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IMPACT OF GROUND WATER DEPLETION ON THE MESQUITE COMMUNITY AT EDWARDS AIR FORCE BASE, WESTERN MOJAVE DESERT, CALIFORNIA

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ABSTRACT

Edwards Air Force Base (EAFB) provides a habitat refugium for mesquite woodlands in the western Mojave Desert of the Antelope Valley. Although many mesquite communities in the arid southwest are considered invasive as they reduce the extent of grazing lands, the community at EAFB is composed primarily of large, widely spaced trees that provide food and shelter for local wildlife species and recreational opportunities for base personnel. Unfortunately, the range of these mesquite trees appears to be contracting as mature and old individuals dominate the community. Although anecdotal evidence suggests that the fall in the local groundwater table is responsible for the decline of the mesquite community at EAFB, no research has been carried out to confirm this. Our results corroborate the hypothesis that the groundwater table at EAFB has declined in the second half of the 20th century and that the area of the mesquite community is diminishing. Although the mesquite community expanded vigorously from 1956 to 1968, it contracted considerably from 1984 to 2000. The evidence for this observed decline is reinforced by the results of the age-class analysis as the community in 2003 is made up largely of mature, old, dying and dead trees. Few saplings (older than 2 years) and no new seedlings (1–2 years) are present in the study sites, suggesting that the mesquite community may not be able to replenish itself.

Key words: age-class analysis, groundwater, mesquite, Mojave Desert, range contraction.

INTRODUCTION

While many of the mesquite communities dominated by *Prosopis glandulosa* Torr. var. *torreyana* (L.D. Benson) M.C. Johnst. across the southwest United States represent invasions of small trees into open rangelands, mesquite communities in California deserts are generally composed of large, widely-spaced individuals associated with groundwater resources. These stands of mesquite support local ecological resources, acting as a keystone species that enhances value for wildlife and increases species diversity. Much of the significance of mesquite comes from its remarkable growth rate that produces large amounts of palatable leaves and pods. The ability of its deep roots to tap underground water sources and the presence of nitrogen-fixing root nodules allow mesquite trees to largely decouple their growth from the major limiting factors of water and nitrogen (Rundel et al. 1982). Open stands of old-growth mesquite with large diameter and widely spaced trees offer benefits to the local plant populations by accumulating carbon and nitrogen under their canopy and providing shade for developing seedlings (Tiedemann and Klemmedson 1973; East and Felker 1993).

Edwards Air Force Base (EAFB) in the Antelope Valley of the western Mojave Desert once supported an extensive mesquite community. However, in contrast to the range expansion of mesquite seen across many areas of the arid southwest of the United States, the mesquite community at EAFB appears to be contracting as many mature trees have died in the last decades of the 20th century (Fig. 1). While falling groundwater tables in the region are presumed to be responsible for this decline, no formal research has yet been undertaken to examine the apparent decline of this community. Groundwater levels in the Antelope Valley of California fell through the 20th century as groundwater pumping rates outpaced recharge rates. As the groundwater table falls, even phreatophytic (deep-rooted) species such as mesquite have the potential to become increasingly water stressed if the roots are unable to grow fast enough to keep up with the drop in water table levels. Therefore, water withdrawals and the resulting decline in groundwater levels are a concern for phreatophytic communities throughout the arid southwest of the United States and the world (Gou et al. 2015). There may be non-linear threshold responses in canopy condition linked to rooting depth that can occur relatively abruptly, with chronic groundwater decline decoupling trees from deep soil moisture resources. The quantification of groundwater depth thresholds is likely to be critical for management aimed at conserving groundwater-dependent biodiversity (Kath et al. 2014).

This study was designed to examine the distribution and historic changes in the mesquite community at EAFB (Figure 2) and to investigate the causal factors responsible for observed changes. EAFB is a large military base extending over 121,000 ha of the western Mojave Desert in southern California (Charlton and Rundel 2017). We have utilized aerial photography of EAFB taken from the 1950s to 2000s and evaluated these in conjunction with data on groundwater level records, precipitation records and mesquite age-class analyses to determine historic changes in this community over those 50 years. To assess the effect of water table decline on the health and distribution of the local phreatophytic mesquite community, we have examined the following questions: (1) How severely has the groundwater level changed over the past century? (2) How has the areal coverage

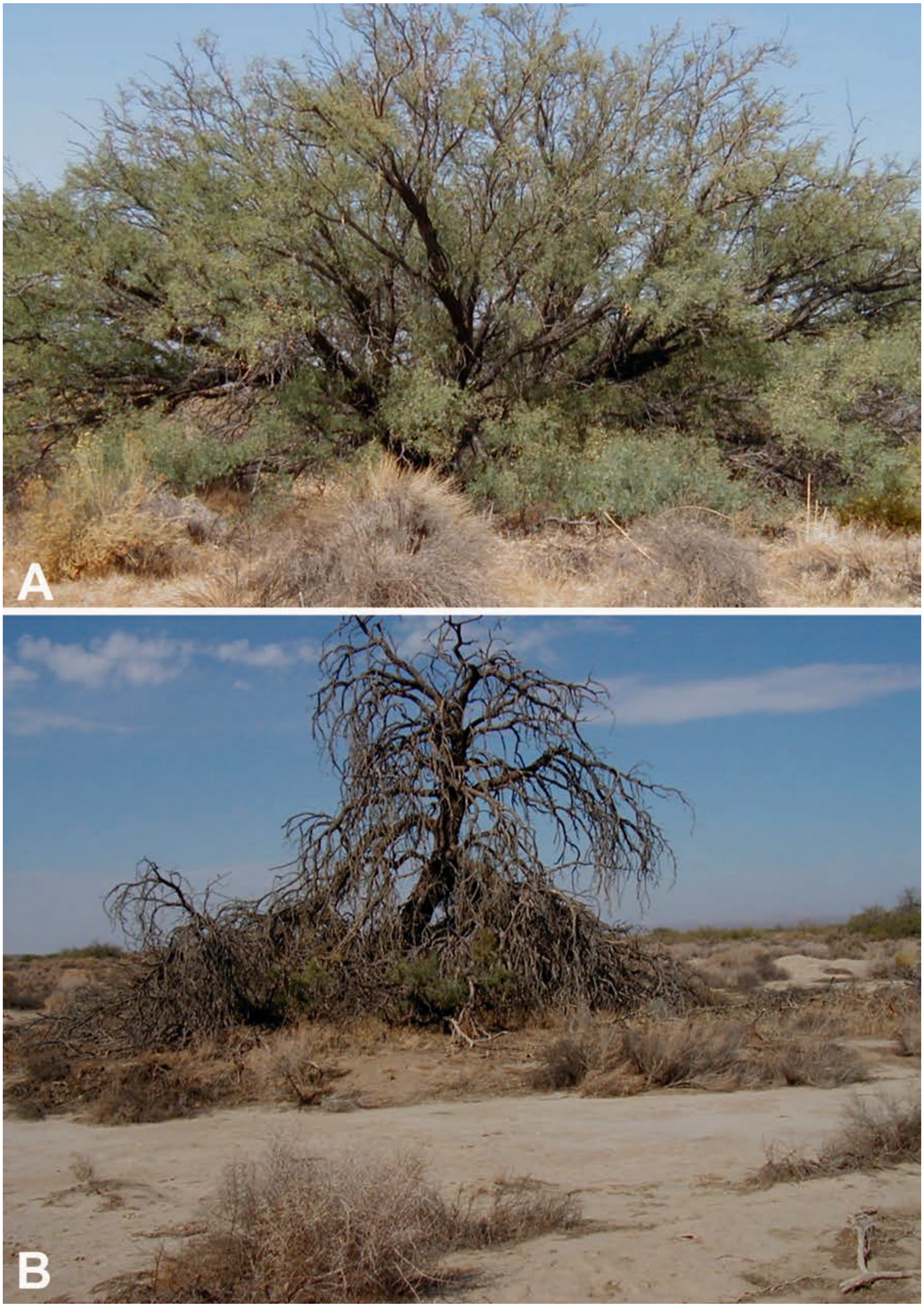

Fig. 1. Mesquite community at Edwards Air Force Base, California. A. Healthy stand of large mesquite trees. B. Skeletons of dead mesquite trees.

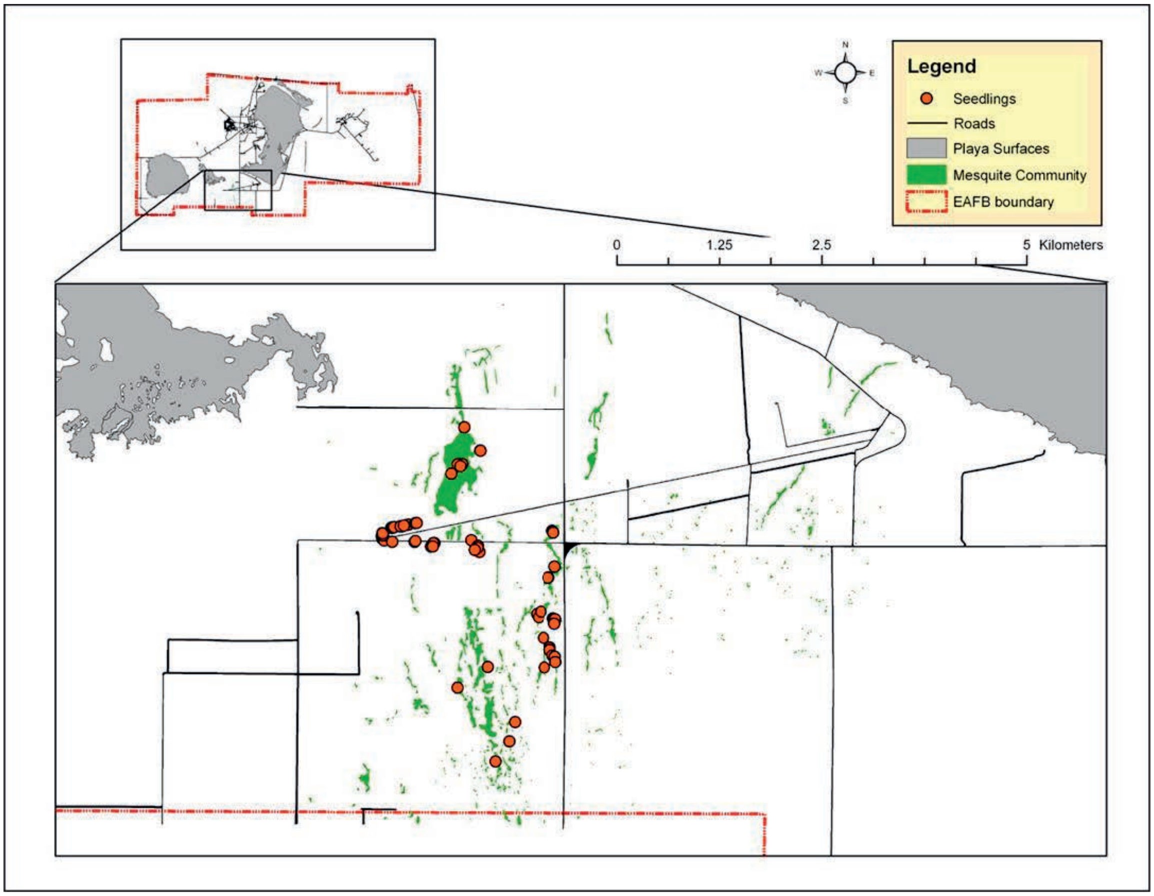

Fig. 2. Distribution of the mesquite community and mesquite seedlings in 2003 at Edwards Air Force Base, California.

of individual mesquite trees changed over the past 50 years? (3) How has the areal extent of the overall mesquite community changed over the past 50 years? Finally, (4) what is the current age-class structure of the mesquite community and does this represent a healthy mix of life stages?

MATERIALS AND METHODS

Groundwater Dynamics

The US Geological Survey (USGS) maintains records on hundreds of groundwater wells in the Antelope Valley. These records span over one hundred years of information and provide valuable insight into historic groundwater changes. However, most records cover only brief time spans and are focused on measurements of deep, confined aquifers and not the uppermost groundwater resource with which the mesquite community interacts (e.g., Carlson et al. 1998; Carlson and Phillips 1998). To ascertain the depth of the groundwater and local variability of the groundwater resource available to the mesquite community, eight new wells were drilled within the mesquite community at EAFB during spring 2003 using a 4-inch split-spoon, hollow stem auger. A total drilling depth of 19.8 m was available for each borehole. A drilling depth threshold of approximately 20 m was considered adequate to describe the groundwater potentially available to the mesquite trees as previous research shows that groundwater levels below 18 m is too deep for long-term mesquite growth (Stromberg et al. 1992; 1996). Groundwater depth is defined as the vertical distance from the mean ground level at a site to the upper edge of moisture availability.

Aerial Photo Interpretation

Standard air photo interpretation techniques were employed to determine changes in spatial extent of the mesquite community. Aerial photographs were systematically taken over the entire country by the U.S. Department of Agriculture (USDA) beginning in the mid-1930s, but with most of the initial imagery taken of selected agricultural lands. As a result, aerial photographs are not available for the lands incorporating the mesquite community at EAFB until the mid-1950s. Table 1 shows the medium-scale aerial photographs that were acquired

Table 1. Aerial photographs of the mesquite community at Edwards Air Force Base.

Image date	Resolution	Photo number (USGS)
17 Oct 1956	1:32,500 (B&W)	ARMPTF164010199 & -200
13 Sep 1968	1:32,500 (B&W)	ARM684290V70200
June 1973 (unused)	1:117,669 (CIR)	AR6239001600042
22 Sep 1984	1:58,000 (Color)	NHAP84F 263-54
May 1992	1:3,000 (Color)	Images provided by EAFB
April 2000	1:15,840 (Color)	Images provided by EAFB

Table 2. Description of mesquite age classes.

Growth form	Description
Sapling	Very small plants; active growth (likely ≤10 years old).
Young	Small plants; active growth; smooth, light-colored bark; trunk ≤ 10 cm diameter (likely >10 years of age).
Mature	Small to large plants; active growth; rough, dark bark at main stem; leaf coverage on all branches of plant; trunk >10 cm diameter.
Old	Large plants; extensive basal sprouting; sparse leaf coverage on central branches; healthy leaf growth from basal sprouts.
Dying/dead	Sparse to no leaf coverage over entirety of plant.

for this analysis. The 1973 image shown in this table was the only photo located during that decade that covered the entire extent of the mesquite community. However, it was deemed unsuitable for use in the analysis due to its coarse scale relative to the other images.

Potential changes in the extent of the mesquite community were assessed by examining aerial photography for the changes in extent of both individual mesquite trees and groups of mesquite within one-hectare plots. One-hectare plots were chosen because plots of this size encompass the natural spatial variability of mesquite trees, as they are often sparsely distributed throughout the community. For the analysis of individual mesquite trees, two hundred target trees were randomly chosen within the boundary of the mesquite community using a point randomization algorithm downloadable from ArcView 3.1 (*http://downloads.informer.com/arcview/3.1/*). For each random point, the area of the closest mesquite tree was calculated from each of the photographs listed in Table 1 (excluding the June 1973 image). In many instances, the closest mesquite tree to the random point was clustered with other mesquite trees and therefore indecipherable from the surrounding clump of trees. In this case, the nearest free-standing mesquite tree was chosen in its place. It should be noted that this resulted in the preferential selection of younger trees due to the fact that older trees were more likely to be located within these larger, conjoined clumps. However, this problem was considered to be of minimal importance as only four of the initial 45 points had to be moved for the above reason.

Similarly, 45 one-hectare plots were randomly placed within the extent of the mesquite community to yield a broader perspective on changes within the boundary of the mesquite community. Plot locations that included any portion of an anthropogenic disturbance (e.g., road cut, rocket-sled track course, fallowed farm field, etc.) were discarded and another randomly placed plot was used in its place. Unlike the sampling methodology for the analysis of individual trees, this methodology did not result in the preferential analysis of young and mature trees. The area of mesquite canopy within each plot was determined by a GIS for each aerial photograph described in Table 1.

Mesquite Age-Class Analysis

In addition to aerial photographic analysis of the 45 one-hectare plots, mesquite trees in each plot were placed into one of five growth-form classes to assess the population structure of the community (Table 2). In addition to the examination of age classes, special attention was given to mesquite seedlings found within the community. The location of all seedlings and saplings encountered while working within the community were recorded as they were found. This effort represents individuals not only within the 45 one-hectare plots, but all juvenile mesquite within the extent of the community. This was considered important not only as an attempt to identify the location of "hot spots" for recruitment, but also to provide a database of seedling and young sapling locations which will allow for future monitoring to determine if the individuals have survived the upcoming summer months or if they are short-lived individuals that have contributed little to the long-term structure of the EAFB mesquite community.

RESULTS

Groundwater Changes

USGS wells show a history of fluctuating water tables within the Antelope Valley. While some wells do exhibit steady or slightly recharging water table levels from 1950 to 2000, most well data show a marked decrease. Three USGS wells with long-term records outside the area of the mesquite stands show a steep drop in groundwater levels during the 1950s, 1960s and 1970s, followed by less drastic losses and even recharge during the 80s and 90s (Fig. 3). Well 8N10W5A6 within the mesquite community reflects shorter-term changes in the groundwater table with a drop in depth to groundwater within the mesquite community of nearly 1.4 m in 12 years.

Depth to groundwater was recorded in each of the eight boreholes drilled during this study. These eight wells showed a wide amount of variation in spite of their relative proximity. Of those eight boreholes drilled within the mesquite community, depth to groundwater ranged from 7.7 m near Rogers Dry Lake to 19.9 m near EAFB's South Gate at the intersection of Mercury Blvd and Lancaster Blvd. These two boreholes were only 4.1 km from each other, yet showed a 12.2 m difference in depth to groundwater. Even more striking was the 3.4 m difference in groundwater depths between the two boreholes south of Rosamond Dry Lake that were only 0.5 km apart. Such differences in groundwater depth over short distances typically reflect changes in substrate geology that confine moisture flow. Despite the major differences in groundwater depths, there was no observable difference between plant communities or geomorphic formations over this area (see Lichvar et al. 2004; Orme 2008).

Aerial Photo Interpretation of Individual Mesquite Trees

Inspection of aerial photography shows strong evidence of change in the canopy size and extent of the mesquite community over five decades. Analysis of individual mesquite trees shows both increases and decreases in plant size since 1956. Figure 4 shows a decadal time series of aerial photographs that illustrates the canopy growth of individual mesquite trees from the 1950s to 2000s. Conversely, Fig. 5 shows a similar time series of photographs that illustrates a pattern of decline in the canopy coverage of other individual mesquite trees over that same time period.

While expanding and declining trends have been seen to occur in the mesquite community at EAFB, there was an overall increase of nearly 49.7% in the canopy size of individual mesquite

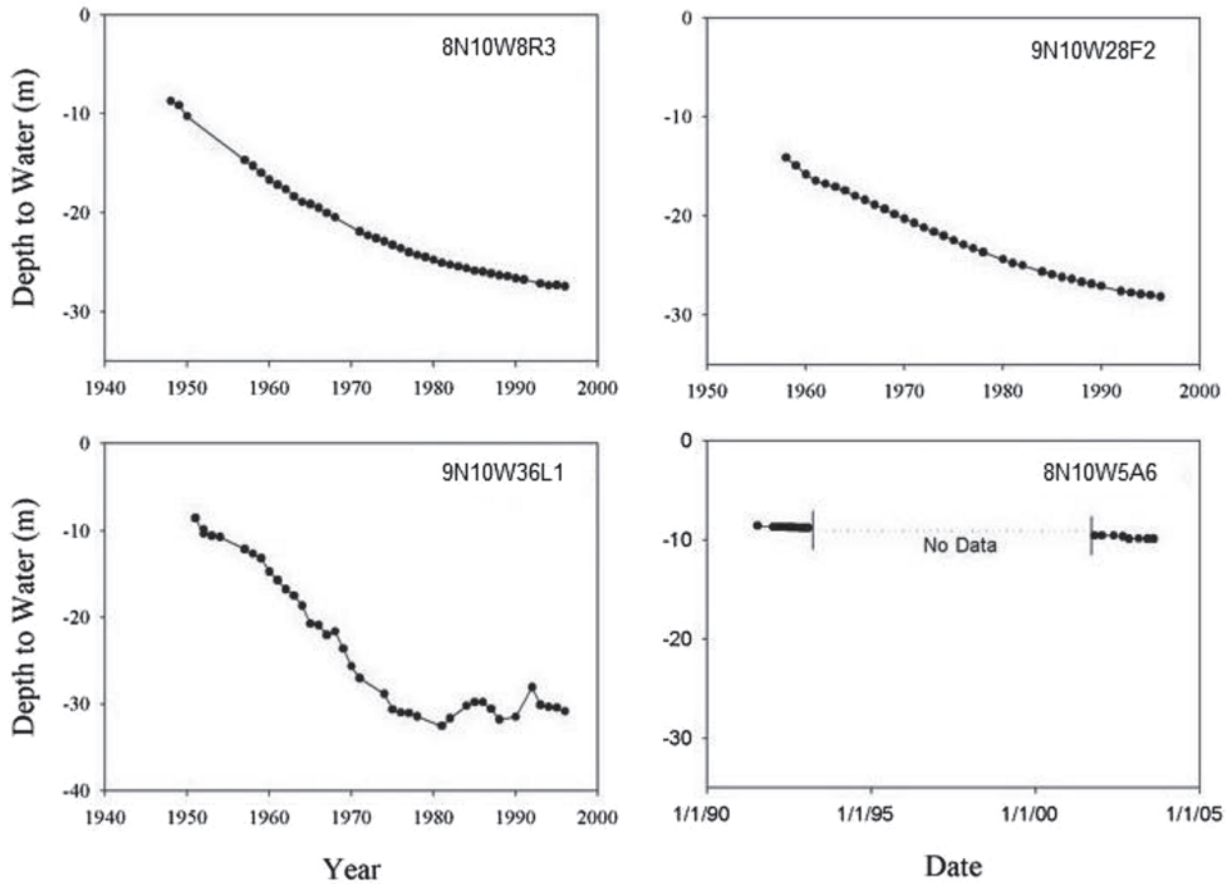

Fig. 3. Declining trends in groundwater levels at four USGS groundwater wells in the vicinity of the mesquite community at Edwards Air Force Base, California.

trees from 1956 to 2000 (Table 3). This suggests that vigorous expansion in the mesquite canopy cover is occurring. However, it was apparent upon closer inspection that most of this expansion occurred from 1956 to 1968. Indeed, during the 1956–1968 time period there was a 37.9% increase in mesquite canopy coverage as measured by individual trees. The 1968–1984 images also showed a marked increase (23.2%), but this increase was less than that seen previously. Likewise, the increase in individual mesquite canopy area from 1984 to 1992 was much less than the previous time periods, totaling only 7.7%. By the 1992–2000 time period, the trend had reversed and individual trees had begun to decrease in overall area by a total of 21.1%.

Aerial Photo Interpretation of Canopy Coverage One-Hectare Plots

Analysis of the 45 one-hectare plots (Table 4) shows both similar and dissimilar trends in the canopy size and extent of the mesquite community when compared with the analysis of individual trees. Like the analysis of individual mesquite trees, there was an increase in mesquite area from 1956 to 1968 (15.2%). However, while the individual tree analysis resulted in a net increase in tree canopy size from 1956 to 2000, an overall decrease of 14.1% in the area of the mesquite community occurred during this time span.

Also, by the 1968–1984 time period there was already a noticeable decrease in the canopy coverage of the mesquite trees (2.6%). This trend continued as reductions in mesquite coverage of 14.0% and 10.9% followed during the 1984–1992 and 1992–2000 time steps, respectively. The numbers of one-hectare plots gaining and losing mesquite coverage reflect these temporal changes as well (Table 4).

Mesquite Age-Class Analysis

Initial visual analysis of the mesquite community at EAFB by base officials suggested that the mesquite community was suffering from insufficient recruitment. The results of this study have shown those concerns to be valid. Figure 6 illustrates the presence of a highly uneven age class structure with mature, old and dying/dead trees dominating the overall mesquite community. A total of 1289 mesquite individuals were counted in the 45 one-hectare plots. Saplings and seedlings accounted for only 2.6% and 4.3%, respectively, of the total number of mesquite trees. Mature, old, and dying/dead individuals accounted for 93.1% of the trees in the community. Our study found that 29 of the 45 plots have >50% cover of old and dying/dead individuals. Of those plots that are dominated by mature or younger trees, most occurrences are in the northern section of the mesquite community, proximal to Branch Park Blvd.

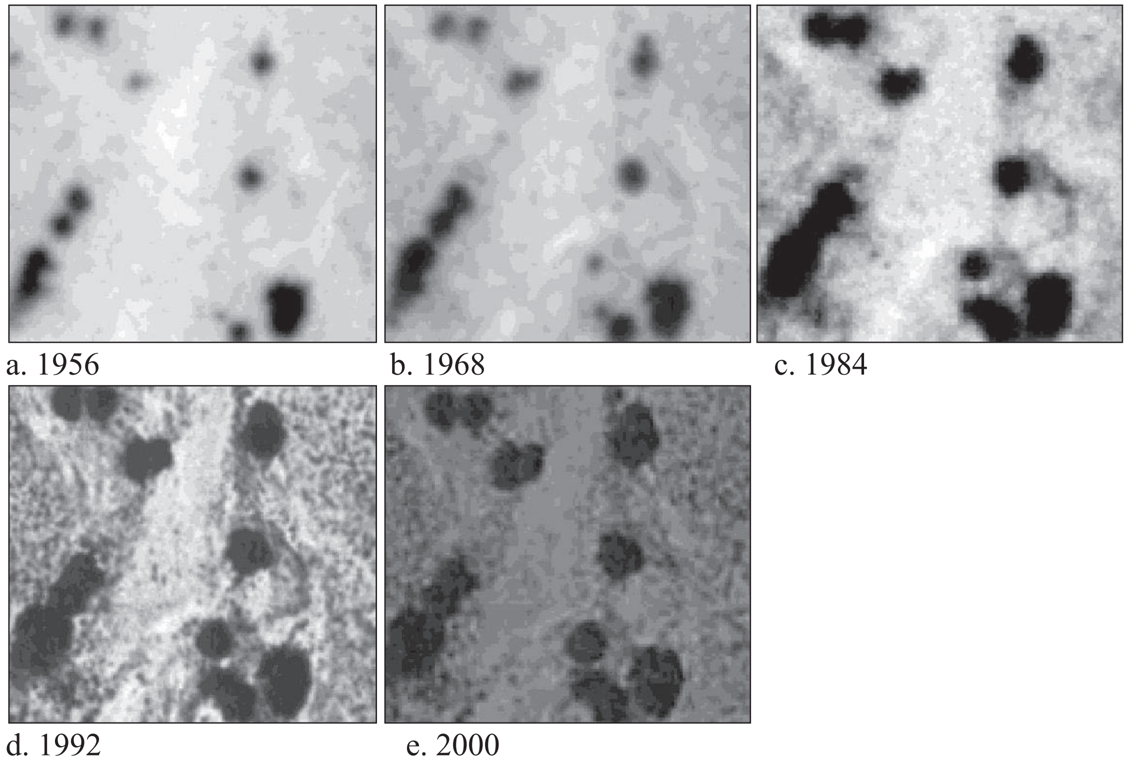

Fig. 4. Individual mesquite trees showing an increase in canopy area from 1956 to 2000 at Edwards Air Force Base, California. The center of the image is located at the UTM coordinates 416,760E 3,851,050N.

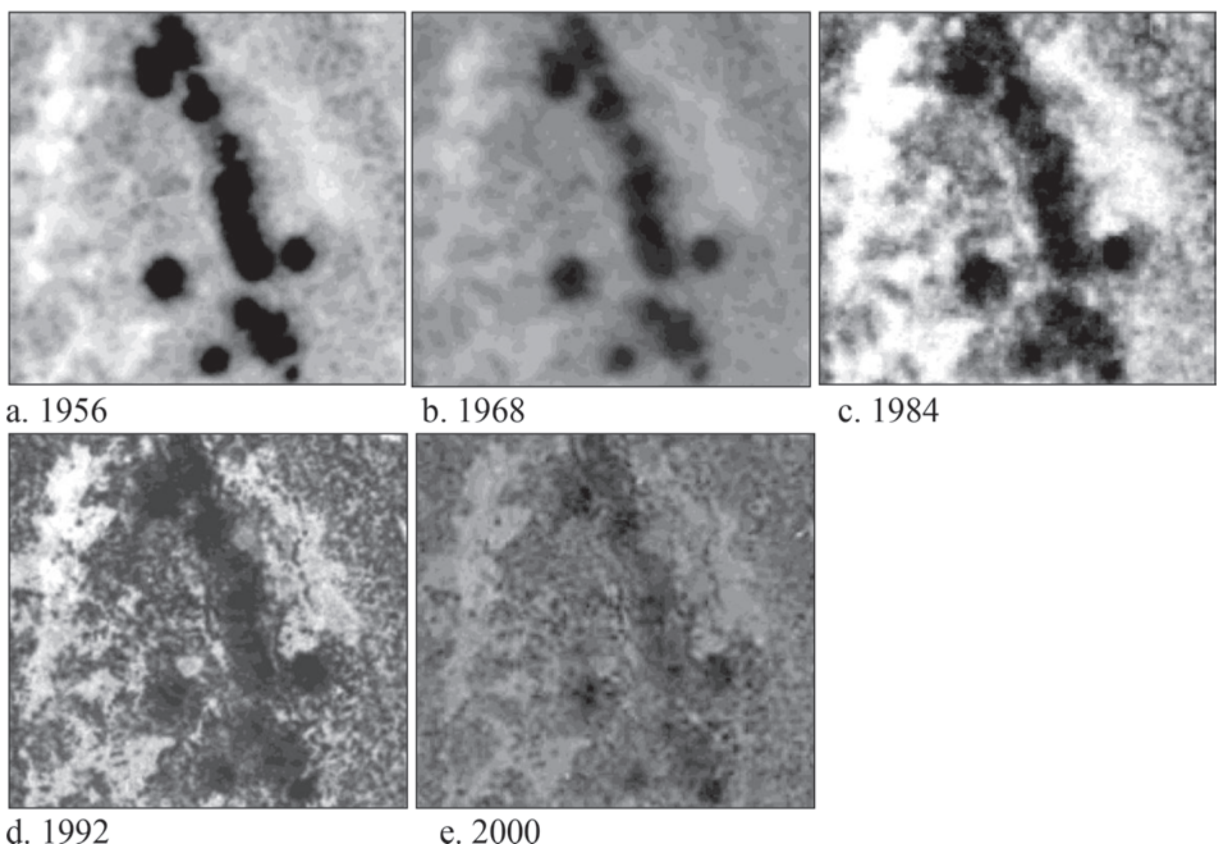

Fig. 5. Individual mesquite trees showing a decrease in canopy area from 1956 to 2000 at Edwards Air Force Base, California. The center of the image is located at the UTM coordinates 416,675E 3,851,430N.

Table 3. Areal changes in 200 individual mesquite trees over five time intervals at Edwards Air Force Base. The relative change shown is in reference to the baseline earlier date for each interval. Standard deviation values are shown in parentheses.

	1956–1968	1968–1984	1984–1992	1992–2000	1956–2000
Total change (m^2)	+7548.5	+4486.8	+1458.7	−4007.3	+9575.2
Mean change (m^2)	+37.9 (28.0)	+23.2 (38. 6)	+7.7 (26.8)	−21.1 (50.8)	+49.7 (72.3)
Number of trees gaining canopy area	185	144	74	67	156
Number of trees losing canopy area	14	53	123	131	35
Number of 1956 target trees that died by 2000	1	3	3	2	9
Number of random points with non-target tree closer to point by later date	7	4	1	0	12

The survey of seedlings found throughout the mesquite community led to surprising results. A total of 73 seedlings was located in the mesquite community (Fig. 1). Thirty-four of these seedlings were located within the 45 one-hectare plots described above, while 39 were identified outside the plots. Although many seedlings were observed, clearly most of the seedlings identified in this study were associated with disturbed habitat conditions: 38 of the 73 seedlings were found in ditches associated with the former EAFB rocket sled track or within 60 m of Mercury Blvd. Most of those occurring along Mercury Blvd were located in roadside ditches. Of the remaining seedlings, 17 were found within 250 m of Lancaster Blvd. Only 18 seedlings were located more than a quarter of a kilometer from a road or major disturbance. In addition, only seven seedlings were located in the portion of the mesquite community between Branch Park Road and Mercury Boulevard where the adult mesquite trees are growing most vigorously.

DISCUSSION

The evidence indicates that the mesquite community at EAFB has experienced a period of degrading environmental conditions associated with groundwater decline during the 20th century associated with anthropogenic impacts. Records for the base indicate that groundwater pumping reached an all-time high in 1953 at over 400,000 acre-feet (130 billion gallons). This period of extreme pumping resulted in a rapidly declining regional groundwater table. USGS well data over the past half century show that the drop in groundwater levels was most extreme during the 1950s, 1960s and into the 1970s. Concurrent with high rates of groundwater pumping, precipitation rates were relatively low during this time. Mean annual rainfall was lower than long-term means from the late 1940s to 1977. This period was followed by a relatively wet interval from 1978 to 1985, with a peak year with 400 mm of precipitation in 1984. A dry period occurred from 1986 to 1991, followed by high variable annual precipitation through the period up to this study in 2003 (EAFB 2008).

Despite these relatively poor conditions for plant growth, aerial photo interpretation of the mesquite community at EAFB shows vigorous growth in canopy coverage during the 1950s and 1960s. Although the groundwater table was rapidly declining during these years, it appears that the phreatophytic mesquite trees were still able to extend taproots to the capillary zone (the zone from which roots are still able to obtain moisture via capillary movement) and were not immediately affected by the decline of the water table. Indeed, analysis of individual trees and trees within the one-hectare plots showed vigorous aerial growth (7550 m^2 and 14,858 m^2, respectively) from 1956 to 1968.

By the late 1970s and 1980s, groundwater levels, although still falling, began to decline at a slower rate than those seen in the 1950s to early 1970s. There were three primary reasons for this change in the groundwater dynamics. First, increased rainfall in the Antelope Valley led to wetter winters and, subsequently, higher rates of local aquifer replenishment. Second, the importation of substantial amounts of water associated with the California State Water Project decreased the need to pump local groundwater wells. Third, the decreased taxation on the local aquifer system as agricultural needs for groundwater diminished much faster than the concurrent, but relatively minor, rise in municipal needs for groundwater. Taken together, these factors have contributed to lower groundwater pumping rates over the past 50 years.

Table 4. Areal changes in 45 one-hectare mesquite plots from 1956 to 2000 at Edwards Air Force Base over five time intervals. The relative change shown is in reference to the earlier date for each interval. Standard deviation values are shown in parentheses.

	1956–1968	1968–1984	1984–1992	1992–2000	1956–2000
Total change in area (m^2)	+14868.3	−2973.0	−15379.6	−10316.2	−13800.5
Mean change (m^2)	+330.4 (419.9)	−66.1 (452.2)	−341.8 (471.7)	−229.2 (308.1)	−306.7 (838.4)
Relative change (%)	+15.2	−2.6	−14.0	−10.9	−14.1
Number of plots gaining area	35	19	9	8	15
Number of plots losing area	10	26	36	37	30

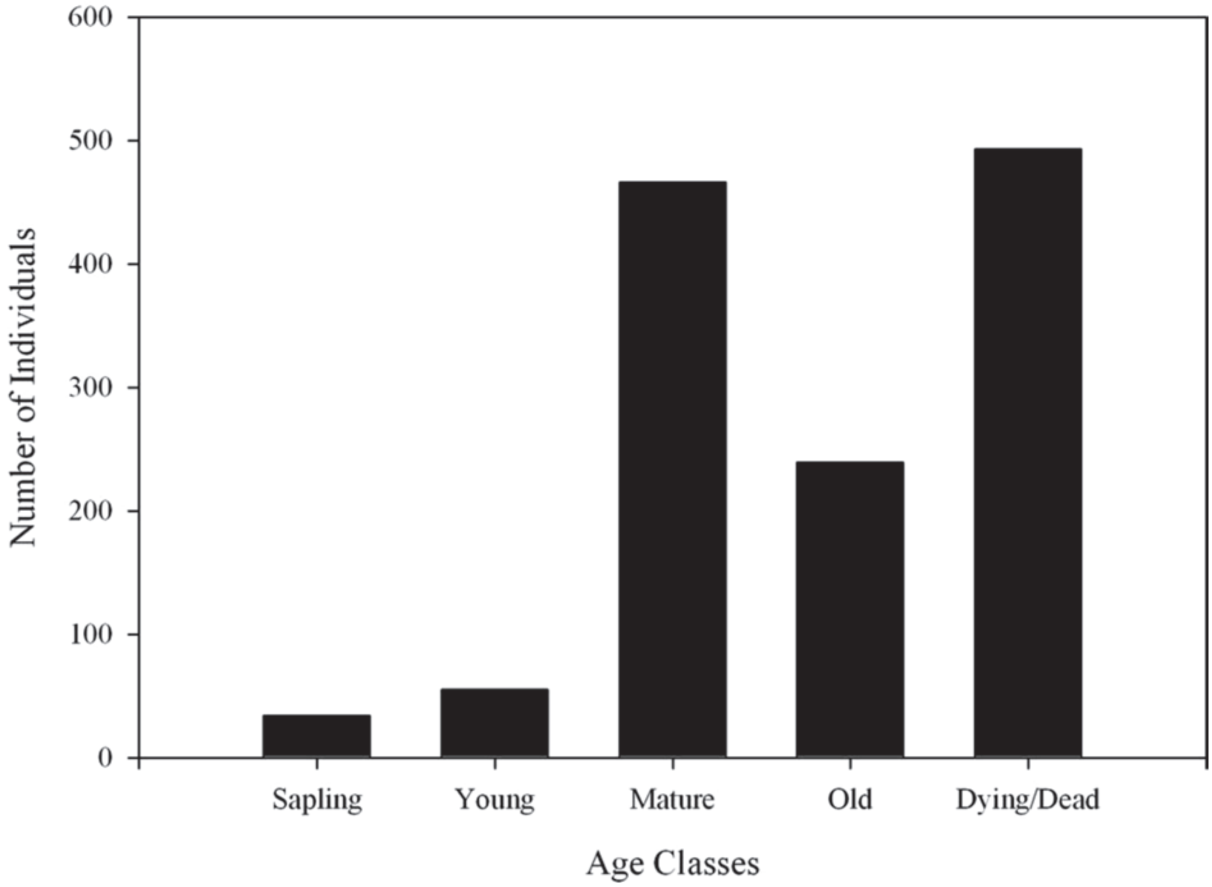

Fig. 6. Number of mesquite trees in each of the five age classes identified located in the 45 one-hectare plots at Edwards Air Force Base, California, during fall 2003.

The change in environmental conditions during the 1970s and 1980s was matched by changes in the developing mesquite community at EAFB. Analysis of aerial photographs taken from 1968 to 1984 shows that the growth of individual mesquite trees slowed during this time period. Although there is an increase of 1460 m^2 in the individual mesquite trees examined, there is also a concurrent decrease of 15,380 m^2 in aerial coverage of mesquite trees within the 45 one-hectare plots. This discrepancy is explained, in part, by the fact that the individual tree analysis preferentially examined the younger trees in the community due to the nature of the sampling methodology. These younger trees would have maintained extensive areal expansion during a longer time span than would the relatively older trees analyzed in the 45 one-hectare plots. Regardless, this suggests that there is an overall sizeable net decrease in the extent of the mesquite coverage at EAFB from 1968 to 1984. The most logical explanation for the decrease in overall areal coverage during this time period is that the community had begun to experience dieback owing to aging in the community, road building and other military activities.

Through the 1990s to 2003, there has been a continuing decline in groundwater pumping rates. Land uses have shifted from predominantly agricultural in the 1950s and 1960s to almost exclusively municipal by the 1990s. Water use in the valley has changed radically due to this change in land use. In spite of these land use changes and reductions in groundwater uses, groundwater withdrawal still exceeds groundwater recharge. Templin et al. (1994) suggested that the groundwater withdrawal rate in 1991 is more than double recharge rates. Although depletion rates over this period are less rapid than rates seen in previous decades, the declining groundwater levels are a problem that may impact the continued existence of the phreatophytic mesquite community at EAFB.

Age-class analysis of the mesquite suggests that there is uneven age-class distribution within this community. Seedlings and young trees account for less the 7% of the total population. Although mesquite trees are long-lived and only occasional episodic seedling establishment may be sufficient to maintain population size, this lack of young trees is atypical of healthy mesquite stands. Seedlings are primarily located in disturbed areas or areas adjacent to roadways where runoff water accumulates. In addition, the local groundwater table in the south-central section of EAFB is highly variable, ranging from 7.7 m to 20.5 m in depth. As expected, those mesquite trees growing in areas where the water table is shallowest (e.g., approximately 10 m along Branch Park Blvd and 7.7 m at Boy Scout Ranch) appeared to be growing vigorously compared to the rest of the community. However, plant water potential studies during 2001–2003 did not indicate significant differences ($p > 0.05$) between the mesquite individuals with different groundwater table depths (R. Sharifi, unpubl.). These studies found that there was little to no water stress to the mesquite trees at EAFB, which suggests that the depth to groundwater is not currently having a negative effect on mature, established individuals within this community. Nevertheless, while groundwater pumping is only a fraction of what it was in the 1950s, the depth to groundwater is now believed to be too deep in some areas to promote adequate seedling establishment and sapling growth. In addition, this deep groundwater most likely has a significant negative impact on the ability of young mesquite trees to develop and replace those aging trees that are currently dominating the community. As this community continues to age and die off, it will be imperative to monitor and assist in the establishment of seedlings and the growth of seedlings and young trees to assure long-term survival of mesquite community at EAFB.

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