of dead (n = 6, $\bar{x}$ = .04, S.D. = .06) than did Redfield Canyon Upslope (RUP) site (n = 12, $\bar{x}$= .15, S.D. = .10, p = .02), but a similar proportion to the other 2 sites, Pride and RCR (p > .05). Pride (n = 9, $\bar{x}$ = .11, S.D.= .12), RCR (n = 9, $\bar{x}$ = .13, S.D.= .16) and RUP sites have means of the proportion of agave dead that are similar (p > .05).

When comparing mortality of the smaller height classes 1 and 2 (primarily new recruits), between treatments, there were no significant differences. The effect of the treatments seems to show up again in height classes 3 and 5 (Table 1.10). An analysis using a MANOVA model showed a slight effect of treatment on the proportion of height class 3 agaves dead (df = 2, p = .07) with no site effect (df = 7, p = .44) and no overall treatment effect at height class 5 (df = 2, p = .56), again with no site effect (df = 7, p = .20). Using Wilcoxon/Kruskal-Wallis tests, there was a significant difference between burned and unburned plots in the mortality of agaves in height class 3 (>22 cm < 45 cm) (p = .03). There were also significant differences between unburned and augmented plots in the proportion of dead at agaves in height class 3 (>22 < 45 cm) and in height class 5 (> 80 cm) (p = .02 and .05 respectively). There was a greater overall mortality in augmented plots than unburned plots in April 2000 (p = .05). Significant differences in mortality also occurred between unburned and burned plots in height class 3 (22-44cm), with burned plots having a higher proportion dead (p = .03). At height class 5 (>79 cm), there was also greater mortality in burned plots than unburned plots (p = .08), but no differences in mortality were detected between burned and augmented plots in any height classes (Table 1.10). At height classes 1 and 2, MANOVA models also show no effect of treatment (df =

2, p = .64 and p = .48 respectively) nor of site (df = 7, p = .58 and p = .36 respectively). A repeated-measures MANOVA using the mortality results from the three post-burn surveys, and using the July 1998 post-burn survey, counting all agaves as living, as the pre-burn value, there is a within interaction through time by treatment (Pillai's Trace p = .001).

In April 2000, there was no difference in the number of living recruits by treatment or in the proportion of recruits to the number of total living plants by treatment (Table 1.9).

Overall, the total number of agaves counted before the burn (using post -burn July, 1998 number counted) in unburned plots ($\bar{x}$= 15.1, S.D.= 2.13) was not significantly different than the total number of *A. palmeri* living after the burn ($\bar{x}$ = 17.3, S.D.= 7.7, p = .52). Similarly, in burned plots, the total number of agaves before the burn ($\bar{x}$ = 18.5, S.D.= 10.2) did not differ (p = 1.0) from the number of living agaves 2 years post-burn ($\bar{x}$ = 17.8, S.D.= 9.5) (Figure 4). The total number of agave living in augmented plots in April 2000 ($\bar{x}$ = 14.4, S.D.= 12.2) was significantly fewer (p = .05) than the number of agave living before the burn ($\bar{x}$ = 19.8, S.D.= 12.4), with the difference occurring in the smaller size classes (Figure 5). The overall density of living agaves in burned and unburned plots has increased since the fire (after July 1998), while the density in the augmented plots has decreased (Figure 6).

Two years after the burn, though the numbers of living *A. palmeri* in the different height classes were higher in burned than unburned and augmented plots for height classes

1, 2 and 3, the means of these numbers were not significantly different (Figure 7) except in height class 5 where unburned plots had a significantly greater number of agave plants than augmented plots (p = .05), but not a greater amount than in burned plots (p = .16). The change in the distribution of plants among the height classes between July 1998 and April 2000 varies according to treatment (Figure 8).

DISCUSSION

Mortality of *A. palmeri* immediately after a fire was observed primarily in relatively small agaves (< 21 cm). One year after the fires, very few agave were dead in all treatments. Not only were few dead, but few of the dead from the 2-week post-fire survey were observed in subsequent surveys. Thus, dead agaves disappeared, which suggests that they were foraged by animals, a practice commonly seen on grazed desert grasslands after a fire since the spines may have been singed by the fire (Martin 1983). Two years after the fires, an increasing number of larger *A. palmeri* were found dead on the burned and fuel-augmented plots, and more larger agave died with greater fuel loads. *A. palmeri* observed immediately after the fire in condition 4, when only the apical meristem was green, had a 20% survival rate. Larger agave, that were severely burned died slowly and were observed as dead in the April 2000 survey, two years after the burn. Some disappeared between surveys, so were never counted as dead and probably were consumed as forage. In July of 1999, no agaves < 8 cm were dead in any plot, which suggests that these were primarily new recruits.

Two years after the prescribed burn, mortality increased on all treatments. Many of the dead plants were of the smaller height classes (< 21 cm), suggesting that environmental factors other than fire played a role in the survivorship of new recruits. This could be abnormally high or low seasonal temperatures, a decrease in average yearly precipitation (Figure 1), or an increase in parasites. (Damage by agave beetles was observed on height class 3 and smaller agaves (< 44 cm), especially in unburned plots 2 years after the fire.) Precipitation in the summer of 1999 was 75% greater than the previous 10 year average precipitation which might allow for germination and seedling establishment of agaves (Nobel 1988). The following three seasons though had at least 50% less precipitation, probably causing mortality to the new recruits in 2000 (Figure 1). Fall drought also predisposes small agaves to freeze damage (B. McDaniels, pers. comm.). Nearly 30% of agaves < 21 cm were dead on augmented and burned plots and 12% were dead on unburned plots. There was not a significant difference between treatments in mortality of recruits in 2000. Apparently post-fire recovery of *A. palmeri* populations and survivorship of recruits depend on environmental conditions following fires.

When *A. palmeri* was associated with mesquite trees, a dried, dead agave parent plant, or a combination of the two, mortality was almost certain. This relationship was independent of agave height and was accentuated in the augmented plots.

Recruitment occurred at higher rates on augmented and burned plots than unburned plots. It is possible that fewer recruits were observed in unburned plots due to more grass cover however this is not likely since a study conducted by TNC on vegetation monitoring plots (located near my *A. palmeri* plots) after the Double R burn indicated that by September 1998, 3 months after the burn, total ground cover on burned plots was within 10% of the cover two years pre-fire. By September 1999, 15 months after the burn, ground cover exceeded the pre-burn ground cover by about 5% (D. Gori pers. comm.).

Approximately 75% of recruits occurred in cluster type 4, clusters of other living agave. This suggests either that agave responded to fire by producing offshoots or, seedlings established from seeds that fell to the ground in a group.

Agave seedling establishment is limited by water quantity and temperature, as larger agaves can tolerate longer periods of drought than seedlings because larger plants more water in their leaves (Nobel 1988). Seedlings that established during the relatively wet summer monsoon season of 1999, probably could not withstand the following three seasons of much reduced precipitation (Figure 1). Seedlings typically established beneath mesquite trees in burned and unburned plots, but did not establish beneath dead mesquite trees in the augmented plots; recruitment in the latter plots may have been constrained by high temperatures that occurred in the litter beneath the trees at the time of the fire (Wright and Bailey 1982). A reduction in recruitment under mesquite trees in augmented plots could not have been due to removal of the canopy cover as the canopy cover was also removed in the burned plots. Anecdotal evidence of the blackened, burned soil under the dead trees in the augmented plots leads the author to believe that lack of recruitment is due to something that happened at the soil surface.

A conservative estimate of percent mortality due to the effect of the fires can be calculated using the number of agaves counted at time 4 (April 2000) subtracting those agaves < 14 cm in height at time 4, then dividing that number by the number of agaves counted at time 2 (July 1998).This estimate includes all the agaves (except recent recruits) counted at time 4. Using these figures, it is estimated that when fuel is added to plots containing *A. palmeri*, up to 47% of those agaves die over a 2-year period. In plots burned with extant fuels, up to 37% of those agaves die over 2 years. Using this same calculation, the unburned plots had a mortality of 18% over 2 years (Figure 4). If we adjust the mortality rates of the augmented plots and burned plots using 18% as a baseline, then 29% of *A. palmeri* mortality is attributed to fire in fuel-augmented plots and 19% is attributed to fire in plots burned with extant fuel. If all living recruits at time 4 (April 2000) are added back into the population, the total change after fire in burned plots is an decrease of 4%. In augmented plots, the *A. palmeri* population remains at a deficit of 27%. When recruits are added back into the plots that did not get burned, a 13% increase in *A. palmeri* population after 2 years is achieved. Howell (1996) claims that *A. palmeri* populations tended toward the larger height class after fires, but she did not take into account recruitment. The results from this study show that in plots burned with extant fuel, the number of smaller agave plants actually exceeds that in unburned plots, and is greater than the number of larger agave plants (Figure 7). *A. palmeri* populations are dynamic and are influenced by many factors in the environment.

Before the fires, several agaves were associated with mesquite or acacia trees. The fuel from these woody plants increased the mortality rate of *A. palmeri* associated with them, but where these trees were not killed on burned plots, recruitment occurred one and two years post-burn. Nurse plants are often associated with succulents and cacti because they decrease temperature and increase available moisture to seedlings (Nobel 1988). Thomas and Goodson (1992) suggested that agaves have invaded grasslands along with woody shrubs due to fire suppression since the late 1800s. The results from this study cannot negate or support their hypothesis. Even though many mesquites had agaves growing underneath, it was not a greater amount of agaves than would be there by chance.

Thomas and Goodson's calculation of 14% *A. palmeri* dying on burnt sites, is lower than the results of this experiment. They also found that 83% *A. palmeri* living on the burnt site survived via regeneration of the apical meristem, which is far more than the 20% survival rate that I calculated. This discrepancy could be due to their lower sample size (41 plants) or to the difference in sizes of agaves sampled: They did not report size of plants, but they may have been of the larger height classes.

It has been suggested that frequent fires (every 3-6 years) bias the demographics of the *A. palmeri* population towards the larger agaves and will not allow reestablishment of the younger agaves (Howell 1996, Robinett 1994). This is probably accurate. In this study, although there is a high recruitment rate 2 years post-fire, young agaves are susceptible to environmental pressures and subsequent fires. Therefore, I recommend applying fire no more frequently than fires occurred before Anglo settlement: every 7-20 years (Wright 1980, McPherson 1995).

MANAGEMENT IMPLICATIONS

Greater fuel amounts near *A. palmeri* cause greater mortality in all height classes. Agaves burned with extant fuel survived at greater rates than those burned with augmented fuel and when recruitment was considered, the population actually increased at a greater rate on burned plots than on unburned plots. Therefore, prescribed fires should not be restricted in an area because a population of *A. palmeri* is discovered. If a fire has not occurred for more than ten years, it would be prudent to burn to decrease the abundance of fuel caused by encroaching shrubs and dead parent agaves. Accumulation of these fuels over a longer period of time could cause more mortality to an *A. palmeri* population which could have a negative effect on the ability of *L. curasoae* to forage because bats would need to commute longer distances and/or compete with more bats for food (Ober 2000).

Lesser long-nosed bats seem to select areas of high food abundance (stands of *A. palmeri* that have high densities of dead standing inflorescences). The high density of *A. palmeri* at these sites in the Muleshoe CMA suggests that these stands may be a core use area and that there are day roosts of *L. curasoae* within approximately 17 km of these stands and night roosts within 1.45 km from the center of these stands (Ober 2000). Many bat roosts are monitored in the Coronado National Forest to the west and south of the Galiuro mountains, in the Huachuca, Chiricahua, and Whetstone Mountains in southern Arizona (USFWS 1995), but none are being monitored at this time on the Muleshoe CMA.

Further research should be conducted to determine effects of fire on the production of vegetative offshoots of *A. palmeri*. Perhaps secondary metabolites provide a signal to agaves that survive fires to increase the agave population by cloning themselves through rhizomes.

If agaves continue to be monitored in post-burn surveys, they should be monitored within a month after the burn and continually monitored for several years. This will ensure a more accurate picture of mortality than obtained by a one-time survey. If managers survey too long after a fire, they will miss the dead plants that were removed by herbivores. If they survey only once after a fire, they will miss the mortality that occurs to the larger agaves several years after the fire.

Teacher as Researcher

The Master of General Biology Program is designed for high school biology teachers. The hope is that as science teachers do their own research and struggle with their own ideas about actually doing science, they will reflect on research and translate that into a more thoughtful approach to teaching. It is designed so that teachers in the program take a current topic of biology class each spring and fall semester, and then take the required classes and do research each summer for 4 years. When I began this program, it was fully funded by a grant from the National Science Foundation. That was very attractive to me as it meant that my masters degree was being sponsored. In the last two years, this program has been minimally funding, which has meant money for tuition and research has been out-of-pocket.

I am a tenth year teacher and am presently teaching ninth grade biology at Ironwood Ridge High School in Tucson, Arizona. When I entered this program 4 years ago, in the summer of 1997, I was teaching eighth grade general science in Tempe, Arizona and had not thought much about the "inquiry" approach to teaching science. I knew little about what ecological research entailed but I had a love of science, a love for teaching it, and a love for nature that drove me to seek more involvement. I accepted this research project knowing the landscape but not knowing the specifics of what I was getting myself into. I had no idea how much I would learn, nor how becoming a researcher would change my teaching and my ideas about learning.

The obvious things I have learned have to do with the actual research I performed:

methods of ecological research. I learned how to use equipment I had never used before: drying ovens, burlap bags, electronic scales, 50-m reel tapes, re-bar, flags, large nails, and a large 4-wheel drive truck on an incredibly hairy and scary back-country trail. I learned how to estimate fuel moisture content in grasses, how to survey a population of plants, how important it is to take precise notes in the field, how fires are ignited for a prescribed burn, and how a fire roars all night long when it's burning thousands of acres.

Once I had my data collected, I spent hundreds of hours inputting the data into a computer spreadsheet and figuring out how to manipulate software programs to analyze the data. I learned how to find out what my data were telling me by using the statistical software and cutting and pasting from the original spreadsheets. I learned statistics. I asked a few of my committee members a lot of questions. I tried statistical tests then went back to the drawing board when I was told I hadn't used the non-parametric test required because "the residuals were homoscedastic." i learned how to pronounce "homoscedastic" and I learned what it meant. I made big mistakes that cost me weeks during my final summer but I am very confident in my ability to analyze data now.

As I slowly worked through the data analysis I got excited about the results I was getting. I found out that doing research can be like solving a good puzzle. I also learned that making mistakes, both in the field and on the computer, are not the end of the world. I learned how to be a better scientist from each one of my mistakes. This is the most important lesson I can bring into the classroom: Scientific mistakes lead to better designed experiments, a deeper understanding of the problem, and more background knowledge for the next investigation.

It's so easy as a classroom science teacher to set up experiments for the students that are fail-proof; give the kids the recipe and the explanation. Now that I understand the importance of independent and dependent variables, I teach the concepts to my students and ask them to ask questions about whatever topic we are involved with. For example, if the question is about seed germination, the students develop their own ideas, make predictions, identify variables, design experiments, collect data and use the computer programs to make spreadsheets and graphs. They don't do it all perfectly. They make mistakes. I ask them questions. They solve their problems with guidance from me as I solved mine with guidance from my committee.

When I talk to other teachers about using the inquiry approach in their own class, they tell me they don't have time. They tell me they have too much material to cover. And I ask them who told them that? With the exception of one teacher I asked, whose curriculum is dictated by a district-wide biology final, most teachers feel this pressure but not from any particular source. When I remind them that "Science as Inquiry" is the first science standard mentioned in the Arizona State Science Standards, they tell me that they "do labs." Doing labs doesn't necessarily mean doing inquiry.

Inquiry forces students to think which is the last thing many of them want to do. But there are always those few students to whom it comes naturally; who want to taste the water to see if it's sweet when we are testing a membrane's selective permeability.

This does not mean that my classroom is chaos. It is not. It also does not mean that I don't test my students or teach them basic scientific and biological concepts. I have high expectations of my students-higher now than before. I expect them to do their background research (i.e., read their text). I expect them to think. I expect them to be able to use the lab equipment correctly and efficiently. I expect them to think some more. I expect them to discuss concepts with their teams and I expect them to teach each other. My students will tell you my expectations are too high. They will also tell you at the end of the year that they learned science this year. They will be almost surprised at admitting it.

Students should be given the opportunities to do what scientists do. For me, it sometimes means keeping my mouth shut when I know the students are heading down a path that will not lead immediately to enlightenment but instead, to more confusion. I know from my own experience, that this leads to the greatest amount of learning if the students are willing to and have the time to stick with their investigation. I will directly teach them how to use equipment and help them to understand how certain biological functions occur, but when they are investigating with the intent to answer a specific question, and they get to that just-give-us-the-answer place, my obligation to my students is to answer their questions with a probing question, to put it right back on them. They are the learners. I cannot force them to learn or to think. I can provide experiences that are similar to the ones I have had as a scientist: I can give them time in the field, time in the lab, time to design an experiment, time to discuss their design. I can teach them how to peer review, and to self-evaluate. I can teach them the power of data analysis, the methods of graphing, the language of science: prediction, independent and dependent variables, controls, treatments, hypothesis, y-axis, x-axis, results, conclusion. I can teach all of this in context, make it meaningful, and related to their own investigations. Teaching kids the facts of science without teaching them inquiry is like teaching children to read by having them memorize isolated words and not ever giving them the chance to understand what those words mean through a richly illustrated story. It's like teaching the word water without ever giving them a cool drink.

Is creating a place where inquiry can take place easy? It is not. Most of the public school teachers I know have over 35 students in each of their 5 classes. They lack space and equipment. My suggestion to science teachers to is to try the inquiry approach with just one unit and one broad question. Then let the students learn by proposing ideas, designing experiments, running the experiments, and analyzing the data. Even if what they learned is that their experiment didn't work, they have learned something of value and something about how science actually works: The solutions aren't always right in front of you. Sometimes experiments and results have to be thought about, mulled over, and then the scientist comes back to the question and starts anew.

TABLE 1.1 Plots containing *A. palmeri* at four sites in souteastern Arizona, ranked and ordered on the number of agaves that they contain. Consecutive triplets were used to randomly assign plots to 1 of 3 treatments (see text for further information).

Site	Plot no.	Number of Agave	Experimental condition	Rank
Bearscat	3	17	burned	1st triplet
Bearscat	4	11	unburned	
Bearscat	9	11	augmented	
Bearscat	1	10	augmented	2nd triplet
Bearscat	5	10	unburned	
Bearscat	20	5	burned	
Redfield Canyon Road	3	27	augmented	3rd triplet
Redfield Canyon Road	8	22	unburned	
Redfield Canyon Road	10	16	burned	
Redfield Canyon Road	11	14	burned	4th triplet
Redfield Canyon Road	4	11	unburned	
Redfield Canyon Road	20	10	augmented	
Redfield Canyon Road	5	7	unburned	5th triplet
Redfield Canyon Road	2	7	augmented	
Redfield Canyon Road	19	6	burned	
Redfield Canyon Upslope	23	49	augmented	6th triplet
Redfield Canyon Upslope	7	29	burned	
Redfield Canyon Upslope	22	24	unburned	
Redfield Canyon Upslope	8	18	burned	7th triplet
Redfield Canyon Upslope	13	18	unburned	
Redfield Canyon Upslope	9	16	augmented	
Redfield Canyon Upslope	20	15	burned	8th triplet
Redfield Canyon Upslope	18	15	unburned	
Redfield Canyon Upslope	25	14	augmented	
Redfield Canyon Upslope	19	11	burned	9th triplet
Redfield Canyon Upslope	14	8	augmented	
Redfield Canyon Upslope	17	8	unburned	
Big Pride Slope	10	34	burned	10th triplet
Big Pride Slope	9	33	unburned	
Big Pride Slope	8	18	augmented	
Big Pride Slope	3	15	unburned	11th triplet
Big Pride Slope	1	13	augmented	
Big Pride Slope	6	8	burned	
Big Pride Slope	7	7	augmented	12th triplet
Big Pride Slope	2	6	burned	
Big Pride Slope	4	5	unburned	

TABLE 1.2. Fuel loads at the time of the burn and the amount of fine fuel added to augmented plots of *Agave palmeri* in several sites in southeastern Arizona. Favorable fuel loads are based on Soil Conservation Service estimates for ecological sites at an elevation between 1,370-1,830 m and 30-41 cm of precipitation per year (USDA 1988).

Site	Plot	Ecological sites	Favorable Fuel load		Fuel load present (kg /100 m^2)	Amount augmented (kg /100m^2)
			lbs /acre	kg /100 m^2		
Bear	1	Volcanic Hills	1800	20.2	5.85	14.2
Bear	9	Volcanic Hills	1800	20.2	5.85	14.2
RCR	2	Loamy Upland	1500	16.8	2.57	14.2
RCR	3	Loamy Upland	1500	16.8	2.57	14.2
RCR	20	Loamy Upland	1500	16.8	2.57	14.2
RUP	9	Loamy Upland	1500	16.8	5.35	11.4
RUP	14	Loamy Upland	1500	16.8	5.35	11.4
RUP	23	Loamy Upland	1500	16.8	5.35	11.4
RUP	25	Loamy Upland	1500	16.8	5.35	11.4
Pride	1	Volcanic Hills	1800	20.2	4.61	15.5
Pride	7	Volcanic Hills	1800	20.2	4.61	15.5
Pride	8	Volcanic Hills	1800	20.2	4.61	15.5

TABLE 1.3. The Double R prescribed fire-weather observations, Muleshoe Ranch, Cochise County, Arizona. No fuel samples were collected at Pride, but moisture content is presumed to be the same as RCR because the sites are within 1 km of each other and were exposed to similar weather conditions. Fires were ignited 22-24 June 1998.

Site	Date of ignition	Time of ignition	Temperature (°C)	RH (%)	Wind Direction	Wind Speed (kph)	Max. wind gusts (kph)	Fuel Moisture Content (%)	Aspect	Slope (°)
Pride	6/23/98	8:00 p.m.	30	12	W	<3.2	5.6	8.0	west	31
RCR	6/23/98	8:00 p.m.	30	12	W	<3.2	5.6	8.0	none	none
Bear	6/24/98	11:00 a.m.	36.1	17	W	6.4	9.6	7.6	west	6
RUP	6/25/98	9:11 a.m.	32.2	21	SE	5.6	12.8	10.7	sw	11

TABLE 1.4 Mean (± SD) number of *Agave palmeri* per plot in 5 different cluster types before the 1998 fires in Cochise County, Arizona. Cluster 0 = agave stands alone; Cluster type 1 = agave is within 50 cm of the base of a mesquite tree. Cluster type 2 = agave is within 20 cm of a dried, dead agave. Cluster type 3 = agave is within 50 cm of the base of a mesquite tree and is within 20 cm of a dried, dead agave; cluster type 4 = agave is within 20 cm of another living agave.

	Cluster Type				
Treatment	0	1	2	3	4
Unburned	5.66 ± 4.6 a*A‡	.92 ± 2.07 bBA	3.5 ± 3.78 acA	1.33 ± 2.42 cA	3.58 ± 3.99 aA
Burned	5.83 ± 3.86 aA	1.25 ± 2.26 bA	1.0 ± 1.41 bA	.66 ± 1.78 bA	6.0 ± 6.4aA
Augmented	6.42 ± 4.92 aA	0.0 ± 0.0 bB	1.92 ± 2.1 cA	.25 ± .62 cA	7.25 ± 8.39 aA

* means within a row followed by the same lowercase letter are not different (p> 0.05) according to Wilcoxon signed-rank test.

‡ means within a column followed by the same uppercase letter are not different (p>0.05) according to Wilcoxon/ Kruskal-Wallis Test (rank sums).

TABLE 1.5. Mean (±SD) number of the absolute value of the change in counts of *Agave palmeri* plants between the first survey just before the fire (May 1998) and the second survey (July 1998) two weeks after the Double R burn (Cochise County, Arizona) as a function of height class. More small agave were counted after the burn in burned plots than unburned plots due to increased visibility caused by the fire. (There was a decrease in forbs and litter in which small agave were hidden.) Change in count is also due to marking error, or counting error due to agaves that were on the border of two plots. n= number of plots which contain agave in these cluster types. The range is the number of plots with a different number of plants before and immediately after the burn.

		Height Class									
		1		2		3		4		5	
Treatment	n		Range		Range		Range		Range		Range
unburned	12	1 ± .7a*	2	1.08 ± 1.1a	3	1.42 ± 1.3a	5	0.58 ± .67a	2	0.33 ± .5a	1
burned	12	3.42 ± 3.2b	11	2.42 ± 2.0a	7	1.25 ± .87a	3	0.83 ± .94a	3	0.25 ± .62a	2
augmented	12	3.58 ± 2.8b	9	2 ± 2.13a	7	1.08 ± 1.3a	4	0.75 ± 1.1a	4	0.08 ± .5a	1

* Means within a column followed by the same letter are not different ($p>0.05$) according to Wilcoxon/Kruskal-Wallis Tests (Rank sums).

TABLE 1.6 Mean ($\pm$ SD) proportion dead (number dead divided by number counted of that size class) *Agave palmeri* per plot in 5 different height classes and overall (all heights) July 1998, two-weeks post-burn, in southeastern Arizona. Height class 1 $\leq$ 7 cm, height class 2 = 8-21 cm, height class 3 = 22-44 cm, height class 4 = 45-79 cm, height class 5 = 80 cm and above. n = total number *Agave palmeri* counted in each height class, in each treatment.

		Height Class										
Treatment	n	1	n	2	n	3	n	4	n	5	n	All heights
Unburned	19	.05 $\pm$ .13A‡a*	39	0.0 $\pm$ 0.0Aa	54	0.0 $\pm$ 0.0Aa	59	0.0 $\pm$ 0.0Aa	10	0.0 $\pm$ 0.0Aa	181	.01 $\pm$ .02A
Burned	65	.26 $\pm$ .36ABa	57	.16 $\pm$ .32ABa	54	.13 $\pm$ .18Bab	42	.02 $\pm$ .06Ab	4	0.0 $\pm$ 0.0A	208	.11 $\pm$ .11B
Augmented	56	.34 $\pm$ .38 Ba	69	.19 $\pm$ .29 Bab	63	.07 $\pm$ .15Bb	46	0.0 $\pm$ 0.0Ad	4	0.0 $\pm$ 0.0Ad	193	.16 $\pm$ .19B

* means within a row followed by the same lowercase letter are not different ($p > 0.05$) according to Wilcoxon signed-rank test. (Excluding All heights.)

‡ means within a column followed by the same uppercase letter are not different ($p > 0.05$) according to Wilcoxon/ Kruskal-Wallis Test (rank sums).

TABLE 1.7 Mean (+ SD) proportion of dead *Agave palmeri* and agave in condition category 4 [(number dead + number condition category 4 found in that cluster type)/number of all agaves found in that cluster type] as a funtion of cluster type in burned and augmented fuel plots in southeastern Arizona, two weeks after the 1998 June burn. Condition category 4 plants were those agaves in which only the apical meristem remained green. n = number of plots with agaves in this type of cluster.

		Cluster type								
		0		1		2		3		4
Treatment	n		n		n		n		n	
Burned	10	.31 ± .39A**a*	6	.60 ± .35Aa	1	.33 Aa	1	.50 Aa	7	.46 ± .28Aa
Augmented	11	0.27 ± .30Aa	3	.44 ± .42Aabc	5	.85 ± .23Ab	2	.97 ± .04Aab	11	.41 ± .27Aac

* Means within a row followed by the same lowercase letter are not different (p>0.05) according to Wilcoxon/Kruskal-Wallis Tests (Rank sums).

** Means within a column followed by the same uppercase letter are not different (p>0.05) according to Wilcoxon/Kruskal-Wallis Tests (Rank sums).

TABLE 1.8 Mean ($\pm$ SD) proportion dead (number dead divided by number counted of that height class) *Agave palmeri* per plot per in 5 different height classes and overall (all heights) July 1999, one year post-burn in southeastern Arizona. Height class 1 $\leq$ 7 cm, height class 2 = 8-21 cm, height class 3 = 22-44 cm, height class 4 = 45-79 cm, height class 5 = 80 cm and above. n = total number of *Agave palmeri* counted in each height class, in each treatment.

		Height Class										
Treatment	n	1	n	2	n	3	n	4	n	5	n	All heights
Unburned	11	0.0 $\pm$ 0.0A‡a*	36	0.0 $\pm$ 0.0Aa	58	0.0 $\pm$ 0.0Aa	59	.05 $\pm$ .15Aa	9	.14 $\pm$ .38Aa	173	.02 $\pm$ .06A
Burned	46	0.0 $\pm$ 0.0Aa	67	.05 $\pm$ .12ABa	50	.01 $\pm$ .04Aa	37	.02 $\pm$ .06Aa	8	.06 $\pm$ .10Aa	208	.03 $\pm$ .06A
Augmented	36	0.0 $\pm$ 0.0Aa	67	.06 $\pm$ .10Bb	49	.10 $\pm$ .30Aab	39	.03 $\pm$ .09Aab	2	0.0 $\pm$ 0.0Aab	193	.05 $\pm$ .09A

* means within a row followed by the same lowercase letter are not different (p> 0.05) according to Wilcoxon signed-rank test. (Excluding All heights.)

‡ means within a column followed by the same uppercase letter are not different (p>0.05) according to Wilcoxon/Kruskal-Wallis Test (rank sums).

TABLE 1.9. Mean (± S.D.) number of recruits of *A. palmeri* per plot and mean (± S.D.) proportion of recruits (number of living recruits /number of total plants living in plot) per plot in July 1999 and April 2000 in southeastern Arizona one and two years after the Double R prescibed burn. July 1999 recruits are all agaves < 8 cm. April 2000 recruits are all agaves ≤ 14 cm. n = number of recruits in each treatment.

		July 1999			April 2000	
		number of recruits	proportion of recruits		number of recruits	proportion of recruits
Treatment	n			n		
Unburned	11	.92 ± 1.24A	.06 ± .08A	30	5.1 ± 3.8A	.29 ± .20A
Burned	46	3.8 ± 7.0AB	.15 ± .20AB	46	7.8 ± 5.5A	.40 ± .22A
Augmented	36	3.0 ± 3.3B	.21 ± .16B	26	5.0 ± 4.9A	.37 ± .19A

* Means within a column followed by the same uppercase letter are not different (p>0.05) according to Wilcoxon/Kruskal-Wallis Tests (Rank sums).

TABLE 1.10 Mean (± SD) proportion dead (number dead divided by number counted of that height class) *Agave palmeri* per plot in 5 different height classes and overall (all heights) in April 2000, two years post-burn in southeastern Arizona. Height class 1 ≤ 7 cm, height class 2 = 8-21 cm, height class 3 = 22-44 cm, height class 4 = 45-79 cm, height class 5 = 80 cm and above. n = total number of *Agave palmeri* counted in each size class, in each treatment.

	Height Class											
Treatment	n	1	n	2	n	3	n	4	n	5	n	All heights
Unburned	33	.04 ± .13A‡ab*	52	.08 ± .11Aa	52	0.0 ± 0.0Abc	65	.04 ± .08Aac	17	0.0 ± 0.0Aac	219	.05 ± .06A
Burned	59	.12 ± .18Aa	82	.21 ± .32Aa	62	.15 ± .24Ba	37	.07 ± .15Aa	11	.23 ± .44ABa	251	.16 ± .15AB
Augmented	30	.10 ± .13Aab	69	.22 ± .23Aa	48	.13 ± .20Bac	48	.03 ± .08Abc	6	.38 ± .48Bac	200	.14 ± .11B

* means within a row followed by the same lowercase letter are not different (p> 0.05) according to Wilcoxon signed-rank test. (Excluding All heights.)

‡ means within a column followed by the same uppercase letter are not different (p>0.05) according to Wilcoxon/Kruskal-Wallis Test (rank sums).

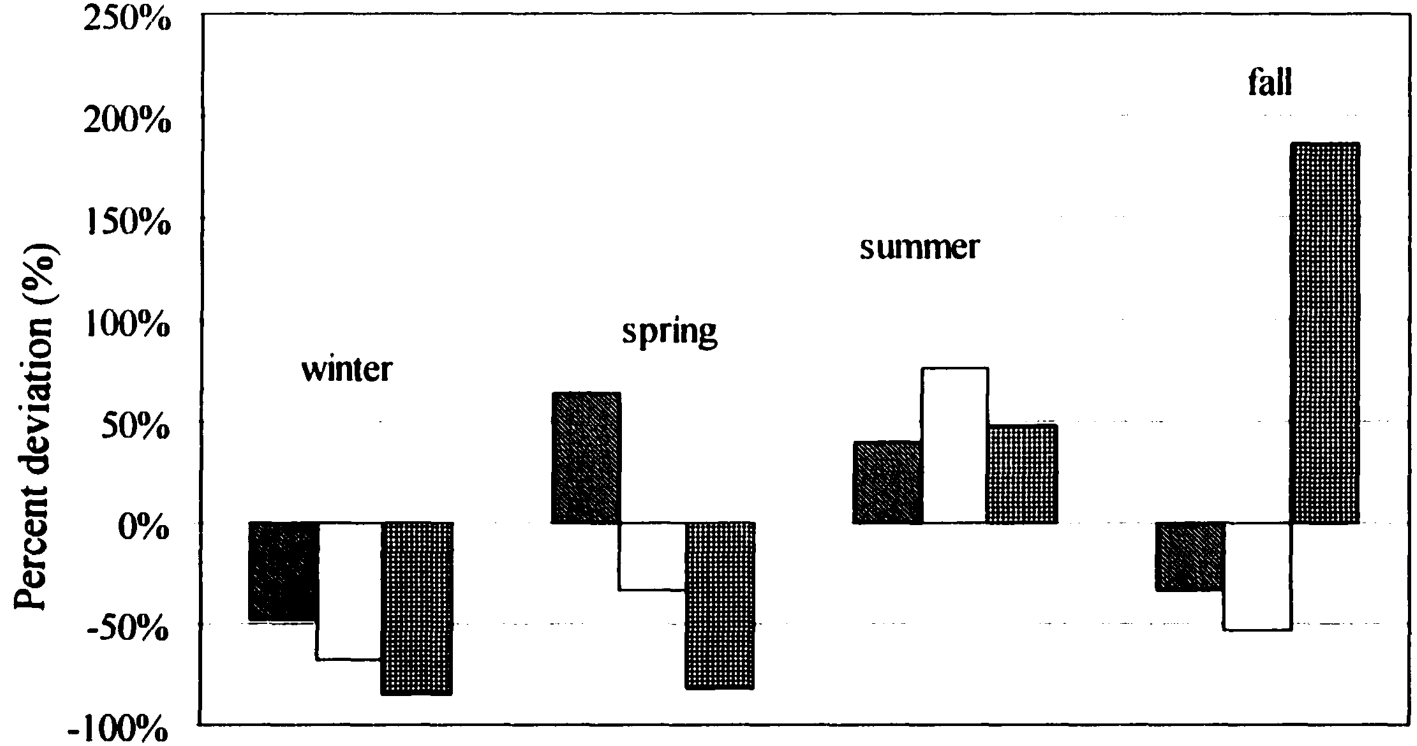

FIGURE 1. Deviations from average precipitation of the years 1988-2000 on the Muleshoe CMA. Diagonal bars represent 1998, unfilled bars represent 1999 and checkerboard bars represent 2000. Winter includes the months of December (of the previous year), January and February. Spring includes the months of March, April and May. Summer includes the months of June, July, and August. Fall includes the months of September, October, and November. Spring of 1998 was when the pre-burn inventory of agave was done. The fires and the first post-burn agave inventory were in the summer of 1998. Time 3 inventory was in the summer of 1999, and time 4 inventory was in the spring of 2000.

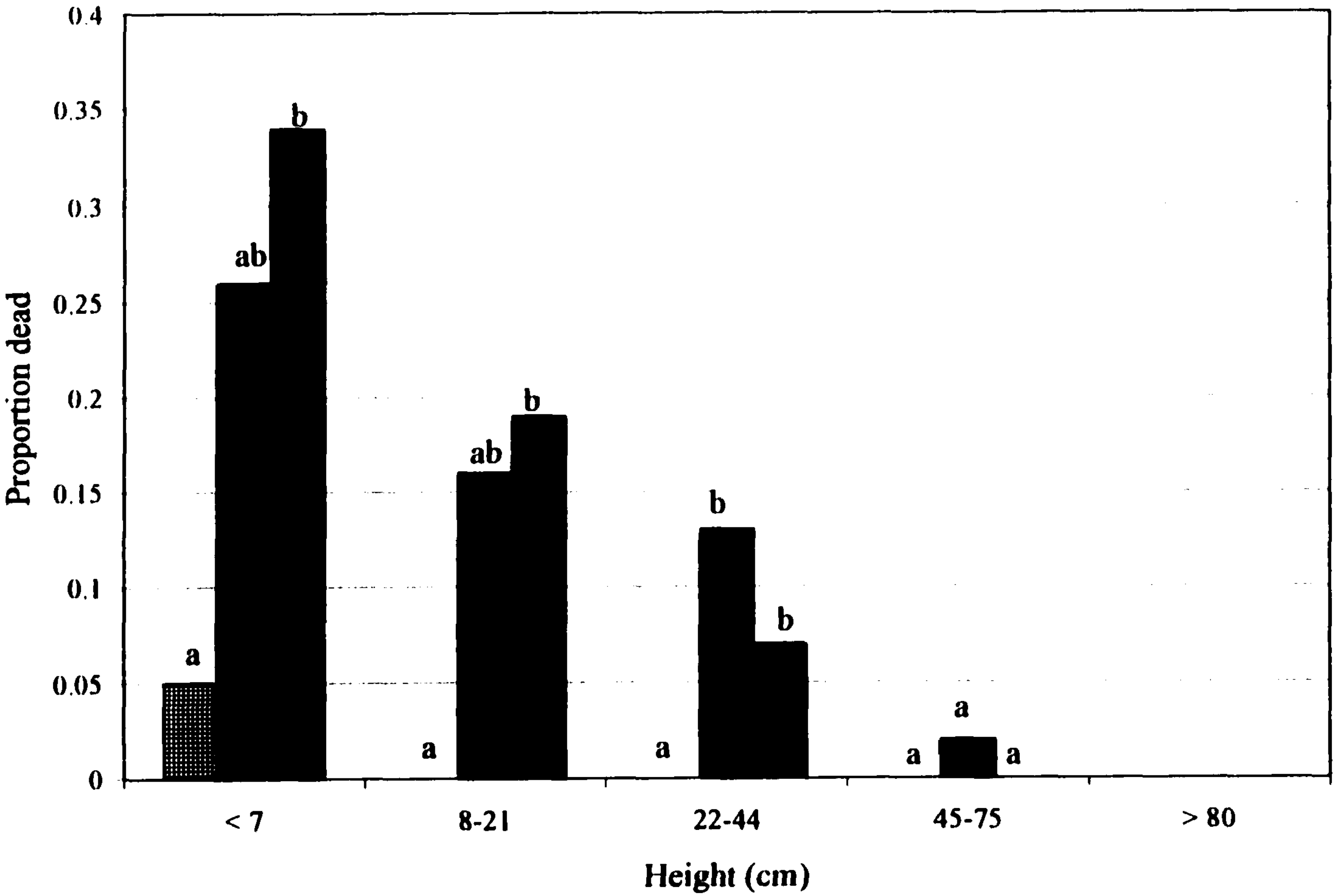

FIGURE 2. Mean proportion of *Agave palmeri* mortality in experimental plots, two weeks after the 1998 Double R prescribed burn, Cochise County, Arizona. Checkered bars represent unburned plots, solid dark bars represent burned plots, solid light bars represent augmented plots. A missing bar indicates none found dead at that height class and treatment. Columns with the same lowercase letter within a height class are not different ($p > 0.05$) according to Wilcoxon/ Kruskal-Wallis test (rank sums).

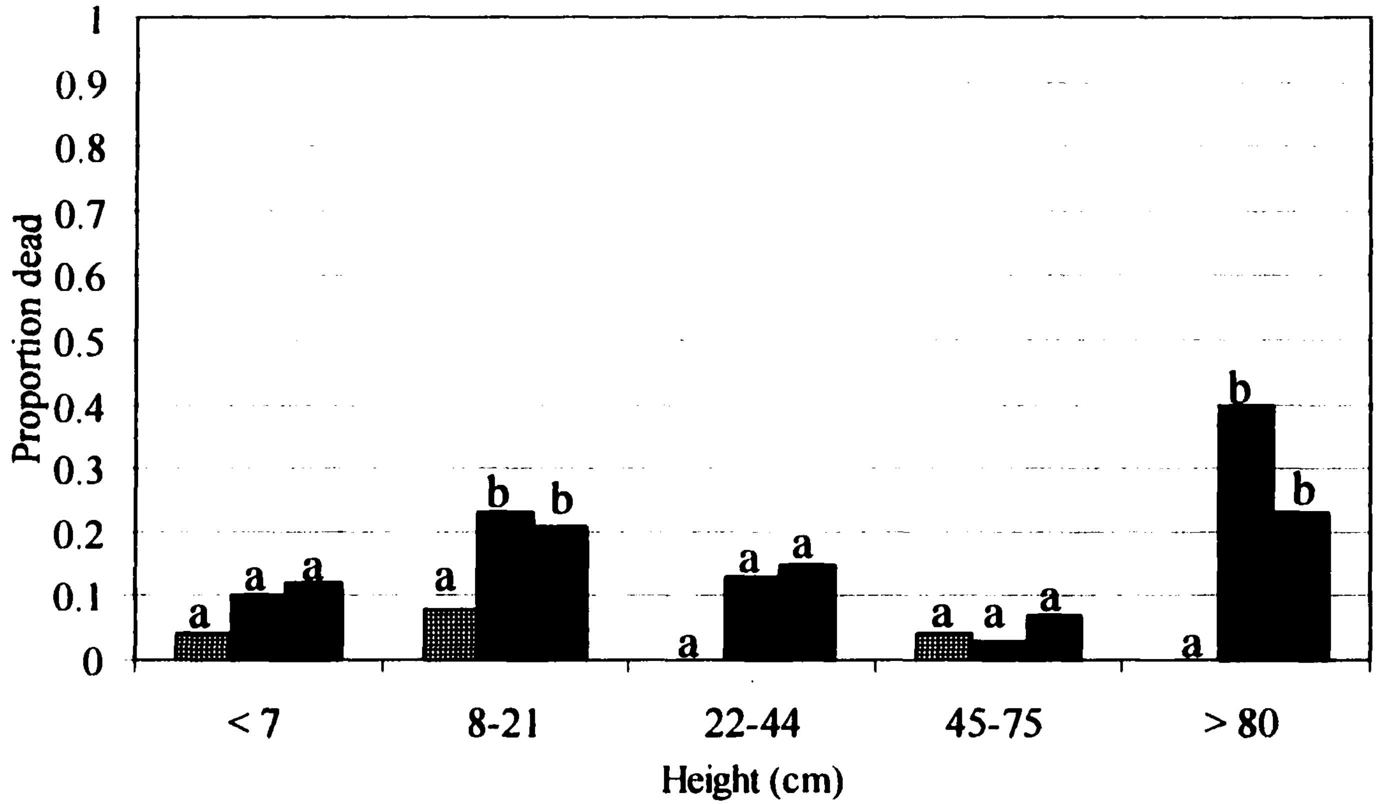

FIGURE 3. The mean proportion (number dead of a size class divided by the number counted of that size class) of *Agave palmeri* found dead in experimental plots April 2000, two years after the Double R prescribed burn in southeastern Arizona. Checkerboard bar is unburned, solid dark bars are burned plots, solid light bars are augmented plots. A missing bar means none found dead at that height class and treatment. Columns within a size class with the same lowercase letter are not different ($p > 0.05$) according to the Wilcoxon Kruskal/Wallis test (rank sums).

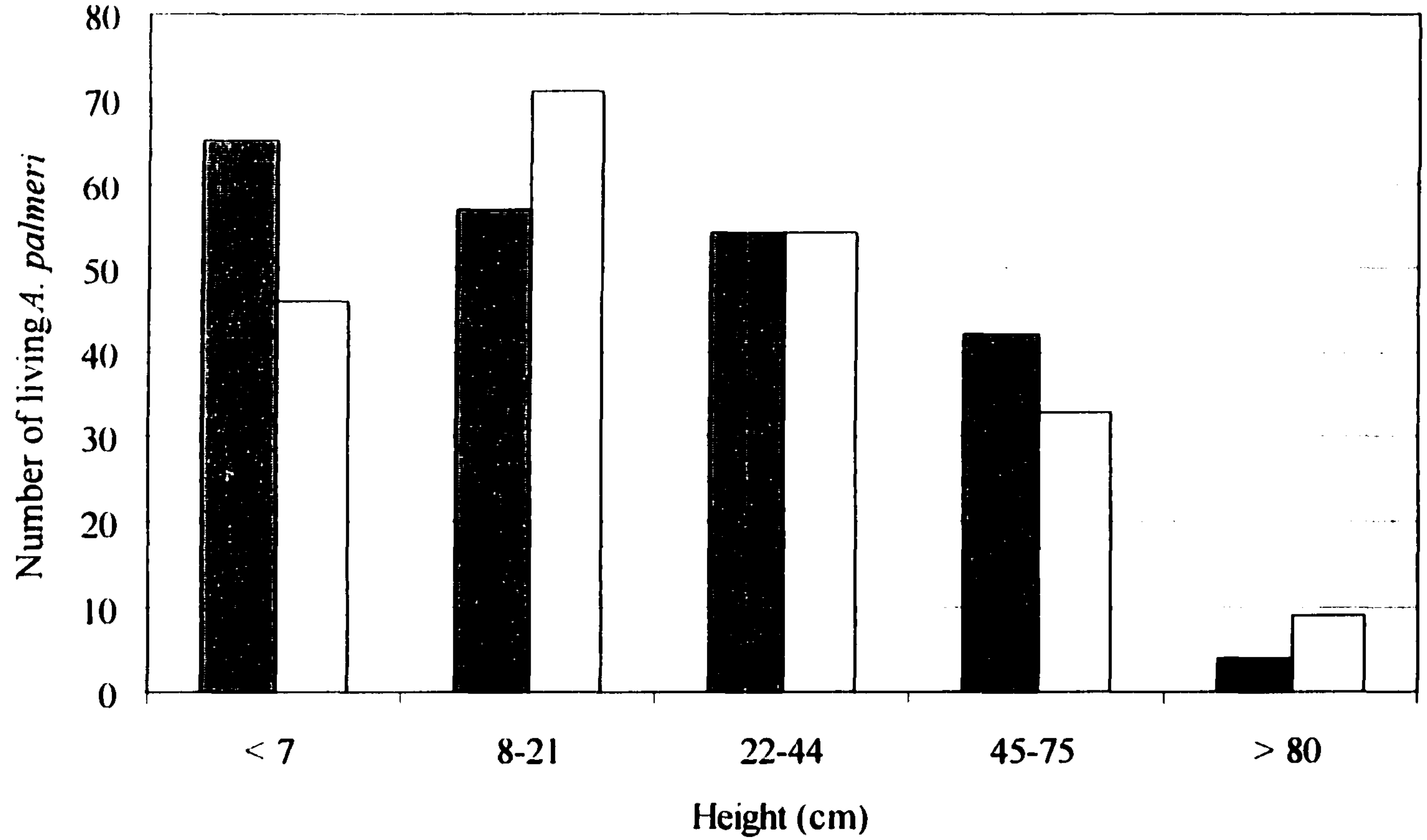

FIGURE 4. Number of *A. palmeri* in each height class on burned plots that were part of the Double R prescribed burn in southeastern Arizona and counted in July 1998 then compared to the number living in burned plots in April 2000. Striped bars represent July 1998 and unfilled bars represent April 2000. Overall, the total number of agaves before the burn in burned plots is not different ($p = 1.0$) from the number of agaves living 2 years post-burn according to Wilcoxon/Kruskal-Wallis test (rank sums).

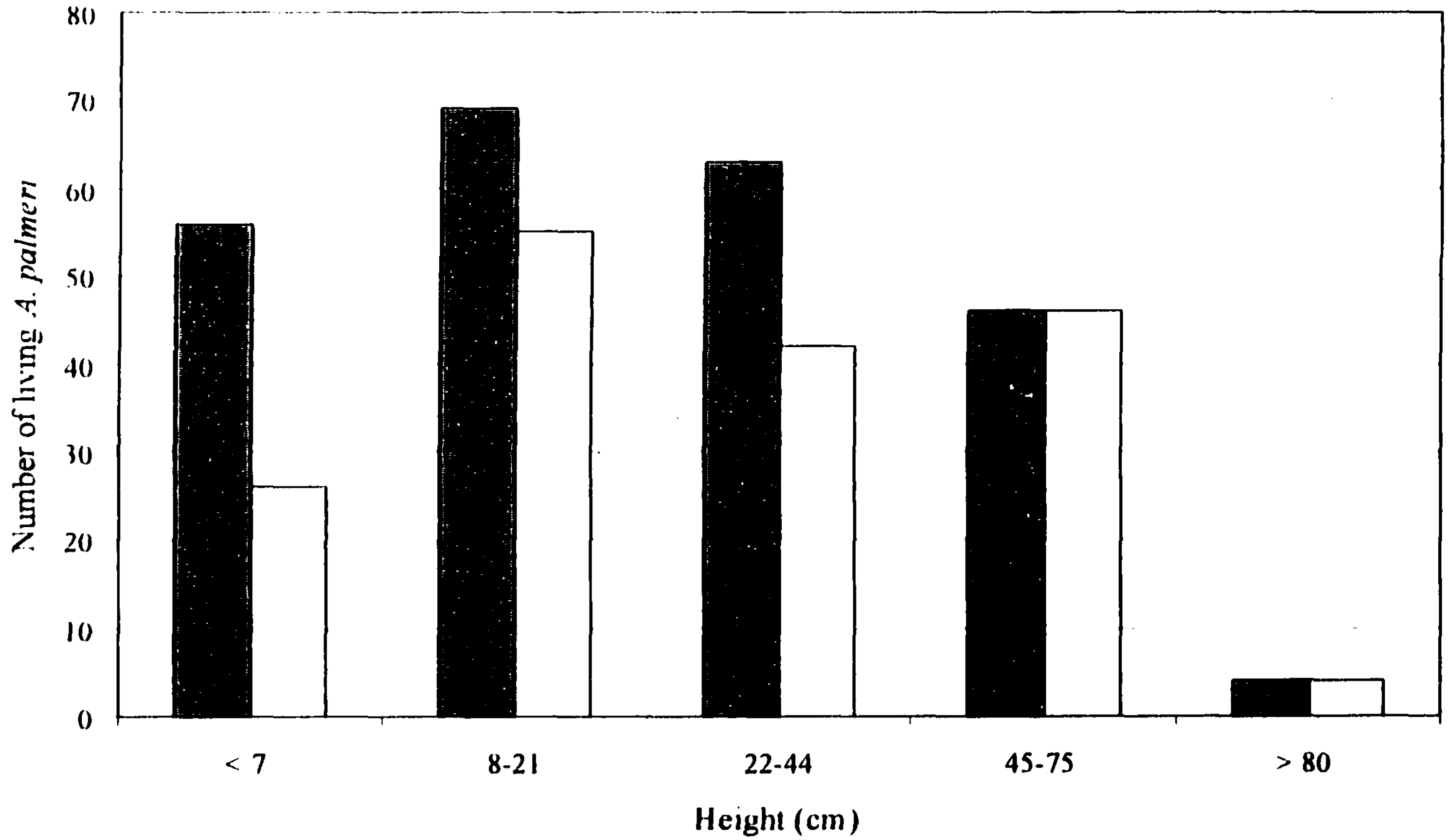

FIGURE 5. The number of *A. palmeri* in each height class on fuel-augmented plots that were within the Double R prescribed burn in southeastern Arizona and counted July 1998 then compared to the number living 2 years post-burn, April 2000. Striped bars represent 1998 and unfilled bars represent 2000. Overall, the total number of agaves before the burn is different ($p = 0.05$) from the number of agaves living 2 years post - burn, according to the Wilcoxon Kruskal/Wallis test (rank sums).

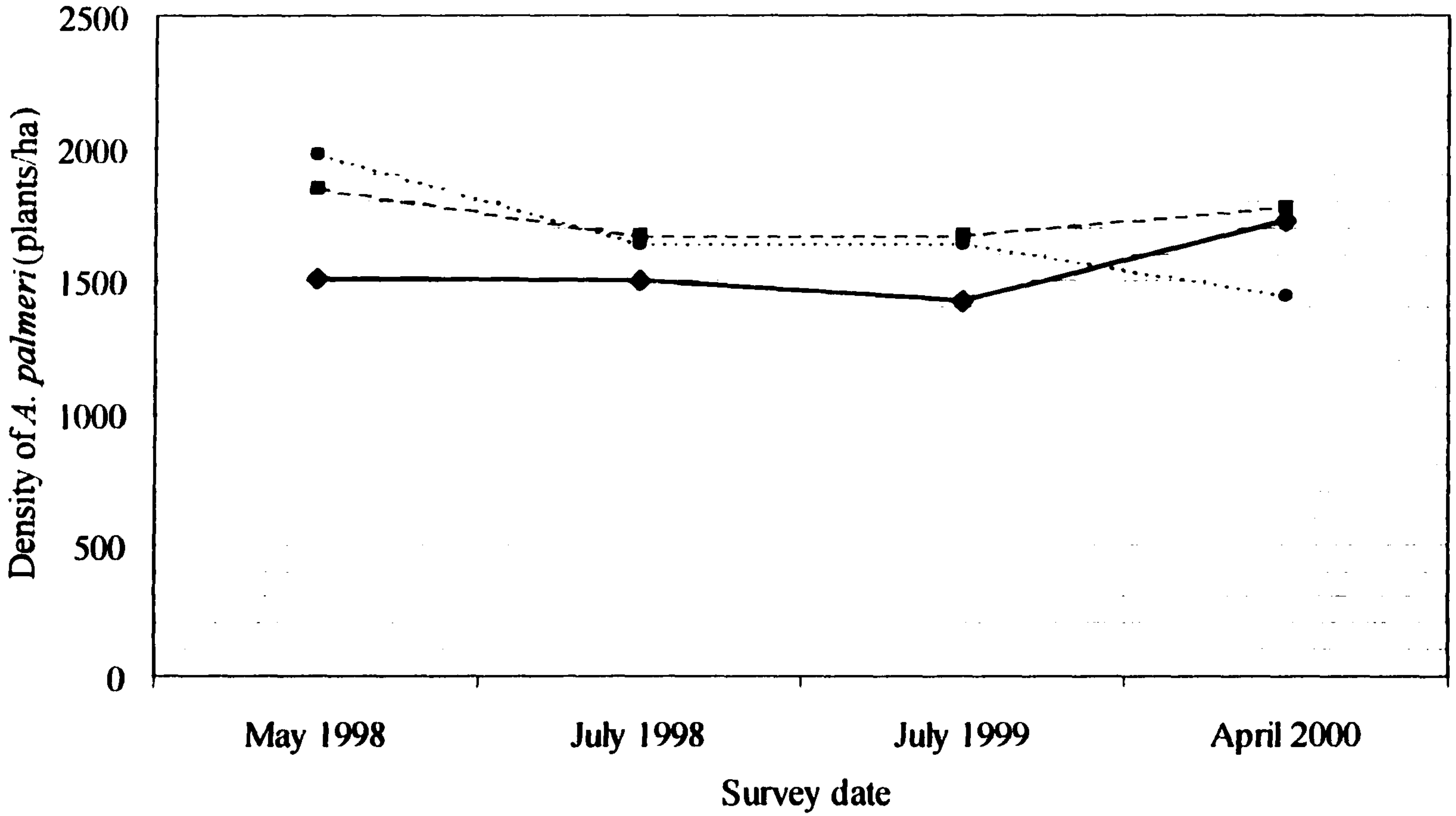

FIGURE 6. Density of living *A. palmeri* in three different treatments before and after a prescribed fire. Augmented plots had added fine fuels. Burned plots burned with extant fine fuels. Unburned plots were left unburned. The fires occurred in June of 1998. Surveys were completed 2 weeks before the burn, two weeks post-burn, one year post-burn and 2 years post-burn. May '98 numbers adjusted based on July '98 post-burn counts of all agaves (see Table 1.6 and text for further explanation).

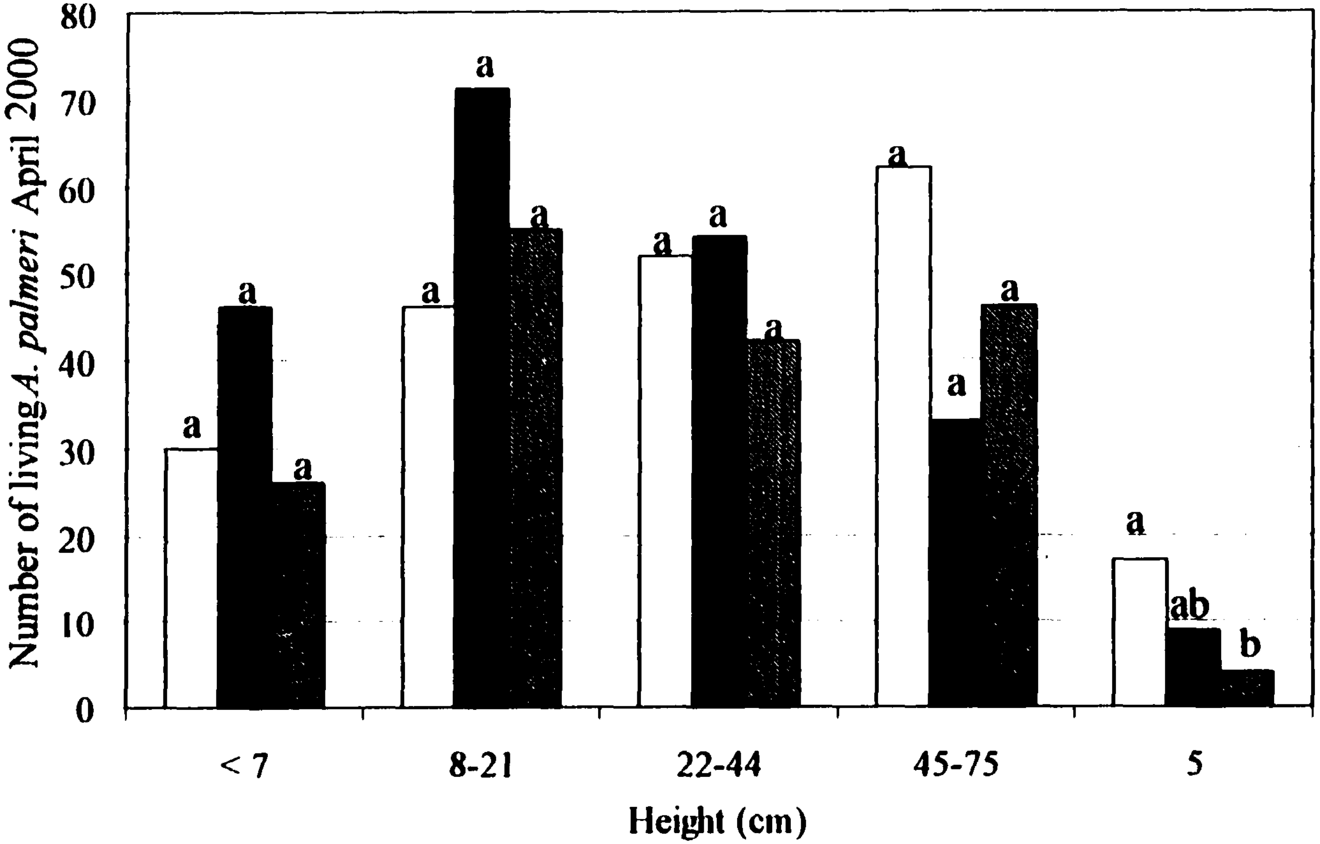

FIGURE 7. A comparison of the number of living *A. palmeri* plants by height class and treatment, 2 years after the June 1998 Double R prescribed fire in southeastern Arizona. Augmented plots (diagonal bars) had added fine fuels. Burned plots (solid bars) burned with extant fine fuels. Unburned plots (unfilled bars) were left unburned. Lower case letters on a bar denote no significant difference in the mean number of living *A. palmeri* between treatments within a height class ($p > 0.05$) according to Wilcoxon Kruskal/Wallis test (rank sums).

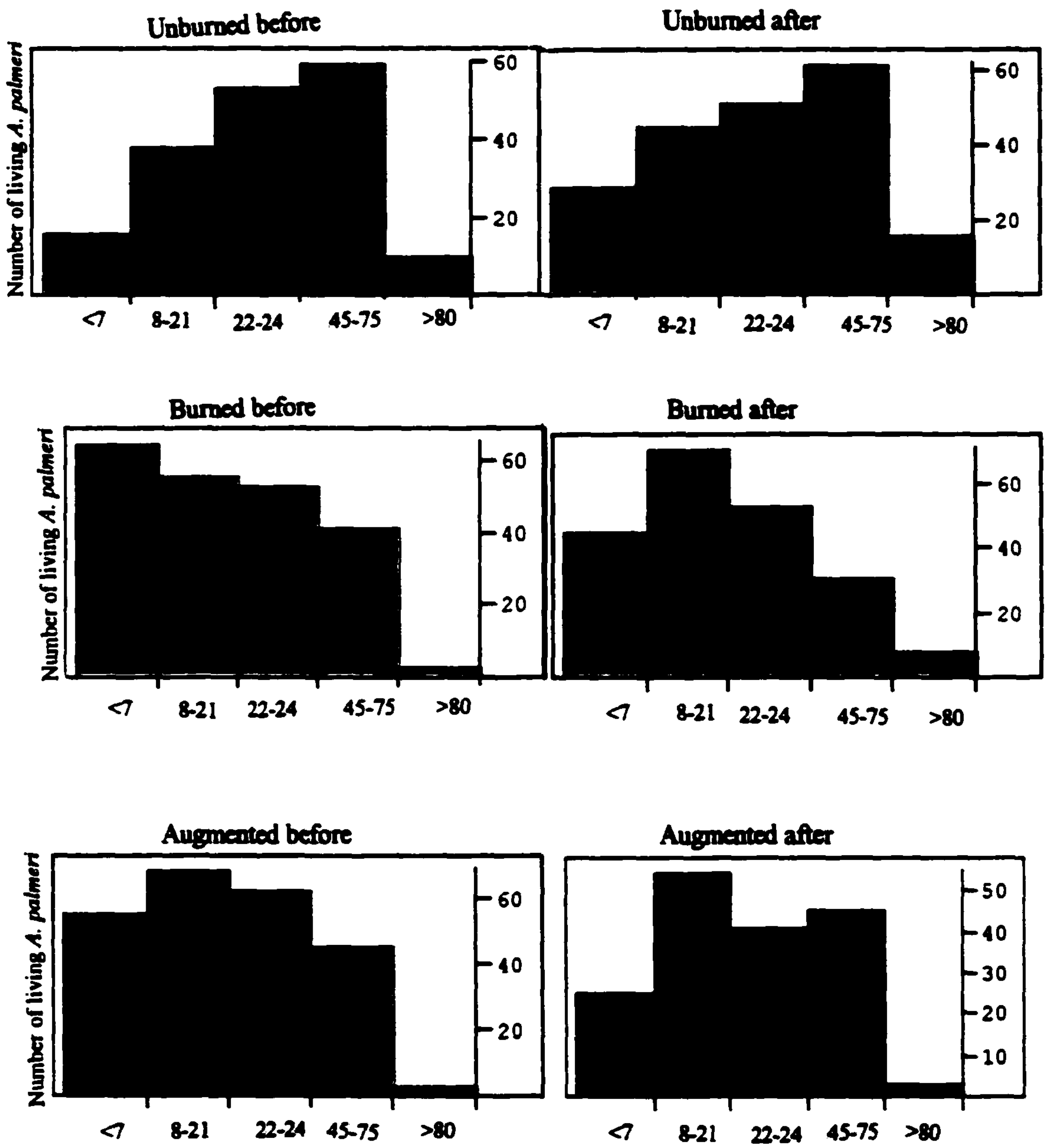

FIGURE 8. The population distribution of living *A. palmeri* among height classes in three different treatments before and two years after a prescribed burn ignited June 1998 in southeastern Arizona. The y-axis is the actual number of living agaves in that height class. Before counts are based on July 1998 post-burn counts of all observed agaves (see text).

Literature Cited

Ahlstrand, G.M 1982. Response to Chihuahuan desert mountain scrub vegetation to burning. Journal of Range Management 35:62-65.

Bahre, C.J. 1985. Wildfire in southeastern Arizona between 1859 and 1890. Desert Plants 7(4)190-194.

Bahre, C.J. 1991. A Legacy of Change: Historic Impact on Vegetation in the Arizona Borderlands. University of Arizona Press, Tucson, Arizona, USA.

Baisan, C.H. 1995. In: Brown, J.K., Mutch,R.W.,Spoon C.W.,Wakimoto, R.H., tech. coords. Proceedings: symposium on fire in wilderness and park management; 1993 March 30-April 1; Missoula, MT. General Technical Report INT-GTR-320. USDA Forest Service, Intermountain Research Station, Ogden, Utah.

Bailey, AW. and M.L. Anderson. 1980. Fire temperatures in grass, shrub, and aspen forest communities of central Alberta. Journal of Range Management 33:37-40.

Bock, C.E. and J.H. Bock. 1976. A study of the effects of grassland fires at the research ranch in southeastern Arizona. Journal of the Arizona Academy of Science 11:49-57.

______. 1978. Response of birds, small mammals, and vegetation to burning sacaton grasslands in southeastern Arizona. Journal of Range Management 31:296-300.

______. 1986. Habitat relationships of some native perennial grasses in southeastern Arizona. Desert Plants 8:3-14.

Britton, C.M. and H.A. Wright. 1971. Correlation of weather and fuel variables to mesquite damage by fire. Journal of Range Management 24:136-141.

Brown, D.E. and R. A. Minnich. 1986. Fire changes in creosote bush scrub of the western Sonoran desert, California. The American Midland Naturalist 116:411-422.

Brunsen, E., D. Gori, and D. Backer. 2001. Watershed improvement to restore riparian and aquatic habitat on the Muleshoe Ranch CMA. Report to the Arizona Water Protection Fund, Project #97-035.

Bunting, S.C., H.A. Wright, and L.F. Neuenschwander. 1980. Long-term effects of fire on cactus in the southern mixed prairie of Texas. Journal of Range Management

33:85-88.

Bureau of Land Management. 1998. Muleshoe ecosystem management plan and environmental assessment U.S. Department of the Interior, BLM, Tucson, Arizona, USA.

Cable, D.R. 1965. Damage to mesquite, Lehmann lovegrass, and black grama by a hot June fire. Journal of Range Management 18:326-329.

_____. 1967. Fire effects on semidesert grasses and shrubs. Journal of Range Management 20:170-176.

_____. 1975. Influence of precipitation on perennial grass production in the semidesert southwest. Ecology 56:981-986.

Cave, G.H. and D.T. Patten. 1984. Short-term vegetation responses to fire in the upper Sonoran desert. Journal of Range Management 37:491-496.

Cox, J.R., H.L. Morton, T.N. Johnsen Jr., G.L. Jordan, S.C. Martin, and L.C. Fierro. 1984. Vegetation restoration in the Chihuahuan and Sonoran deserts of North America. Rangelands 6:112-115.

Cox, J.R., A de Alba-Avila, R.W. Rice, and J.N. Cox. 1993. Biological and physical factors influencing *Acacia constricta* and *Prosopis velutina* establishment in the Sonoran desert. Journal of Range Management 46:43-48.

Daubenmire, R. 1968. Ecology of fire in grasslands. Advances in Ecological Research 5:209-266.

Dwyer, D.D. and R.D. Pieper. 1967. Fire effects on blue grama-pinyon-juniper rangeland in New Mexico. Journal of Range Management 20:178-182.

Fleming, T. H., R. A. Nunez, and L. Da Silveira Lobos Sternberg. 1993. Seasonal changes in the diets of migrant and non migrant nectarivorous bats as revealed by carbon stable isotope analysis. Oecologia 94: 72-75.

Freeman, C.E. 1973. Some germination responses of lechegilla (*Agave lecheguilla* Torr.). Southwestern Naturalist 18:125-134.

Gentry, H.W. 1982. Agaves of Continental North America. University of Arizona Press, Tucson, Arizona, USA.

Griffiths, D.A. 1910. A protected stock range in Arizona. USDA Bureau of Plant Industries Bulletin no.177.

Gori, Dave. 1994. Monitoring upland vegetation on the Muleshoe Ranch Cooperative Management Area: Summary of 1991 results. Paper for The Nature Conservancy, Arizona Chapter. Tucson, Arizona, USA.

Hasting, J.R. and R.M. Turner. 1965. The Changing Mile: An Ecological Study of Vegetation Change with Time in the Lower Mile of an Arid and Semiarid Region. The University of Arizona Press, Tucson, Arizona, USA.

Howell, D.J. 1972. Physiological adaptation in the sydrome of chiropterophily with emphasis on the bat Leptonychteris. Ph.D thesis, University of Arizona, Tucson, Arizona, USA.

Howell, Donna A. 1996. Draft- Agave palmeri on Ft. Huachuca- five years of research on natural history and response to fire. Department of Agriculture Environmental Analysis report contract # 1890C0079.

Humphrey, R.R. 1949. Fire as a means of controlling velvet mesquite, burroweed, and cholla on southern Arizona ranges. Journal of Range Management 2:175-182.

Humphrey, R.R. 1987. 90 Years and 535 Miles: Vegetation Changes along the Mexican Border. University of New Mexico Press, Albuquerque, New Mexico, USA.

Humphrey, R.R. and A.C. Everson. 1951. Effect of Fire on a mixed grass-shrub range in southern Arizona. Journal of Range Management 4:264-266.

Mannetje, L.H. and Haydock, K.P. 1963. The dry-weight rank method for botanical analysis of pasture. Journal of the British Grassland Society. 18:268-275.

Martin, S.C. 1975. Responses of semidesert grasses and shrubs to fall burning. Journal of Range Management 36:604-610.

McLaughlin, S.P. and J.E. Bowers. 1982. Effects of wildfire on a Sonoran desert plant community. Ecology 63: 246-248.

McPherson, G.R. 1995. The role of fire in the desert grasslands. Pages 130-151 in M.P. McClaran, and T.R. Van Devender. The Desert Grassland. The University of Arizona Press, Tucson, Arizona, USA.

McPherson, G.R. 1997. Ecology and Management of North American Savannas. The University of Arizona Press, Tucson, Arizona, USA.

Nobel, Park S. 1988. Environmental Biology of Agave and Cacti. Cambridge University Press. USA.

Ober, Holly K. 2000.Foraging Ecology of Lesser Long-Nosed Bats. A thesis submitted to the School of Renewable Natural Resources, The University of Arizona.

Patten, D.T. and G. H. Cave. 1984. Fire temperatures and physical characteristics of a controlled burn in the upper Sonoran desert. Journal of Range Management 37:277-280.

Ruyle, G.B. (Editor) 1987. Some methods for monitoring rangelands and other natural area vegetation. Division of Range Management Extension Report 9043.

Robinett, D. 1994. Fire effects on southeastern Arizona plains grasslands. Rangelands: 16: 143-148.

Rogers, G.F. 1985. Mortality of burned *Cereus gigantus*. Ecology 66:630-632.

Sall, J. and A. Lehman. 1996. JMP Start Statistics: A guide to statistics and data analysis using JMP and JMP IN software. Duxbury Press, Belmont, California, USA.

Slauson, Liz. 2000. Pollination biology of two chiropterophilous agaves in Arizona. American Journal of Botany 87: 825-836.

Stokes, M.A. and J.H. Dieterich, tech. coordinators. 1980. Proceedings of the fire history workshop. General Tech Report RM-81, USDA. Rocky Mountain Forest and Range Experimental Station.

Swetnam, T.W. and C.H. Baisan. 1995. Historical fire regime patterns in the southwestern United States since AD 1700. Pp. 11-32 in Allen, C.D. Editor, Proceedings of the 2nd La Mesa fire symposium, March 29-31 1994, General Technical Report RM-GTR-286, USDA Forest Service Los Alamos, New Mexico, USA.

Swetnam, T.W. and C.H. Baisan.1996. Fire history of montane forests in the Madrean borderlands. Pp. 15-36 *in* Ffolliott, P.F., L.F. DeBano, M.B. Baker, Jr.,G.J. Gottfried, G. Solis-Garza, C.B.Edminster, D.G. Neary, L.S. Allen, and R.H. Hamre. Effects of Fire on Madrean province ecosystems- A symposium proceedings. USDA Forest Service General Technical Report RM-GTR-289.

Swetnam, T.H. and C. H. Baisan. 1996. Fire history of desert island mountain ranges in the Mexican borderlands regions. Final Report to the Nature Conservancy. Contract No. HQ/AZ-920201-2

Thomas, P.A. and P. Goodson. 1992. Conservation of Succulents in desert grasslands managed by fire. Biological Conservation 60:91-100.

Thomas, P.A. 1991. Response of succulents to fire: A review. International Journal of Wildland Fire 1:11-22.

USDA. 1988. Natural Resource Conservation Field Office Technical Guide for Arizona. Section 2. Soil Conservation Service, Phoenix, Arizona, USA.

U.S. Dept of the Interior. Sep. 1996. Muleshoe Ecosystem Management Plan and Environmental Assessment. Bureau of Land Management, Tucson Field Office, Tucson, Arizona, USA.

USFS. 2000. Biological Opinion: On-going and long-term grazing on the Coronado National Forest:Lesser long-nosed bat (*Leptonycteris curosoae*). Coronado National Forest Service, Tucson, Arizona, USA.

USFS 2000. Biological Opinion: On-going and long-term grazing on the Coronado National Forest: Mexican Long-nosed bat (*Leptonycteris nivalis*). Coronado National Forest Service, Tucson, Arizona, USA.

USFWS 2001. Biological and conference opinion on the Black Diamond Allotment, Coronado National Forest, Cochise County, Arizona. AESO/SE 2-21-01-F-071. Coronado National Forest Service, Tucson, Arizona, USA.

USFWS, 1995. Lesser long-nosed bat recovery plan. U.S. Fish and Wildlife Service. Albuquerque, New Mexico, USA.

White, L.D. 1969. Effects of a wildfire on several desert grassland shrub species. Journal of Range Management 22:284-286.

Widmer, K. and M.P. McClaran. 2001. Inflorivory of Palmer agave in relation to livestock grazing management on the Coronado National Forest. Society for Range Management annual meeting. Kona, Hawaii, Feb. 2001.

Wright, H.A. 1972. Shrub response to fire. Pp. 204-217 in McKell, C.M., J.P. Blaisdell, and J.R. Goodin (Eds). Wildland Shrubs- their biology & utilization. USDA Forest

Service Research Paper Int-1. Intermountain Forest and Range Experimental Station, Ogden, Utah.

Wright, H.A. 1980. The role and use of fire in the semidesert grass-shrub type. USDA Forest Service General Technical. Report INT-85. Intermountain Forest and Range Experimental Station, Ogden, Utah.

Wright, H.A., and A.W. Bailey. 1982. Fire Ecology: United States and Southern Canada. John Wiley and Sons, New York, USA.

Zar, J. H. 1984. Biostatistical analysis. Prentice-Hall. Englewood Cliffs, New Jersey, USA.