Desert Plants

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Gobabeb Training Research Center, Namibia at sunset (M. Siegwarth)

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Desert Plants
A journal devoted to broadening knowledge of plants indigenous or adapted to arid and sub-arid regions and to encouraging the appreciation of these plants.

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From the Editor...
The previous Desert Plants, Volume 26 (1) featured a history of the Desert Laboratory at Tumamoc Hill. The follow-up article featured in this issue portrays the ongoing research at the Desert Laboratory, much of it made possible by the long term research sites set up by the early researchers. The research documents changes in Tucson and the desert area bordering the city and is historical for that reason. This research also teaches scientists the world over, specific methodology for measuring environmental change over extended periods.

Boyce Thompson Arboretum is prominent in this issue. Director Mark Siegwarth submitted a manuscript and many wonderful photographs from his recent trip to southern Africa. His trip helped Mark and all of the Arboretum staff focus on the plans to represent the deserts of southern Africa at the Arboretum. As the plans to develop the southern Africa area at the Arboretum progress, the Arboretum is eagerly anticipating the arrival of Ian Oliver on the Arboretum staff in early 2011. Mr. Oliver comes to the Arboretum from the Karoo National Botanical Garden in South Africa.

Hand in hand with Mark's trip, the Arboretum sponsored three University of Arizona undergraduate students in the University of Arizona Study Abroad Project in Namibia in the summer of 2010. The students visited the Arboretum prior to their trip to Namibia. While in Namibia, the students conducted a floral survey of Central and Northern Namibia and returned with much botanical information to help the Arboretum's Southern African exhibit move forward.

Finally, the Desert Legume Program (DELEP), the research arm of the Boyce Thompson Arboretum, will have a regular presence in Desert Plants. DELEP is a seed bank for desert legumes from around the world. Biodiversity is much in the news and DELEP has been making a huge contribution. More will appear on this effort in upcoming issues.

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A Debt to the Past: Long-term and Current Plant Research at Tumamoc Hill (The Desert Laboratory) in Tucson, Arizona

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Introduction

Long-term research has been recognized as beneficial to our understanding of how ecosystems function and change and how natural systems may be managed, particularly in light of prognostications of long-term climate change (Webb et al. 2009). The Desert Botanical Laboratory (Fig. 1), founded in 1903 (Bowers 2010), has inspired a long history of contributions to desert plant ecology, many of which occurred long after the Carnegie Institution of Washington ceased operations in Tucson in 1940. These contributions are original research conceived by researchers working wholly or partially at Tumamoc Hill, and many involve continuation and (or) modifications of the original research designs conceived by the founders of this historic institution. In this article, we discuss selected recent research findings that had originated with scientists based on Tumamoc and working at least partially on the laboratory grounds.

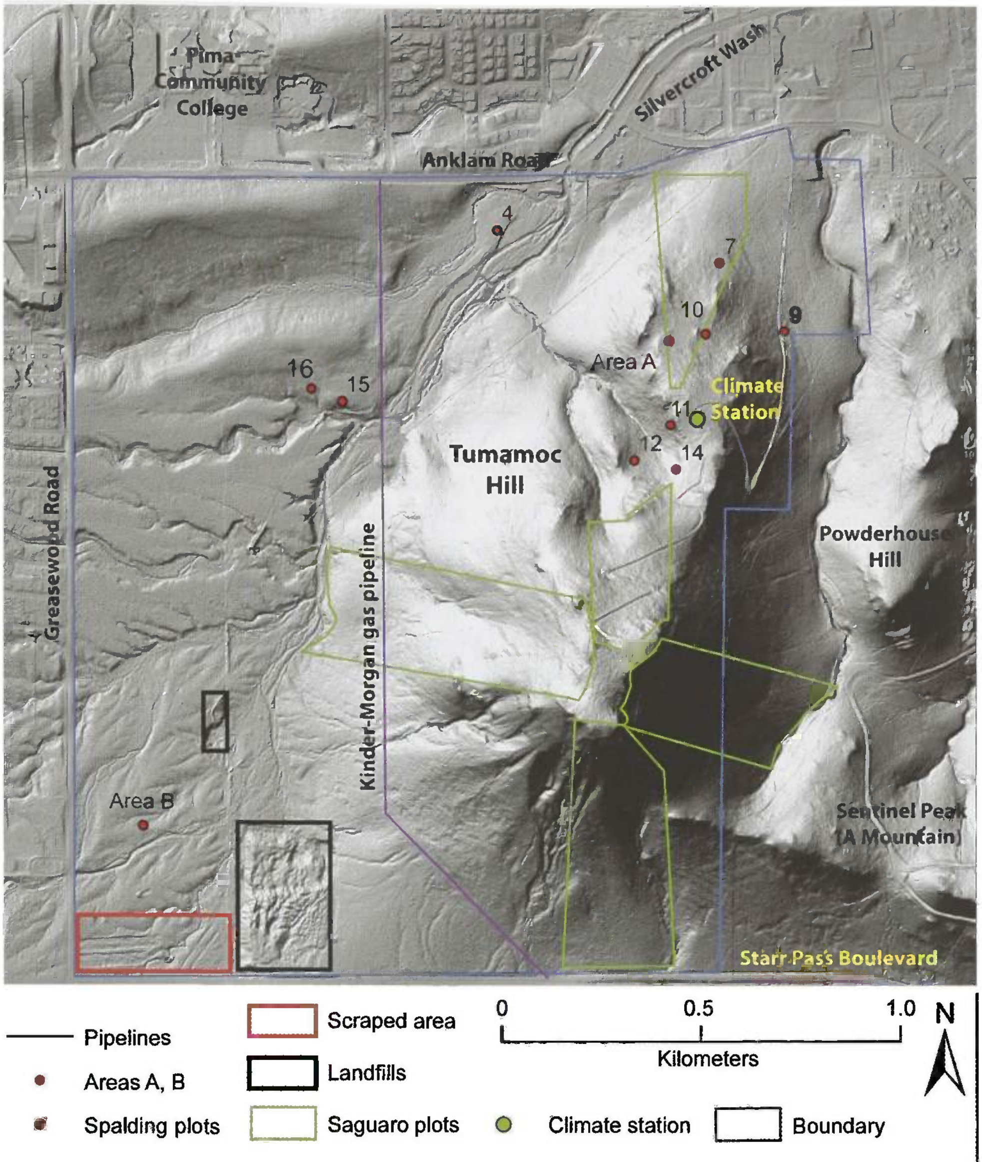
The name of the Desert Botanical Laboratory has changed over the last 100 years and is now known as Tumamoc: People & Habitats. In this paper, we will refer to this place either as the Desert Laboratory, its name over most of the last quarter century, or Tumamoc. The grounds consist of 352 hectares of land that have been fenced from livestock grazing since 1907 (Shreve 1929). Although protected from grazing, numerous other intrusions have created a mosaic of disturbances of different ages on the landscape, ranging from roads and landfills to pipeline corridors and powerlines (Fig. 1). Some of these disturbances, combined with urban development up to the Desert Laboratory boundaries, have reduced the number of long-term plots that were initially established. However, because the disturbed areas are recovering, they offer researchers new opportunities to study natural restoration in the Sonoran Desert. The research findings at this unique research station, which covers the longest period of scientific investigations of desert plants in the world, can be extrapolated to wider questions of long-term change in the Sonoran Desert.

Geology and Climate Variation

Tumamoc Hill and Sentinel Peak (A Mountain) to the east are outcrops of basaltic andesite overlying rhyolite and other volcanic rocks of Tertiary Age (Pearthree and Biggs 1999, Spence et al. 2003). A much larger area of the grounds to the west consists of colluvium and alluvium of mostly Quaternary Age dissected by washes (Fig. 1). The northwest area of the property, for example, is dominated by Pliocene-Pleistocene alluvial deposits of an age between 1 and 5 million years that are characterized by rounded ridges of eroded soils and exposed calcrete horizons developed on coarse, gravelly substrate (Pearthree and Biggs 1999). Younger deposits include alluvium of late Pleistocene and Holocene Ages associated with Silvercroft Wash and recent sediments deposited during storm runoff. Research at Tumamoc Hill has shown that edaphic (soil) conditions strongly affect plant species composition and productivity, primarily owing to effects on rooting depths and infiltration (see Edaphic Relations). The bedrock and surficial geology of the Desert Laboratory is not unique for landscapes of the Sonoran Desert, which is dominated by volcanic rocks of the types that create Tumamoc Hill and Sentinel Peak.

Tucson, which lies in the Arizona Upland subdivision of the Sonoran Desert (Turner and Brown 1982), has a mean annual precipitation of 292 mm at Tucson International Airport from February 1930 to December 2009 (http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?az8820, accessed 22 July 2010) with considerable interannual variation. The climate station at the University of Arizona, the longest record of climatic data in Arizona with initial monthly precipitation data collection beginning in 1868, has an annual precipitation of 288.4 mm (Fig. 2), of which 38% falls in the winter months of November through March and 49% falls in the summer months of June-September. Rainfall data have been collected near the laboratory buildings (Fig. 1) from 1907 until the present with the exception of 6 years when no records were kept (1940-1941, 1972-1975). This record indicates that mean annual rainfall on Tumamoc Hill is 298 mm, with 36% falling between November and March and 53% falling in June-September. The Desert Laboratory receives more than the 250 mm of precipitation, the upper climatic limit of deserts worldwide, and this area better fits the definition of a semiarid environment.

Several attempts have been made to characterize periods of southern Arizona precipitation according to hydrological or ecological effects. Turner et al. (2003) presented one definition of interdecadal climatic variability (Fig. 2, bottom). The Desert Laboratory was founded at the end of the late 19th century drought, and the first measurements of the long-term Spalding vegetation plots were made in 1906, the approximate start of the early 20th century wet period. This wet period generally extends to 1940, although drought periods occurred in southern Arizona at the end of the 1910s and during the 1930s (Fig. 2). What has variously been called the 1950s drought, began in the mid-1940s and extended into the early 1960s in southern Arizona (Fig. 2). It is referred to as the mid-century drought. The late 20th century wet period extends from the mid-1970s through at least 1995 and by many accounts to the El Niño event of 1997-1998. The last decade is known as the early 21st century drought. The early 20th century and early 21st century droughts have similar characteristics, although the early 20th century drought had far more devastating effects on pastoralists and agriculture in southern Arizona (Turner et al. 2003).



[illshade model of topography at the Desert Laboaratory in Tucson, Arizona, showing the locations of permanent plots and set aside for the long-term study of perennial desert vegetation and the location of some of the disturbed sites. Landfill refers lumps covered with material from scraped areas.

Laboratory Collection of Repeat Photography

astings and Raymond M. Turner began matching old s in 1960 as a way of studying bioclimatology of change in the Sonoran Desert (Webb et al. 2007a), ie Desert Laboratory. Originally, their archives were the main University of Arizona campus. The first documented camera station, was a 1960 match of a graph taken by D.T. MacDougall, one of the founders rt Laboratory, in 1960 (Webb et al. 2010a). The first publication from this collection was the classic book *ng Mile* (Hastings and Turner 1965).

er moved to Tumamoc Hill in 1976, he brought the collection with him. At the time of his retirement in illection had about 1280 stake numbers and had grown gest collection of its kind in the world. By 2010, the now known as the Desert Laboratory Collection of tography, contained nearly 5000 stake numbers and ches. Numerous publications featured photographs 1 this archive, including an update of the *Changing Mile* (Turner et al. 2003), documentation of changes in the riverine and desert environments of Grand Canyon (Turner and Karpiscak 1980, Bowers et al. 1995, Webb 1996), changes in subtropical vegetation in Kenya (Turner et al. 1998), a review of changes in regional riparian vegetation (Webb et al. 2007b), and a compendium of world-wide studies using the technique of repeat photography (Webb et al. 2010b).

Hastings and Turner originally conceived their collection to evaluate long-term change in Sonoran Desert vegetation. At the Desert Laboratory, repeat photography documents a number of landscape-scale changes, including the overall increase in foothill palo verde (*Cercidium microphyllum*) (Fig. 3) and changes in saguaro (*Carnegiea gigantea*) populations (Fig. 4). In 2010, a total of 192 photographs of the Desert Laboratory and its environs have been matched, mostly by Turner and his colleagues.

Bullock and Turner (2010) summarized regional population trends in perennial vegetation of the Sonoran Desert as determined from analyses of repeat photography. Because of the long period over

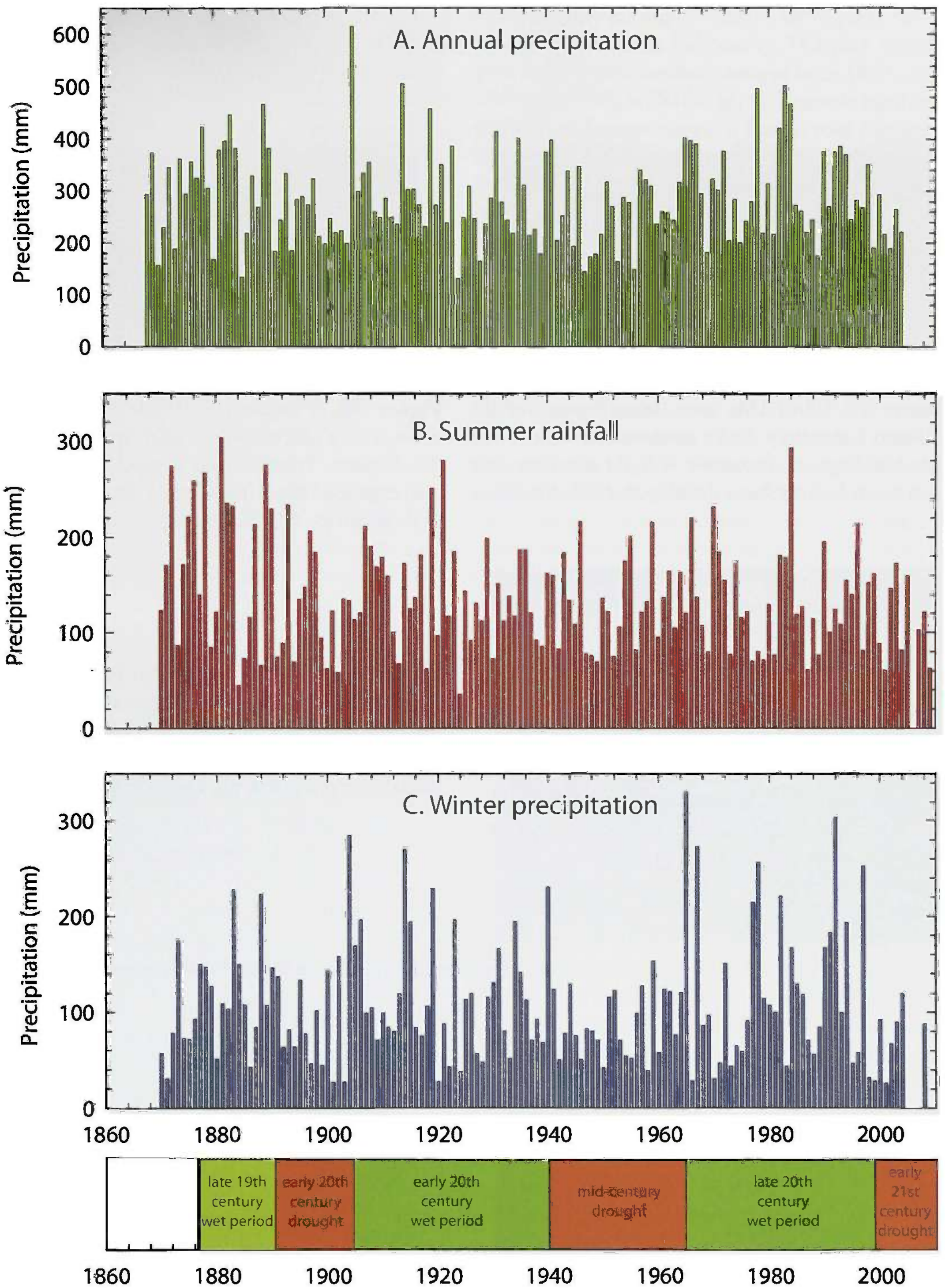


Figure 2. Annual and seasonal precipitation at the Universkty of Arizona from 1868 to 2009. The lower panel shows generalized periods of southern Arizona climate.

which original photographs were taken and matched, age ranges were established of original photographs (1883-1959, median ≈ 1900), first repeat photographs (1933-1985, median =1962-1963), and second repeat photographs (1984-2000, median = 1994-1995). For the interval between original and first repeat photographs, or about 1900 through 1963, increases in biomass were observed for many common species, including two species of mesquite (*Prosopis* sp.), *Acacia neovernicosa*, burrobush (*Isocoma tenuisecta*), cardón (*Pachycereus pringlei*), foothill palo verde (*Cercidium microphyllum*), and ocotillo (*Fouquieria splendens*), while decreases were observed in cirio (*Fouquieria columnaris*) in Baja California and desert spoon (*Dasylirion wheeleri*) and Palmer's agave (*Agave palmeri*) in southeastern Arizona. For the second period, between 1963 and 1995, no changes were observed in most species studied except for noteworthy exceptions of increases in Palmer's agave, mesquite, pricklypear, cardón, and desert spoon (Turner et al. 2003). They concluded that climate was the most important reason for fluctuations in perennial vegetation, although land-use practices, particularly the intensity of livestock grazing and fire suppression, are also important factors.

Figure 3A. (January 23, 1906) This view, taken by one of the founders of the Desert Laboratory, looks northwest down a ravine to the west of the buildings on Tumamoc Hill. At this time, this part of the Tucson basin had not been developed. (D.T. MacDougal, b4-11).

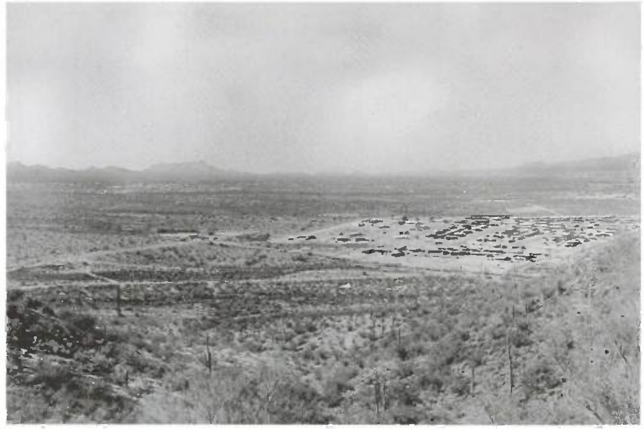


Figure 3B. (February 19, 1964) Tucson has expanded into the view, with a nascent subdivision appearing on the alluvial fans in the distance. Foothill palo verde (*Cercedium microphyllum*) has also expanded blocking some of the view of the midground ravine. (J.R. Hastings, G89-3, Stake 276)

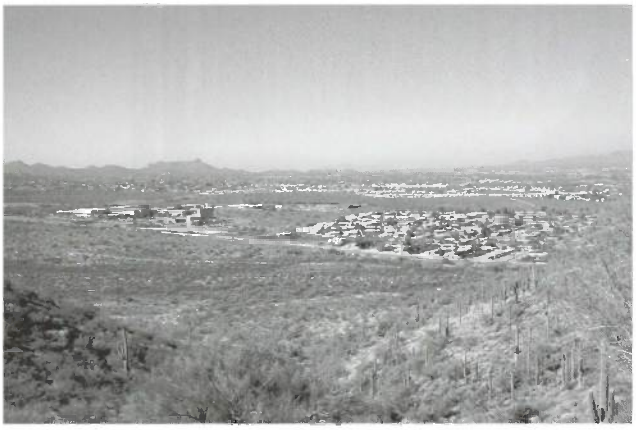


Figure 3C. (December 22, 1998) Pima Community College west campus is now prominent on the alluvial fan at midground, and the north property line of the Desert Laboratory is clearly delineated by Anklam Road. Foothill palo verde have grown and new individuals are present in the view. (R.M. Turner, Stake 276)

Figure 3. Above, repeat photographs showing increase in foothill palo verdes.

Figure 4A. (ca. 1907) This view northeast from the Desert Labaoratory, shows agricultural fields in the midground and the growing city of Tucson in the distance at right. The view also shows perennial vegetation on the north slpe of Tumamoc Hill (Godfrey Sykes).

Figure 4B. (August 27, 2003) Clearly Tucson has grown; St. Mary's Hospital dominates the left midground. The number of saguaros visible from this camera station has greatly increased, particularly at right center. Overall, there is an apparent increase in biomass of perennial vegetation, notably foothill palo verde (D. Oldershaw, Stake 4678)

These regional changes are mirrored on the lands of the Desert Laboratory, although changes are related to the different geomorphic surfaces on the west side of the property. Furthermore, Bullock and Turner (2010) did not evaluate the effects of the early 21st century drought, which were devastating in some parts of the desert Southwest. The permanent plots at Tumamoc Hill chronicle the effects of this drought on desert plants in this mosaic of a landscape.

The Spalding Plots

In 1906, Volney Spalding established a number of permanent vegetation plots with the objective of recording changes in perennial and annual plants with time at the Desert Laboratory (Spalding 1909, unpublished notes 1906). At the time of its establishment, the grounds were considered to be overgrazed and Spalding could not keep the horses, goats, cattle, and burros off his new plots, prompting him to lobby for the boundary fence, which was completed in 1907. The initial measurements on these plots occurred just before the property was fenced to exclude grazing disturbance of unknown magnitude, and Tumamoc Hill became one of the world's first restoration ecology projects as those plots began to recover.

Spalding created 19 plots (Table 1), and the locations of some of these are only vaguely described (Shreve 1929; Shreve and Hinckley 1937, Goldberg and Turner 1986). Although at least two of these plots were only 1 m^2, most of the plots are approximate squares of 10 m × 10 m. The initial measurements used string placed at 1 m intervals to map the position of the root crown of each perennial species, allowing estimation of plant density but not cover. In 1910, Forrest Shreve remapped two of the plots and established Area A, an irregular polygon of 557 m^2 on which large perennial plants are counted but not mapped. On Spalding plots 11 and 15 (Table 1), Shreve mapped both the position of the root crown and the crown perimeter (Shreve 1929), allowing estimation of both density and cover as well as providing information needed to calculate survivorship and life span (Bowers 2005).

Eighteen years passed before the plots were remeasured in 1928-1929. Shreve (1929) remeasured five of the original plots, recounted the plants in Area A, and established Area B, a plot consisting of eight contiguous 10 x 10 m subplots (Shreve and Hinckley 1937). In 1936, Shreve and associates mapped the plots that had been mapped in 1928-1929, ignoring the other Spalding plots (Shreve and Hinckley 1937). The next maps were produced by two master's students, Jack M. Kaiser in 1948 and Ann V. Murray in 1957 (Murray 1959). Between 1959 and 1985, Turner and colleagues mapped four Spalding plots and Area B at irregular intervals (Table 1). In 1968-1969, Turner located and mapped five additional Spalding plots not measured since 1906 and Area A, which had not been examined since Shreve's work in 1936. Since 1969, at least one of these plots has been measured every eight years under the guidance of USGS staff at the Desert Laboratory, and during the past 105 years, the Spalding and Shreve plots have been remeasured as few as 4 and as many as 14 times (Table 1). One of the plots (17) was destroyed by road construction after the 1948 mapping and two others (plots 4 and 9) were damaged along one of their margins.

Spalding plot 16 (Figs. 5, 6) provides a good example of long-term change at the Desert Laboratory. This plot, which is 99.408 m^2 in area, has a total cover that changed from 28.5% in 1928 to 37.5% in 1993 and 17.2% in 2010 (Fig. 7). Creosote bush dominated this plot in 1928, and range ratany, a known root parasite (Cannon 1910), had relatively low cover (Figs. 6A, 7). By the middle of the 20th century, and during the mid-century drought, both creosote bush and range ratany had greatly decreased in cover. In 1993, when plot 16 had its highest measured total cover following the late 20th century wet period, range ratany had a higher cover than creosote bush. In 2010, creosote bush had a higher cover than range ratany, but not by much (Fig. 7) and not to the extent of 1928. Density of plants on this plot mirrors cover (Table 2), although some of the fluctuations are much larger. Total density of the most common species ranged from about 2500/ha in 1906 to about 26,000/ha in 1968 (about 6300/ha in 2010), with large changes in subshrubs. Creosotebush steadily declined through the 20th century from a high of 1610/ha in 1906 to its current density of 700/ha. Long-term change in plot 16 confirms Shreve's assertion that stability or systematic change in perennial plant assemblages in the Sonoran Desert is an illusion, a point of long-term discussion with Frederic Clements during the early days of the Desert Laboratory (Bowers 2010).

Goldberg and Turner (1986) reported many trends in desert plant species at the Desert Laboratory and noted maximum longevities, an important plant characteristic examined further by Bowers et al. (1995) using repeat photography in the Grand Canyon. Bowers (2005) used the permanent plots to examine the effects of the mid-century and early 21st century droughts on survival and longevity of 6 species of woody plants. She found that the effects of the early 21st century drought were much more pronounced than those of the mid-century drought, causing sharp declines in survival and maximum longevity for most of the species. The average life spans for creosote bush (*Larrea tridentata*), Berlandier wolfberry (*Lycium berlandieri*), white ratany (*Krameria grayi*), janusia (*Janusia gracilis*), triangle-leaf bursage (*Ambrosia deltoidea*), and brittlebush (*Encelia farinosa*) are 330, 211, 184, 53, 40, and 16 years, respectively, and reflect drought-induced high mortality during this drought.

Distribution and Expansion of Native and Non-Native Plant Species

Thornber (1909) published the first flora of the Desert Laboratory, which included three non-native species: filaree (*Erodium cicutarium*), Bermuda grass (*Cynodon dactylon*), and wall barley (*Hordeum murinum*). V.M. Spalding (1909) produced maps showing the distribution of filaree and Bermuda grass. Turner began updating the flora in 1968-1969. After a lull of almost a decade, collection resumed in 1977 and continued through 1984 (Bowers and Turner 1985). This revised flora revealed that two native species, ironwood (*Olneya tesota*) and jojoba (*Simmondsia chinensis*), had disappeared and 52 non-native species were present, including the three present in 1909. The new species were mostly annuals that were most common in disturbed habitats created after 1940, such as access roads, pipelines, and landfills (Fig. 1). Urban development had also slowly surrounded the laboratory property and many of the new plant additions undoubtedly originated from nearby residential yards.

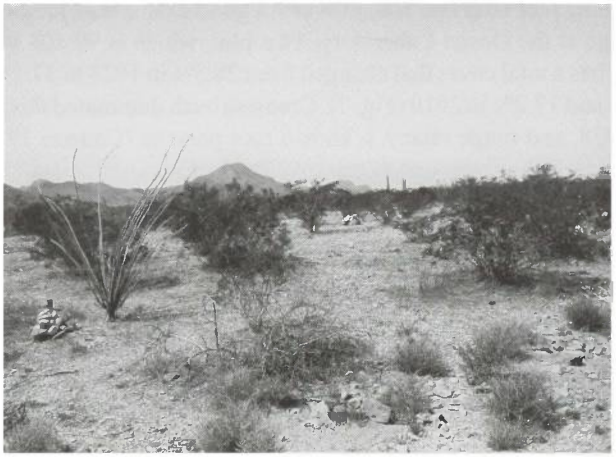


Figure 5A. (March 1906) At the time that it was established, plot 16 was dominated by large creosote bush (*Larrea tridentata*) and a prominent ocotillo (*Fouquieria splendens*), although only root-crown locations were measured in this year (Table 2). (V. Spalding, Stake 376A)

Figure 5B. (November 25, 1928). This view and the ones that follow were taken from a slightly different angle. This photograph shows plot 16 in the year that the first crown oulines were measured (see Figure 6A). The ocotillo is gone but the creosote bush remain prominent (F. Shreve, Stake 376B).

Figure 5C. (1959) This view of plot 16, taken near the end of the mid-century drought, shows an area of low cover and low plant stature (photographer not known, Stake 376B).

Figure 5D. (December 19, 1986). In the middle of the late 20th century wet period, but before the 1993 remeasurement of plot crown cover (Figure 6C), creosote bush has a large stature on plot 16 (R.M. Turner, Stake 376B).

Figure 5E. (Januray 15, 2010) After more than a decade of the early 21st century drought, creosote bush again is diminished in size and cover is reduced. The magnitude of the changes is somewhat masked by the appearance in the foreground of a new cholla (*Cylindropuntia versicolor*) (R.M. Turner, Stake 376B).

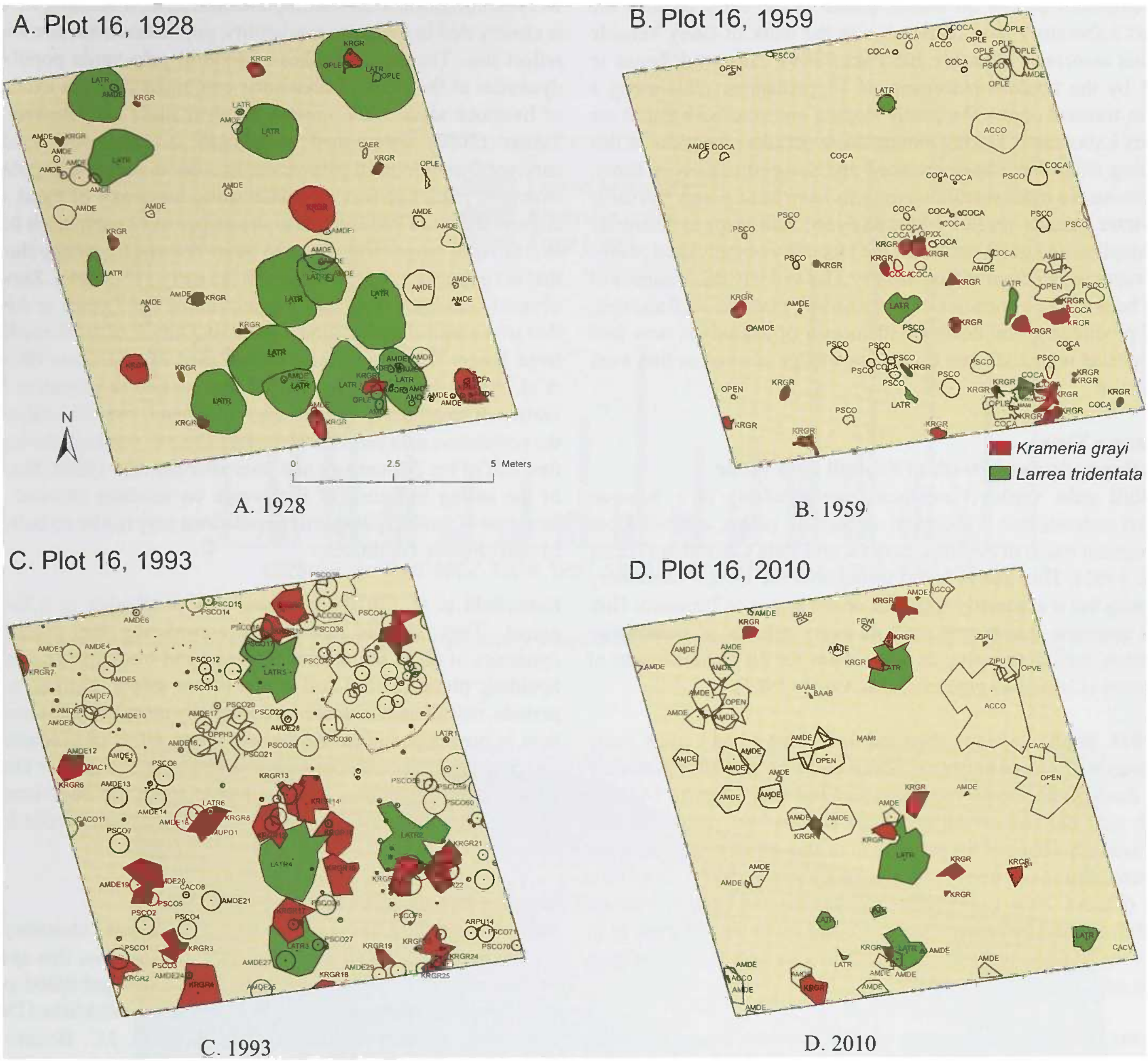


Figure 6. Maps of perennial vegetation on Spalding plot 16 at Desert Laboratory. This plot is 99.408 m^2 in area and was established in 1906 on alluvium west of Tumamoc Hill (Figure 1). The plants are shown as canopies and are labeled with four-letter codes. On this plot, some of the common plant codes are LATR (*Larrea tridentata*), KRGR (*Krameria grayi*), ACCO (*Acacia constricta*), and AMDE (*Ambrosia deltoidea*). In 1993, many BAAB (*Bahia absinthifolia*) plants are not labeled owing to their high density in that year.

Burgess et al. (1991) further evaluated non-native species based on a 1983 survey of these plants across the laboratory property on gridlines designed to map their location and follow their dispersal through time. The gridlines allowed 33 of the 52 species to be mapped but the remaining 19 were too rare. In 2005, Bowers et al. (2006) found 44 non-native species on the gridlines where 33 had been found previously; eight species present in 1983 were not present in 2005, and 19 species newly found in 2005 were not known in the flora previously and probably colonized the Desert Laboratory grounds in the previous 20 years. Interestingly, the non-native flora shifted from agricultural and ruderal weeds to ornamental plants as the surrounding lands shifted from farmlands to subdivisions. Ornamental species comprised 26% of non-native species in 1983 and 50% in 2005.

Several non-native annual species such as Mediterranean grass (*Schismus* spp.), London rocket (*Sisymbrium irio*) and red brome (*Bromus rubens*) had spread densely and uniformly across the property by 1983 and still held their ground in 2005. One introduced perennial grass, buffelgrass (*Pennisetum ciliare*), is a native of Africa that produces persistent, tall, coarse, standing foliage, and its increase at the laboratory is remarkable and problematic because allegedly it is linked to increase fire frequency in areas that previously rarely if ever burned (Esque et al. 2006). Between 1983 and 2005, this species greatly increased on the gridlines, representing the greatest change for any species examined (Bowers et al. 2006).

The emphasis placed on annual plants in the early days of the Desert Laboratory has continued with the work of Larry Venable and his associates (Venable and Pake 1999). This work began in 1982 by the random placement of 15 permanent plots along a 250 m transect across the gently sloping creosote bush flat at the Desert Laboratory. During almost three decades, the plots in this ongoing study have been revisited and mapped numerous times, and numerous other research questions have been posed. Focusing on winter annuals, these workers analyzed their maps to determine germination and death dates and the fecundity of individual plants. Soil cores were obtained from nearby sites to study the dynamics of seed banks. The intricacies of germination, maturation, flowering, seed production, and death of 30 species of annuals is now well understood with additions to this knowledge assured as this work continues.

A Larger View: The Expansion and Death of Foothill Palo Verde

Foothill palo verde (*Cercidium microphyllum*) is a Sonoran Desert endemic that is abundant on bajadas, plains, and hillslopes throughout much of Arizona, Sonora, and Baja California (Turner et al. 1995). This tree is found throughout the Desert Laboratory property but is especially abundant on the slopes of Tumamoc Hill. This common desert tree controls many aspects of community function, including acting as nurse plant for the establishment of saguaros (*Carnegiea gigantea*) (McAuliffe 1984).

In 1911, Shreve (1911b) observed that "I have had a great many thousands . . . come under my observation . . . and have seen only two dead [foothill palo verde] trees of full size." A mere 14 years later, near the end of the early 20th century wet period, he had dramatically changed his perception of this tree's condition when he noted that many trees of all ages had recently died at Tumamoc Hill (Shreve 1924/1925). This reversal did not persist, because foothill palo verde appears to have increased in the 20th century in most repeat photography of the Desert Laboratory, particularly on the flanks of Tumamoc Hill (Fig. 3).

In 1995, at the beginning of the early 21st century drought, foothill palo verde dieback was again observed at Tumamoc Hill (Bowers and Turner 2001). Twelve randomly placed plots were established, with two each on the four slopes facing cardinal directions and four on the flats at the base of the hill. Altogether, 1057 living and dead trees were sampled on the 72 m × 72 m plots. Findings showed that mortality was highest among older, larger plants and was far greater on steep slopes than on level ground. The greater death rate on steep slopes was attributed to the greater aridity of these slopes where rainfall runoff is highest and soils are shallowest. The death of older plants was attributed to the greater susceptibility of older individuals to a variety of lethal forces. This natural senescence interacts with extreme drought, hastening the death of the older trees. Bowers and Turner (2001) concluded that, at the time of their study, establishment of foothill palo verde was not keeping pace with mortality and that the number of younger individuals was not great enough to maintain a stable population, but the long-term history is one of fluctuating populations, much like that of the saguaro (see next section).

The apparent influence of drought on survival of mature foothill palo verdes prompted another study that examined the effect that wet years might have on seedling establishment. If seedling survival is closely tied to moisture availability, population structure should reflect this. The earlier studies of foothill palo verde population dynamics at the Desert Laboratory, combined with the exclusion of livestock since 1907, created an ideal study site. Bowers and Turner (2002) determined population structure and seedling survivorship of foothill palo verde. In order to measure population structure, plant age was estimated using the proxy of basal stem circumference of 980 living and dead trees in 12 plots, each 0.5 ha in size. Ages ranged from 1 to 181 years and age frequency showed that the population was in decline in the early 21st century. Survival of newly emerged seedlings was monitored for 7 years in Area A that was established by Shreve in 1910. Only 2 of 1008 seedlings lived longer than 1 year and all had died after 4 years (Bowers et al. 2004). But the low survival was related to predation by a variety of small herbivores instead of climate. Further analysis of the population data showed that establishment was high during the first half of the 20th century and poor after the mid-1950s. Because of the strong influence of herbivores on seedling survival, age structure of foothill palo verde populations may not be an indicator of past climatic conditions.

Butterfield et al. (2010) countered this conclusion to a limited extent. They showed that when considering the population dynamics of all of the perennial shrubs and trees growing on the Spalding plots, rainfall had a significant effect. During wetter periods, recruitment increased substantially more beneath canopies than in openings, indicating that the direct effect of precipitation on recruitment beneath canopies was different and greater than its effect in the open. Their work suggests again the importance of foothill palo verde in nurturing other perennial plant species in the Sonoran Desert.

Saguaro Demography and Growth Rates

The high regard that the early workers at the Desert Laboratory had for the saguaro is shown by the emphasis placed on this species in their research. It was the subject of the first published paper (E.S. Spalding 1905) emanating from the newly established Desert Botanical Laboratory (Bowers 2010). In 1908, J.C. Blumer and crew used a plane table to map all of the saguaros on the Desert Laboratory property and on Powder House Hill and Sentinel Peak (A Mountain) to the east (V. Spalding 1909, Plates 15 and 16). These maps covered more than 690 ha, showed thousands of plants, and depicted the saguaro's habitat preferences. W.A. Cannon prepared a detailed report of the root system of this cactus (E.S. Spalding 1909, p. 59-66) and E.S. Spalding described the mechanical adjustment of the pleated saguaro stem to varying amounts of precipitation over a period of almost 4 years (V. Spalding 1909, p. 59-66). Shreve analyzed the relation between height and age of the saguaro at Tumamoc Hill and then calculated its rate of establishment (Shreve 1910). He also closely examined the influence of low temperature on the plant's survival in a laboratory study where he inserted thermometers into small saguaros and then placed the plants in freezers (Shreve 1911a).

The early emphasis placed on the saguaro was not lost on later workers at Tumamoc Hill. Hastings was one of the first to study saguaros in the late 1950s, when he extended E. S. Spalding's study of the saguaro's response to rainfall (Spalding 1905). At a site on the flat to the west of Tumamoc between Spalding Plots 15

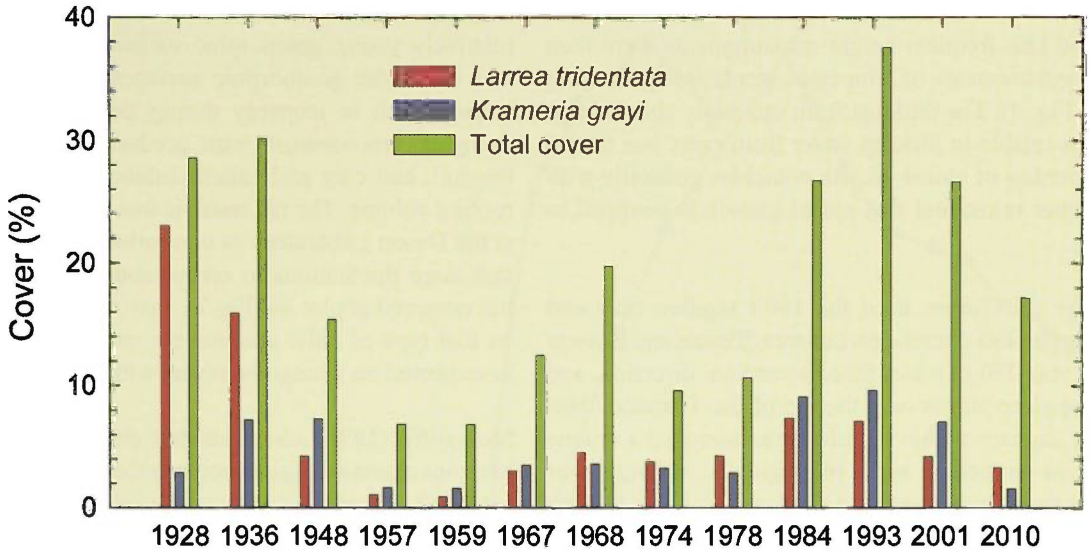


Figure 7. Trends in cover of creosote bush (*Larrea tridentata*), range ratany (*Krameria grayi*), and total cover in Spalding plot 16.

Figure 8. Photograph of the east slope of Tumamoc Hill showing the distribution of buffelgrass (*Pennisetum ciliare*), an invasive perennial grass, as the tan colored areas. Experimental work using saguaro dendrometers (inset, lower left) is being conducted mid-slope on the right side of this view.

and 16 (Fig. 1), Hastings placed spring loaded brass bands around 10 saguaros, with a wire-wound resistor attached to one end of the girdle and to the other, a contact arm (Hastings 1961). A modern illustration of this appears in Figure 8. Using photogrammetry (measurements from photographs), change in height of 11 plants was measured. The near continuous measurements of stem circumference and less frequent height measurements were then compared with measurements of temperature and precipitation at adjacent gauges (Fig. 9). The findings from this study showed that the saguaro seems unable to pick up water from rains less than 5 mm; that the beginning of apical growth coincides generally with the onset of summer rains; and that apical growth is confined to summer.

In 1964, Hastings and Turner used the 1908 saguaro map and superimposed 4 large plots over the earlier area (Turner and Bowers 1988). Each plot was 250 m wide, faced a cardinal direction, and extended from the steep slopes near the top of the Tumamoc Hill to its base. Every saguaro within the plots was assigned a unique number, its location marked on aerial photographs, its height was measured, and the number of branches was recorded. Later, the two maps were matched by superimposing the new aerial photograph over the 1908 map. The population on the 4 slopes was roughly 1.5 to 2.0 times greater in 1964 than in 1908. These 4 plots were remeasured in 1970 and 1993 (Pierson and Turner 1998). Their analysis showed that saguaro populations nearly doubled on all 4 slopes since 1908 (Fig. 4), with the greatest density of saguaros persistently occurring on south- and east-facing slopes. Their study enabled them to convert saguaro height to age, which revealed that there was an extended period of decline from about 1860 to 1908 and a surge in recruitment that began in the 1920s and peaked in the 1970s. The populations are once more in decline at the beginning of the 21st century.

Because saguaro establishment is rare, and the population is subject to boom and bust cycles, one question asked is whether those cycles are due to variation in seed production or climatic variation. Saguaros have short-lived seeds and warm temperature requirements for germination, and therefore germination and establishment must occur shortly after the seeds are dispersed. From 1967 to 1988, Bowers (1996c) studied the environmental triggers that control flowering date, raising the question as to what limits seed production. She found that flowering is controlled by cool-season rain, increasing day length, and a combination of increasing solar radiation and warming temperatures. A cool-season (November-March) rain of at least 6-9 mm is probably the initial trigger. Another study suggests a possible explanation for poor establishment rates at times in the past. Schmidt and Buchmann (1986) found that honeybees were the main pollinators of saguaro flowers. These insects are so efficient at pollen harvesting that, starting at daybreak, they will have removed virtually all of the pollen by 9 or 10 a.m. Honeybees were introduced to the region about 100 years ago and, prior to that time, the intermittent lack of native pollinators may have sporadically limited fruit set.

Edaphic Relations and Perennial Vegetation

Soils have been called the foundation of ecosystems, yet the influence of soil (edaphic) conditions on desert plant assemblages was poorly understood until the mid-1980s. Although Shreve's research on the effect of caliche (indurated soil carbonate horizons) on paloverde root distributions was well considered, ecologists took notice when Joe McAuliffe published a paper linking the multidisciplinary concepts of geomorphology, soil hydrology, and ecosystem function (McAuliffe 1994). In a complex analysis comparing vegetation assemblages on three geomorphic surfaces at the Desert Laboratory, he showed that creosotebush preferred relatively young geomorphic surfaces with less pedogenic clay, and that older geomorphic surfaces underlain by caliche place creosotebush in jeopardy during droughts. To survive periodic droughts, creosotebush must produce roots at multiple levels in the soil, and clay and caliche inhibit root elongation, restricting rooting volume. The net result is that creosotebush varies spatially at the Desert Laboratory as controlled by the geomorphology, and that large fluctuations in creosotebush cover and density, which has occurred at plot 16 (Fig.7), may represent merely what occurs on that type of older geomorphic surface. Less fluctuation might be expected on younger surfaces with higher infiltration capacity.

McAuliffe (1994) observed that development of clay (argillic) horizons exerts strong control over the plant species that can survive extended drought periods on those surfaces. He also observed that maximum plant diversity may occur on surfaces undergoing erosion because of the reduced infiltration effects of increased clay and caliche. Species that can persist on seasonal moisture, particularly summer rainfall with limited soil penetration, may be at an advantage on older geomorphic surfaces. This may help explain why many succulent species, particularly cacti, are more common on older geomorphic surfaces than on young ones at the Desert Laboratory.

Species-Specific Research

Numerous studies have been conducted at the Desert Laboratory concerning physiological ecology, germination and establishment, and phenology and reproduction of individual desert plant species. Shreve Plot Area A, established in 1910, has been used for several studies in recent years. In an eight year study, Bowers used this plot to evaluate the conditions controlling the seedling emergence of three prominent Sonoran Desert species (Bowers 1994). Both minimum rainfall triggers and the appropriate minimum temperatures for emergence were described for foothill palo verde (*Cercidium microphyllum*), ocotillo (*Fouquieria splendens*), and brittlebush (*Encelia farinosa*) from 1987 through 1992. In another study running concurrently with the previous study on Area A, Bowers described the germination behavior and seed bank persistence of triangle-leaf bursage (*Ambrosia deltoidea*) from 1987 to 2000 (Bowers 2002). Bowers et al. (2004) studied the timing and spatial pattern of seedling emergence and early survival for 15 species from 1987 to 1993 on Area A and found that few species emerged in all years of the study, the first-year survival averaged across all 15 species was 3.7%, and only 0.1% of seedlings lived as long as 4 years.

In 1956 and 1957, Turner (1963) measured the seasonal growth and flowering of trees found at the Desert Laboratory. He used a dendrometer to measure slight changes in the stem radius of velvet mesquite (*Prosopis velutina*) and blue palo verde (*Cercidium floridum*) growing along a water course on the west side of the property and ironwood (*Olneya tesota*) and foothill palo verde growing several kilometers to the west on a hillslope. The use of dendrometers was pioneered by MacDougal (1936, 1938) at the

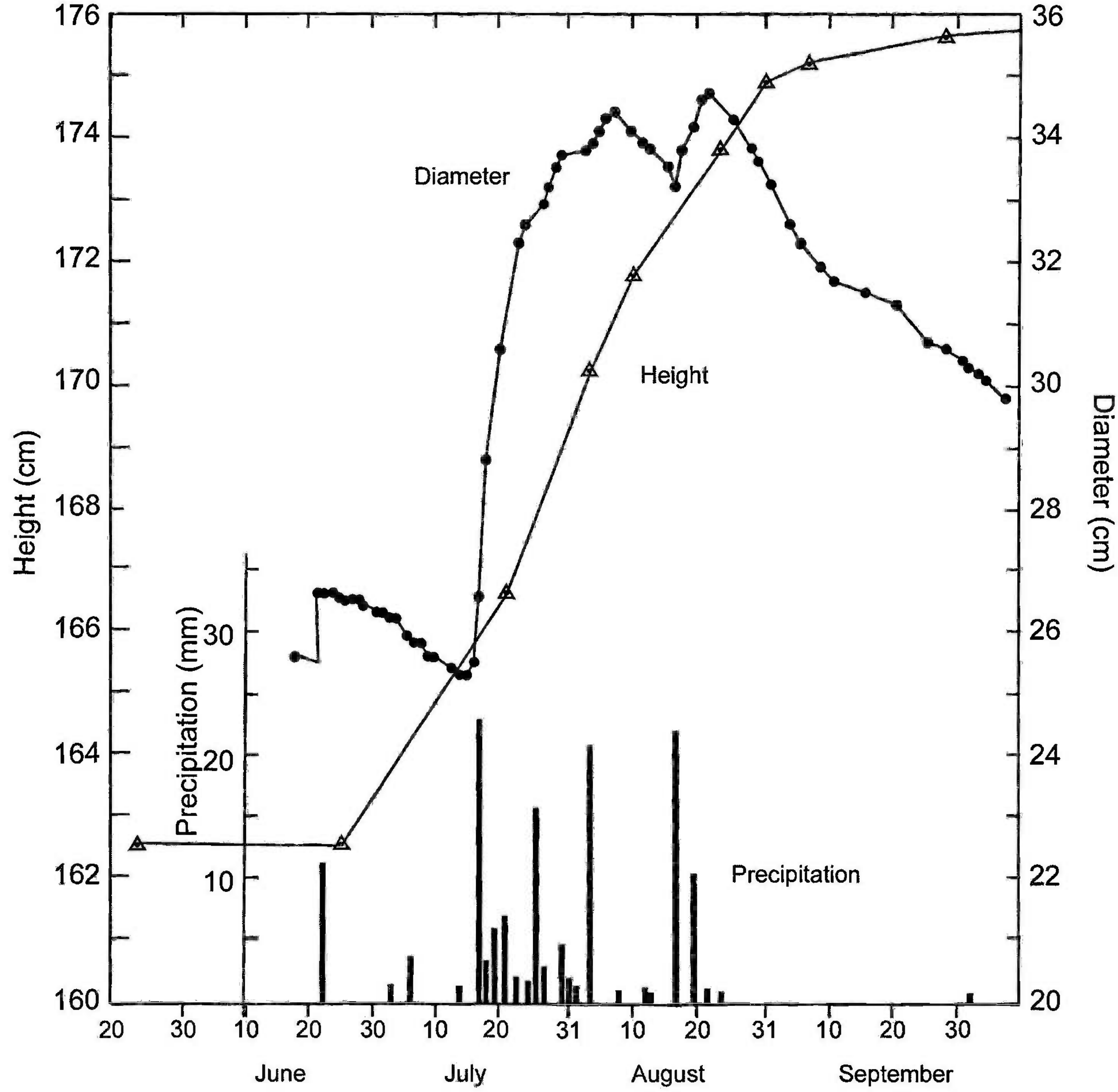


Figure 9. Graph showing growth of saguaro 4A in relation to summer precipitation in 1959 (Hastings 1961). This plant was at a site between Spalding plots 15 and 16 on the west side of the Desert Laboratory.

Desert Laboratory, and Turner's work seemed a natural extension of the early work. The two lowland species had a flush of radial stem growth in the spring in response to winter rains, while radial growth in the upland plants occurred after summer rains. Leaf growth followed different pathways for the trees. For example, in mesquite, initiation of leaf growth was closely timed – apparently by photoperiod – while leaf growth timing in the palo verde, with its extensive photosynthetic stems, was erratic. Timing of floral development in the four species was well defined, although no flowers appeared for foothill palo verde in the spring of 1956, a drought year.

As illustrated by research on saguaro, reproduction and phenology of cacti are favored research topics at the Desert Laboratory. Bowers (1998) studied flower, fruit, and seed production of barrel cactus (*Ferocactus wislizeni*), and her work revealed basic characteristics of this short columnar cactus, which produces an average of 25 flowers/yr – a relatively low number for a desert species – but have a fruit set with up to 25,000 seeds per plant. Plants begin their reproduction when they reach a diameter of about 19 cm, which is relatively small for a species that regularly has mature adults with a diameter of >50 cm.

In the Sonoran Desert, prickly pear is one group of cacti that has greatly increased, presumably the result of decreasing frequency of severe frost (Turner et al. 2003). Bowers (1996a, 1996b, 1997) conducted sustained research on reproduction and phenology of Engelmann prickly pear (*Opuntia engelmannii*), one of the most common species of prickly pear in the Sonoran Desert. She found that the age of plants could be determined from the number of pads (cladodes) (Bowers 1996a). Her work indicated a complex tradeoff of pad production versus flower production, since both are produced from the same areoles on the margins of the pads. During wet years, the plants produced flowers instead of new pads, whereas pad production appears to have increased during some drought years (Bowers 1996b, 1997). She estimated a maximum lifespan of 20-25 years for this species (Bowers 1996a) and explained the apparently longer-term persistence of up to a century (Bowers et al. 1995) by vegetative propagation of pads from seedling plants that appeared to have died.

This raises an important question: when do individuals that propagate vegetatively die? Is it when the stem of the plant that germinated and established is dead, or is it when all the remaining clonal material has disappeared? This important question extends to larger issues, such as the reported extreme longevity of creosote bush of many thousands of years (Vasek 1980, McAuliffe et al. 2007). This species persists via clonal material that expands into rings long after the center of the original plant has died.

Relevance: Global Change and Desert Vegetation

As with long-term global temperature and precipitation data, long-term plot data anchors our concepts of the influence of climate change – whether human influenced or natural fluctuations – on ecosystem properties and function. For example, without long-term data on saguaro demographics and growth rates, we would have little idea that this species undergoes boom and bust cycles of mortality and establishment, and that snapshots of this species' status at any given time can be extremely misleading in regard to its long-term population trajectory. Similarly, knowing this species' propensity for reproduction during wet periods and the current long-term prognostications of sustained drought, we might be concerned that at some point 50-100 years in the future, this species might not have its current visual stature on southern Arizona landscapes. We now know this simply can be attributed to its known lifespan and rare germination and establishment of new individuals. Drought may be the best explanation for changes in some parts of Saguaro National Park, where landscapes once visually dominated by saguaro now appear to be a sea of foothill palo verde (Turner et al. 2003, Plate 60).

Although geologists developed the technique of repeat photography in the late 19th century, researchers at the Desert Laboratory systematically applied this technique to regional vegetation change. Sustained application of repeat photography, especially in concert with other remote-sensing techniques, could be a cost-effective technique for addressing spatial variability of long-term change in the Sonoran Desert and other arid regions that cannot be obtained from permanent plots alone. While data collection from permanent vegetation plots, such as the Spalding and Shreve plots at the Desert Laboratory, might be the ideal way for assessing long-term landscape changes, regional establishment of permanent plots is costly and unfeasible. As Bullock and Turner (2010) demonstrate, assessments of change in species abundance using repeat photography can provide a reasonable means for evaluating regional change.

Abiotic control of desert vegetation has long been a theme of research at the Desert Laboratory. Research results from the Desert Laboratory have shaped modern ecological thought on how long-term changes in vegetation are driven by soils, substrate lithology, and climate. We now know that geomorphic and soil characteristics can control ecosystem function and vegetation response to climate change. Researchers who develop monitoring programs that stratify desert ecosystems according to geology and geomorphology owe a debt to the pioneering research of scientists at the Desert Laboratory.

Tumamoc Hill is the premier site in the Sonoran Desert for long-term documentation of establishment and spread of invasive species. Repeated mapping of the grounds shows the rate of expansion of non-natives, especially buffelgrass, which some consider to be the largest threat at present to ecosystem function in this region (http://216.104.181.187/drupal-6.16/index.php, accessed 30 August 2010). At the same time, the mapping shows that some non-native species either have disappeared or have not significantly expanded or increased in abundance. Moreover, increases in ornamental species underscore that the urban-wildland interface is the front line of the effort to control expansion of non-native species into the desert environment.

Land use in the Sonoran Desert continues to exert a strong pressure on desert ecosystems, and future climate change will exacerbate recovery. The Desert Laboratory provides many examples of natural recovery from disturbances, in some cases repeated disturbances (Fig. 10). If severely disturbed areas, such as the pipeline corridor depicted in Figure 10, are not restored by active measures, such as reseeding or planting of shrubs and trees, then climate will play a role in the course of natural recovery. As shown in Figure 10, the pipeline corridor disturbed in the 1950s had substantial revegetation of trees and shrubs by 2003, following about a half century of recovery with no additional disturbance. Will the scene depicted in 2004 follow the same trajectory, or will, in the face of long-term climate change, this newly denuded surface require much longer times to recovery? This is one of the many research questions that could be addressed from the foundation of long-term research that started at the Desert Laboratory in 1903 and continues to this day.

Acknowledgments

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Figure 10A. (September 1958) Southerly view of a newly installed pipeline for transporting gasoline from El Paso, Texas to Tucson and Phoenix. It crosses the western edge of Tumamoc Hill on an easement through the Desert Laboratory property. The vegetation present is mostly annual forbs and grasses (R.R. Humphrey).

Figure 10B. (February 21, 1978) By 1978, the beginning of the late 20th century wet period, subshrubs had become established in the pipeline corridor (R.M. Turner, Stake 905A).

Figure 10C. (October 27, 2003) What appears to be a mature Sonoran Desert plant assemblage, albeit without saguaros, had become established in the pipeline corridor more than 45 years after disturbance (R.M. Turner, Stake 905A).

Figure 10D. (June 3, 2004) The new pipeline was installed a few months before this match. The ocotillo in the right foreground was one of several of these plants that were salvaged and planted along the pipeline corridor (R.M. Turner, Stake 905A).

Figure 10E. (April 25, 2010) In nearly 7 years after the new disturbance, many new subshrubs have become established in the pipeline corridor. The transplanted ocotillo has tilted to the west (R.M. Turner, Stake 905A).

Ray Turner with *Agave turneri* and *Bursera microphylla*, Sierra Cucapá, Mountains, south of Mexicali, Baja, California

Table 1. Measurement years of the Spalding permanent perennial vegetation plots at the Desert Laboratory, Tucson, Arizona

Plot	Size (m)	1906	1910	1928	1929	1936	1948	1957	1959	1960	1967	1968	1969	1974	1975	1978	1984	1985	1993	2001	2010	Total maps
1	10 x 10	x																				1
2	10 x 10	x																				1
3	10 x 10	x																				1
4	10 x 10	x										x				x		x		x	x	6
5	10 x 10	x																				1
6	10 x 10	x																				1
7	10 x 10	x										x				x		x		x		5
8	10 x 10	x																				1
9	10 x 10	x										x				x		x		x		5
10	10 x 10	x										x				x				x		4
11	10 x 10	x	x	x		x	x			x		x			x	x	x		x	x	x	13
12	10 x 10	x			x	x	x			x		x			x	x	x			x		10
13	1 x 1 ?																					1
14	10 x 10	x											x			x		x		x		5
15	10 x 10	x	x	x		x	x		x			x			x	x	x			x	x	12
16	10 x 10	x		x		x	x	x	x		x	x		x		x	x		x	x	x	14
17	10 x 10	x		x		x	x															4
18	10 x 10	x																				1
19	1 x 1	x																				1
Area A	about 557 m^2		[x]	[x]		[x]							[x]			[x]						1
Area B	20 x 40			8		8	8	8				8				8	8			8	10	9
Total plots measured		18	2	12	1	13	13	9	2	2	1	16	1	1	3	17	12	4	2	17	14	97

Table 2. Density (plants/ha) of selected perennial species in Spalding plot 16 at the Desert Laboratory, Tucson, Arizona

SPECIES	DENSITY (plants/ha)													
	1906	1928	1936	1948	1957	1959	1967	1968	1974	1978	1984	1993	2001	2010
All chollas	100	400	500	900	1310	1110	700	700	0	100	100	100	200	200
All perennial grasses	0	0	0	0	100	0	1210	700	0	100	400	6540	400	0
Acacia constricta	200	0	0	100	300	200	200	200	300	200	200	200	200	300
Ambrosia dumosa	0	3620	4730	3220	700	600	1010	1410	1410	1310	2110	2520	3520	3220
Bahia absinthefolia	0	0	0	0	0	0	7850	13,280	3620	5030	1710	4120	300	400
Cercidium microphyllum	0	0	100	0	0	0	100	100	400	100	100	0	0	0
Krameria grayi	500	1510	8150	6340	2520	2520	2720	2620	1910	2210	2210	2210	2210	1210
Larrea tridentata	1610	1410	1310	1010	700	600	700	805	500	500	500	604	700	700
Opuntia engelmannii	0	0	0	100	200	300	300	400	200	200	200	300	300	300
Psilostrophe cooperi	0	0	3220	600	1910	1710	2110	5530	200	500	1610	7850	1710	0
Senna covesii	0	0	0	0	0	0	1210	1107	18,610	200	0	1110	1310	200
Tiquilia canescens	200	0	3720	1410	1210	2720	400	500	200	0	0	0	0	0
Total Density[1]	2620	6940	21,700	13,700	8950	9760	18,500	27,400	27,400	10,500	9150	25,600	10,900	6540

[1] Total density only refers to the species in the table. Other plants were found at different times on this plot.

BTA's Director Travels to South Africa

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In the last issue of Desert Plants, I referred to my pending trip to South Africa and Namibia and promised a few details for this issue. My two week trip in March included driving over 1,200 miles, 1,800 pictures, five national botanic gardens, several national parks, museums, private gardens and a Desert Research Center, with a 19.5 pound backpack. There is too much to cover in one article, so I will stick to my promise of a few details.

Before I begin, I would like to explain why a trip to Africa was so important for the Arboretum. The purpose of the Boyce Thompson Arboretum is to instill in people an appreciation of plants through the fostering of educational, recreational, research and conservation opportunities associated with the world's arid land plants. Over the last two years, we have made great strides in our North and South American Exhibits as well as in our Australian area. To fully represent the world's arid plants, it is time to tackle the two largest areas of arid lands as shown in the chart on page 22.

Even adopting the newer concept of drylands and using the terms hyper arid, arid, semi-arid and dry sub-humid as used in the *World Atlas of Desertification* (UNEP, 1992), Africa and Asia clearly remain at the top of the list in total and in almost every category. Dr. Feldman, former Director of the Arboretum, had already laid important groundwork in the 1990s, both in Africa and Asia. Based on his work, the Arboretum has a strong basis to expand our Deserts of Southern Africa and Asian areas. I was lucky to retrace some of his steps in Africa and renew some friendships as well as make new ones in the process.

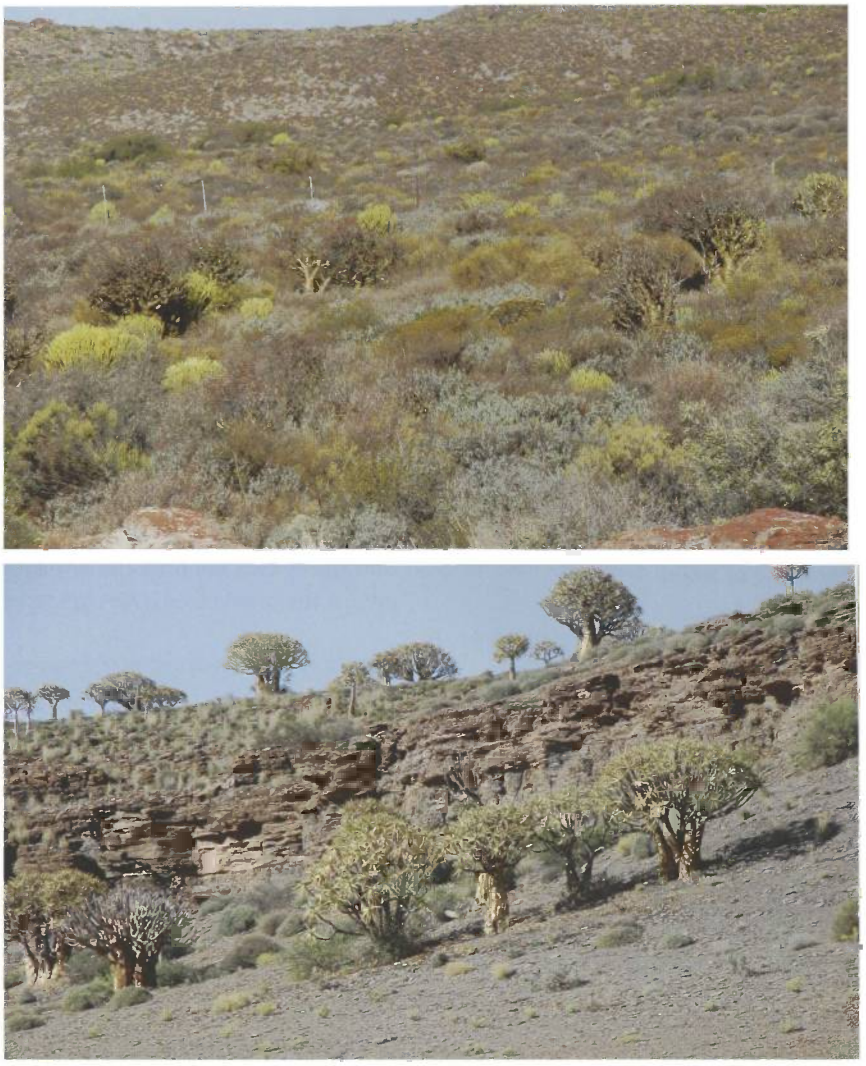
Karoo Desert National Botnaical Garden Greenhouses, Worcester, South Africa (M. Siegwarth)

My first and most important stop was the Karoo National Botanical Garden in Worcester, South Africa to meet their Curator, Ian Oliver. Readers of Desert Plants might be familiar with him through his June 2003 article on the Karoo. Mr. Oliver, curator since 1991, has achieved international stature for the garden and its' succulent collection. Boyce Thompson Arboretum had extended an offer to Mr. Oliver to be the Curator of our Deserts of Southern Africa area. My trip was to solidify this offer and get a better understanding of the flora and its interpretation in order to move forward with our plans at Boyce Thompson Arboretum. I am pleased to announce that the trip was successful and Mr. Oliver should be on staff at Boyce Thompson Arboretum in January, 2011.

My next stop, the Kirstenbosch Botanical Garden in Cape Town, is arguably the flagship of the South African gardens. The Kirstenbosch is the one garden that displays and interprets the flora from across the varied terrain of South Africa. Their conservatory houses arid land plants from the Namib, Kalahari and Karoo Deserts and showcases not only the difficulty but also the marvelous diversity of the plants from this region of the world.

Kirstenbosch National Botanical Garden, Cape Town, South Africa (M. Siegwarth)

Approximately four hours away, is the newest National Botanical Garden, the Hantam. I entered an area of South Africa, that if not for the Quiver Trees and Euphorbia, I would have sworn I was back in Arizona. The Garden is world renowned for its incredible diversity of bulbous plants. Some 40% of the flora comprises bulbs that create spectacular displays in autumn and spring each year.



Terrain and Quiver tree (*Aloe dichotoma*) forest outside of Nieuwoudtville, South Africa (M. Siegwarth)

To date, 1,350 plant species have been recorded on the Bokkeveld Plateau, where the garden is located, including 80 range-restricted or endemic species. Almost a third of the species endemic to the Bokkeveld Plateau are threatened with extinction. There is a great opportunity to partner with the Hantam and help protect these beautiful and endangered plants.

Even though the Arboretum focuses on arid land plants, I took some time to marvel at the diversity of the Cape Floral Kingdom. With over 8,700 species, the Cape Floral Kingdom compares with some of the richest floras in the world. In addition to the Kirstenbosch, the Harold Porter National Botanical Garden and the Cape of Good Hope are both great places to view this rare and endangered flora and landscape.

My visit to Namibia was to experience the other great desert of southern Africa, the Namib. Much like the saguaro defines the Sonoran desert, the *Welwitschia mirabilis* defines the Namib. In traveling the landscape, it was clear to me that a lot of work would be required to successfully exhibit the flora of the Namib at Boyce Thompson Arboretum. The Curator of the National Botanic Garden of Namibia, Silke Rugheimer is eager to work with Boyce Thompson and we hope to have her visit and lecture at Boyce Thompson in 2011. Also, the University of Arizona study abroad program just finished their third trip to Namibia. Realizing that students were traveling to Namibia on an annual basis, Boyce Thompson Arboretum offered scholarships to students who would focus on botanical research on our behalf. The results of this partnership are in the accompanying article, Floral Survey of Central and Northern Namibia.

A bulb photographed at the Hantam National Botanical Garden, Nieuwoudtville, South Africa (M. Siegwarth).

Welwitschia mirabilis drying out in in Namib-Nuakluft National Park, outside of Swakopmund, Namibia (M. Siegwarth).

Penguin colony, Betty's Bay, South Africa (M. Siegwarth)

Harold Porter National Botanical Garden, Betty's Bay, South Africa (M. Siegwarth).

Continent	Extremely Arid	Arid	Semi-Arid	Total
Africa	4,558	7,034	6,081	17,943
Asia	1,051	7,909	7,516	16,476
Australia	0	3,864	2,517	6,381
North America	31	1,279	2,657	3,967
South America	171	1,217	1,626	3,014
Europe	0	171	844	1,015

Arid lands in thousands of square kilometers, Gobabeb Desert Research Center, Namibia.

Continent	Hyper Arid	Arid	Semi-Arid	Dry Sub-Humid	Total
Africa	6,720	5,035	5,138	2,687	19,580
Asia	2,773	6,257	6,934	352	16,316
North America	31	815	4,194	2,315	7,355
Australia	0	3,030	3,090	513	6,633
South America	257	445	2,645	2,070	5,417
Europe	0	110	1,052	1,835	2,997

Chart is in thousands of square kilometers.
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Cape Peninsula National Park, near Cape Town, South Africa (M. Siegwarth)

In closing, it was an extremely productive trip and we have laid a strong foundation to advance our Deserts of Southern Africa exhibit at the Arboretum. Therefore, if you are not fortunate enough to be able to visit Africa, you can at least get a taste of what you are missing in Superior, Arizona in the not too distant future.

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Floral Survey of Central and Northern Namibia

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Abstract
The Boyce Thompson Arboretum, an Arizona State Park located in Superior, Arizona, selected a three member team of researchers to study unique plants found in central and northern Namibia. The results of this study will be used to select plants for cultivation in a new southern African flora exhibit at Boyce Thompson Arboretum representing the floral diversity of the Kalahari, Karoo and Namib deserts. This botanic survey was conducted during a University of Arizona study abroad class which took place May 24 - July 4, 2010. As part of the survey, the related soil, ecologic, climatic, geographical, and ethnobotanic characteristics were recorded. Size, distribution, and location for each species were noted and land formations were documented. The land formations and soils of Namibia were superficially similar to those of southeastern Arizona. To contribute to Boyce Thompson Arboretum's educational public outreach objectives, we recorded the varied uses of plants based on personal observations, data found in published materials, and interviews conducted with the Himba people. Based on our results, we recommended 21 species suitable for cultivation and interpretation in the new exhibit.

Introduction
The Namib and Kaokoveld desert ecosystems, consisting of sand dunes, gravel plains, and harsh mountain landscapes, are characterized by extreme aridity, as well as extremely low and variable rainfall. With an estimated age of at least 55 million years, the Namib and Kaokoveld deserts have generated plant species well-adapted to arid conditions (Lovegrove, 1994). The soil present in these deserts can be generalized as nutrient-poor, and the native flora have adapted accordingly (Wilkins-Ellert, 2004).

Landforms are described based on morphology or the shape of a particular landscape component. (Graymer, Helley, 1997). The land formations and soil types in southern Arizona (Figure 1) resemble those of central and northern Namibia (Figure 2). The landscape of Namibia consists of five geographical areas: Central Plateau, the Namib Desert, the Great Escarpment, the Bushveld, and the Kaokoveld Desert. Each area contains different temperature regimes and varying amounts of precipitation. The future site of the southern African exhibit at Boyce Thompson Arboretum contains a grassland area, an ephemeral river bed, and rocky slopes.

Vegetation in each area of Namibia varies; however vegetation types overlap between areas. Most of the agriculture in Namibia is in the Central Plateau where summer temperatures can exceed 40°C and frost is common in the winter. The Namib Desert contains hyper-arid gravel plains and dunes that stretch the entire coastline. This area contains little vegetation aside from dry river beds. The Great Escarpment is characterized by coastal fog, which diminishes closer inland. The area is rocky with soils lacking nutrients. Vegetation fluctuates in form and density with plant communities ranging from dense woodlands to shrubs with scattered trees (Weber, 2010). The Bushveld area has cooler and milder temperatures and receives more rain than the rest of the country, averaging 41cm per year (Streissguth, 2008). The land is flat with mostly sandy soils, incapable of holding much water; however, it is still able to support woodlands, shrubs, and dense riparian areas.

Namibia and Arizona are distinguished by large alluvial fans and/or pediments that have been formed by fluvial processes (Weber, 2010). These surfaces can be found at the base of mountains, providing a variety of substrate for vegetation. Rocky areas are common along with dry river beds cutting through the land. Rocky hill slopes can vary from little or no vegetation to scattered trees, shrubs, and grasses.

Aside from the vast dune formations and coastal regions found in Namibia, Arizona's landscape is similar. The climate of Namibia ranges from arid to semi-arid. The coastal regions are cooled by the Benguela current, which causes fog and reduces precipitation. Temperatures in this region are stable, ranging from 15 to 25°C (SA-Venues, 2010). Rain occurs most frequently in the summer months from November to February. The interior has a short rainy season from October to December and a longer one from mid-January to April. During the rainy seasons, the land becomes alive with new vegetation. Winter is from May to September, characterized by warm days and cool nights with temperatures occasionally falling below freezing. The northern region of Namibia receives more rainfall than the rest of the country and the climate is more temperate with temperatures rarely reaching freezing.

Precipitation in Arizona and Namibia is governed by elevation and season of the year. On average, Namibia receives annual precipitation of 70cm in the far north, 2.5-15cm in the south, 35cm in the central plateau, and some regions have gone nearly a century without a drop of rain (Encyclopedia of the Nations, 2009). In comparison, the average annual precipitation of Phoenix, Arizona is 21cm (IDcide, 2010).

Figure 1. Boyce Thompson Arboretum terrain

Aspects of the soil such as soil texture and pH, play a key role in determining plant establishment and survival (Hewitt, 2004). With analysis of the soil and landscape near plant specimens, we can compare the physical plant conditions of native flora in the Namib to the existing site conditions at Boyce Thompson Arboretum.

During May through July, 2010, our student group from The University of Arizona traveled to Namibia as part of a study abroad program in Desert Ecology and Conservation Biology. It was a six week course about conservation biology in the context of Namibian cultures. Each student chose a research topic, conducted a field study, and wrote a paper summary. We conducted our studies with support from the Boyce Thompson Arboretum as part of the research necessary to develop a proposed Southern Africa Flora Exhibit. Our research topics included Namibian landforms and geology, soil classification, and plant uses by the Himba people, an indigenous group of pastoralists presently residing in part of the arid Kaokoveld desert, which merges with the northern portion of the Namib and is the least inhabited region of Namibia (Hall-Martin, 1988).

Materials and Methods

In preparation for our visit to Nambia, we visited the Plants for the Southwest Nursery in Tucson, Arizona. We were able to get a preview of the types of plants we would encounter on our study as well as view living specimens of *Lithops ruschiorum, Adenium boehmianum, Aloe dichotoma,* and *Welwitschia mirabilis*. Our study was limited to the northwestern region of Namibia, beginning in Windhoek and traveling north to the Angolan border and west to the Atlantic Ocean. Dr. Hans-Werner Herrmann and Dr. Tom Wilson, Faculty Instructors from The University of Arizona, along with assistance from local guides, helped us locate and identify plants. Dr. Herrmann and Dr. Wilson knew how to locate plants based on previous study abroad sessions in Namibia. We also gathered information on other plants that could be grown in the new exhibit.

Plants selection was based on the following criteria:

1. Potential for cultivation. There are some plants such as the *W. mirabilis* which may be difficult to cultivate because it grows slowly over many years. The leaves of the *W. mirabilis* grow at a rate of 8-15cm/yr (Earle, 2010).
2. Suitable climate.
3. Aesthetic appeal. We examined the overall appearance of the plant and any features that make it unique. For example, *L. ruschiorum* has an uncommon and interesting physical appearance.
4. Bark, leaves, flowers, and/or fruit. We took these factors into consideration with species such as *A. boehmianum*. The A. *boehmianum* has beautifully symmetrical pink flowers growing from twisted branches.
5. Scarcity. We estimated plant density by scanning a representative area and counted individuals within and among species and measured distance between plants.

For each species, we recorded the coordinates of individuals using a Garmin Vista GPS unit and collected a soil sample from 7.5cm below the surface at the base of the plant. We later analyzed the samples to classify the soil and to determine pH. We also evaluated the texture of samples for soil, silt, and clay content. For each GPS location, we recorded the relief, geological features, and land formations where the plants were found. We also used plant guide books to compare the size of mature plants with the sizes we encountered in the field.

Figure 2. Namibian terrain resembles the rocky terrain found at Boyce Thompson Arboretum.

We determined soil texture using field texturing techniques. To prepare the soil sample, we isolated the fine-earth fraction of the sample by passing the soil through a 2 mm sieve to remove rock fragments and organic debris (Burt, 1995). In order to determine the textural class, we moistened a small portion of the soil and used reference charts provided by the class instructors. We determined the pH of the soil sample with pHTestr 2 handheld pH meters and a 1:1 soil:water ratio. Due to the lack of neutral water, we used well water with a constant pH of 7.55 and adjusted the pH values.

The increased precipitation near Epupa Falls on the Kunene River in northern Namibia promotes greater plant diversity and population density. Isolated, single family Himba compounds are also scattered in the region. We interviewed four of these indigenous groups about the cultural uses of selected plants, choosing the families based on the proximity of the compound from the main town in order to evaluate the influence of modern development on the traditional culture. On June 21, 2010, we hired a Herero interpreter fluent in Otjihimba and English, and during the following three days we visited the four compounds during the morning to interview the adults before the men set out with their goats for the day. Using a digital slide show of select plants in the region, we showed the images to the Himba adults while the interpreter asked if the plant was known. If it was, the interpreter requested the name in Otjihimba and asked whether any part of the plant was eaten or used medicinally. We recorded both the translations and the exhibited body language and gestures. We also took notes on the observed use of plant material around the compound. However, we could only evaluate the plants in the Epupa region that are known and used by the Himba. Due to these limitations, we conducted additional research with field guides, plant books, Namibian travel guides and published articles.

Discussion

The many ethnic groups of Namibia collectively utilize every part of a plant. They also tap hollow trunks for stored water after rain (Van der Walt, 1999). Northern Namibian cultures such as Bushmen, Caprivians, Damara, Himba, Kavango, Owambo, are more likely to select fine-grain wood to carve dishes and utensils, such as the wood of *Boscia albitrunca* and *Euclea pseudebenus* (McIntyre, 2007). In contrast, the Kavango people, noted for their fine woodwork, are more likely to select harder, more termite resistant wood such as acacias for fences, building construction, and tool crafting (Gibson, 1981). Nomadic pastoralists also commonly select *Commiphora spp.* for fences due to their ease of propagation from cuttings (Palgrave, 1977) and the Topnaar people, a small branch of the Nama, traditionally select the fine grained wood of the *Parkinsonia africana* for tobacco pipes which will not crack with heat (Van Damme, 1922). The Nama and Damara people use bark with high concentrations of tannins to tan leather (Van Der Walt, 1999) and the Himba weave pliable young strips of bark into sturdy ropes for day to day purposes such as carrying gourds of water or lashing together roof thatching. The Himba harvest the insects found on trees, such as the large larvae found on Baobab trees and Mopane trees which are dried and stored for times when food is scarce (Termote, 2010).

The inhabitants of Namibia often eat fruits and seeds raw or cooked into dishes. People with convenient access to *Adansonia digitata* and the people of the lower Kuiseb River who have convenient access to *Parkinsonia africana* trees may boil the young leaves and twigs into stews (Mannheimer, 2009). The local populations throughout Namibia often collect the roots and pods of various trees, dry them and grind them into flour for porridge or bread. They also commonly collect various seeds to roast, grind, and brew into beverages similar to coffee (Termote, 2010). Many acacia species have sweet, edible resin (Ross, 1979); however, Damara people also commonly boil root and fruit pieces to form sweet, concentrated syrups such as with the fruit of *Salvadora persica* and the roots of *Boscia albitrunca* (Mannheimer, 2009). Even toxic plants are useful; hunting groups use the latex to poison tips of arrows for hunting (Van der Walt, 1999), and the pastoral Himba groups soak pieces of the toxic plant with meat for bait to eliminate predators.

For medicinal purposes, the local population often boils a plant and consumes the resulting extract (Van Vamme, 1922). Medicinal uses range from alleviating the common cold to more severe ailments. The local populations in the northwest region of Namibia use the roots of *Acacia nilotica* to cure tuberculosis, while in the former Namaland, men boil *Acacia mellifera* roots for venereal diseases (Mannheimer, 2009). For surface skin ailments, people are more likely to use plant sap: the Himba use *Aloe littoralis* sap to ease discomfort after breastfeeding and seed sap from *Cyphostemma currorii* to treat flesh wounds and skin disorders.

The inhabitants of Namibia use diverse plants based on many factors: seasonal availability, species abundance or ease of access, and current needs of the individuals (Van Damme, 1922). While one group may use a tree in its entirety, another may just feed on its fruit. People are also more likely to seek a cure for a common ailment. Although harder wood is preferable for construction, if a tree with less resilient wood is more abundant in the area, individuals may reject the stronger wood for the sake of practicality. The chemical and physical characteristics of a tree vary considerably even between visually similar species. While select acacia species may have palatable sweet seeds, another may have seeds too toxic for consumption (Mannheimer, 2009).

The rocky and hilly slopes found at the Boyce Thompson Arboretum resemble many land formations that we encountered in Namibia. We found four species growing within 1-2 meters of each other and often directly out of rock formations: *Cyphostemma currorii, L. ruschiorum, Moringa ovalifolia,* and *Pachypodium lealii.* We found that these plants consistently grew on the side of the slope where partial shade is provided at some point during the day.

Each analyzed soil sample was either sandy loam or loamy sand based on the clay and sand concentrations. The majority of the pH readings fall within the range of 7.0-7.5, which is the average soil pH at the Arboretum site (Stone, 2010). The surveyed species are almost all located on or near gravel plains, sand dunes, and valleys. Their adaptations to the harsh climate of Namib and Kaokoveld deserts and other southern African ecosystems may enable them to flourish in similar conditions of southern Arizona. The plants often establish on rocky slopes, facing a direction where partial shade is provided at some point during the day, although this changes throughout the year. All of the soil samples resembled Aridisols, which are associated with low organic matter concentrations and are the most common soil order in southern Arizona.

We recommend fencing at the Arboretum to reduce the damage posed by wild animals on young trees or small succulents until they become established. A solid fence can be placed around plants with a minimum height of one meter. There should also be fencing below ground to keep out burrowing animals. Smaller plants that may be exposed on the ground can be placed in an above-ground pot as part of an interpretive display. We encountered several species of *Euphorbia virosa* in the study that were known to be poisonous and may help to deter wildlife.

We found several plant species growing together as part of a community. In the Bushveld region, we commonly found plant groupings under the canopy of a *Colophospermum mopane* tree. We found several species of *Aloe* growing against the base, observed three trees where a *Euphorbia spp.* was growing directly out of the tree trunk (Figure 3). We also saw an *Acacia erioloba* tree with *Euphorbia avasmontana* growing at its base. Replicating these natural arrangements of plant species will add an authentic appeal to the exhibit.

We recommend using a glasshouse structure to showcase plants that are frost sensitive. Certain species such as *Adansonia digitata* may not survive a winter frost. *A. digitata* can survive well indoors planted in a pot or in the ground. It should be planted in well drained soil and kept dry during the winter months (Naturel, 2010). The Kirstenbosch Botanical Garden in Cape Town, South Africa has a large collection of plants growing outdoors along with a glasshouse to protect frost-sensitive species such as *Aloe spp., Commiphora spp., Cyphostemma spp., Euphorbia spp.,* and *Hoodia spp.* This garden can be used as a reference for cultivating southern African plants that require different climates at the same location.

We conducted the study during the winter season, thus many of the species which were encountered had been partially or fully defoliated. A plant's appearance both in the winter and summer should be taken into account for the new exhibit. For example, *C. currorii* looks like a large ginger root growing out of a rock crevice in the winter, but in the summer it has very broad, green leaves. Furthermore, *A. boehmianum* has a rigid, gray trunk that changes appearance with the growth of thick green leaves in the spring and summer. It is possible that we may have overlooked certain species due to the absence of leaves. We were only able to spend six weeks in Namibia and we were limited to the north, west, and central regions of the country. A more extensive survey conducted in the future during the summer season would provide a more complete assessment.

Three species of plants we encountered in Namibia that resemble species found in southern Arizona. This presents the opportunity for healthy trees to remain onsite since there is little visual difference from the African species. *Acacia erioloba* species (Figure 4) resemble *P. glandulosa* (Figure 5) with respect to leaves, thorns, and general shape. The *Parkinsonia spp.* are also similar in appearance. *Tamarix* is an invasive genus native to southern Africa and commonly found along river beds in Arizona and across the southwestern United States (Westbrooks, 1998). *Euclea pseudebenus* of Namibia and *Salix laevigata* of southern Arizona have a similar morphology with their cascading leaves and branches.

In the future we recommend soil sampling at the Boyce Thompson Arboretum exhibit site to provide further information about plant suitability. We did not account for seasonal fluctuation in soil pH and further research during different seasons will provide additional data on the range and rate of pH fluctuation.

Figure 3. An example plant community of a *Euphorbia spp.* growing directly from the base of a Mopane tree.

With more research, the compiled list of plant uses is expandable. To further our knowledge of cultural uses of southern African plants, we can examine the chemistry of the plants to determine their actual nutritional and medicinal values. We can also further interview the local populations to study the actual process of converting raw materials into food or medicine. Despite the limitations of the survey, the data contributes to the educational public outreach objectives of Boyce Thompson Arboretum, and provides a foundation for future research into specific species.

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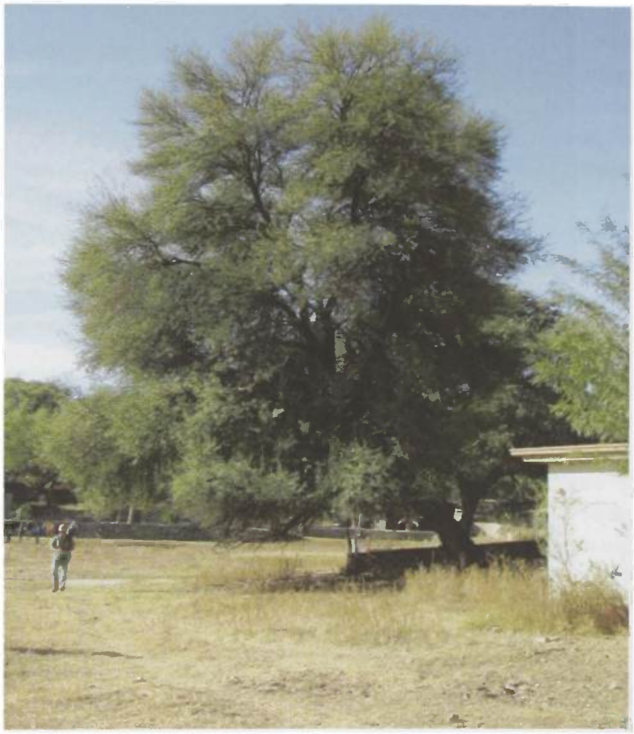

Figure 4. *Acacia erioloba*

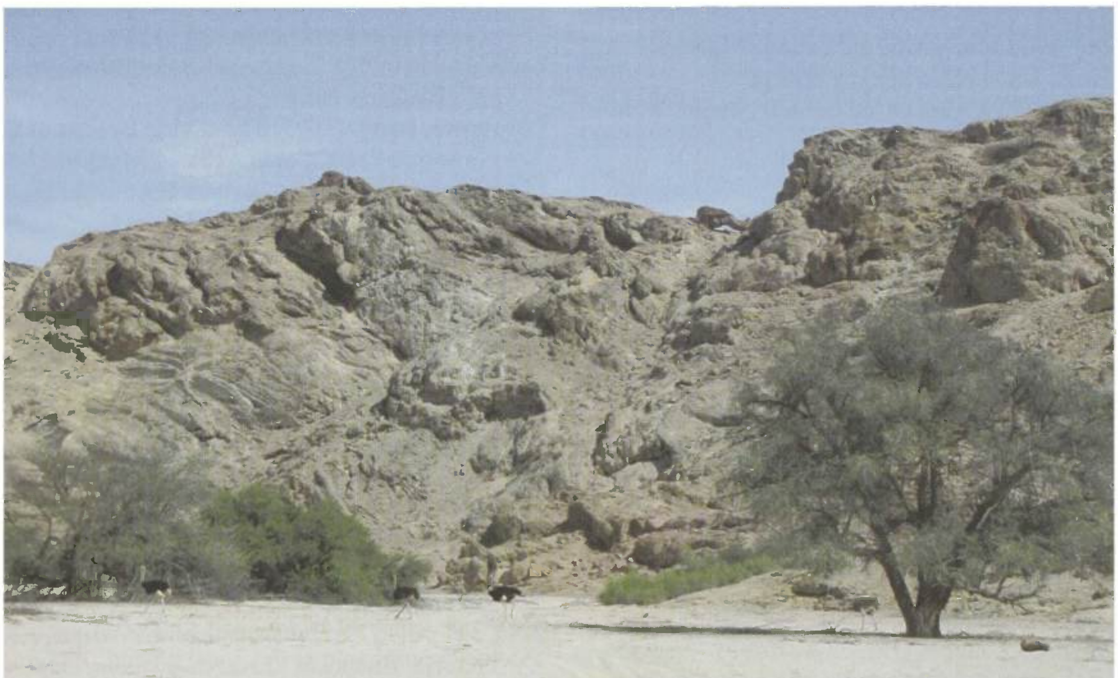

Figure 5. Mesquite spp. resembles *Acacia erioloba* and can be used in its place.

Appendix 1: Plant Species List

Latin Name Family Common Name	Location	Location Notes	Soil Texture	Soil pH	Aspect	Average Distance Between Plants	Size
Acacia erioloba Fabaceae Camelthorn	727m, S 17.00439, E 13.24464	Along granite slopes Very common and widely distributed, preferring sandy soils, depressions, and dry riverbeds	Coarse Sandy Loam	8.63	East	20-30m	Semi-deciduous tree up to 20m high
Acanthosicyos horridus Cucurbitacea !Nara	727m, S 17.00439, E 13.24464	Dunes	Coarse Sand	8.74	East	n/a	Spreading shrub up to 2m high
Adansonia digitata Bombacaceae Baobab	727m, S 17.00439, E 13.24464	Common near rivers, growing among rock formations, plains, slopes, and flood plains, in frost-free regions.	Coarse Sandy Loam	9.24	North	1000m	Deciduous tree up to 20m high with a thick trunk
Adenium boehmianum Apocynaceae Desert Rose	727m, S 17.00439, E 13.24464	Nested between boulders In savannah and rolling woodland	Loamy Sand	9.24	North	1000m	Usually deciduous and 1 to 2m high, occasionally reaching 3.5m high
Aloe dichotoma Aloaceae Quiver Tree	1132m, S 22.89137, E 15.67218	On/near granite slopes and ridges within grassland areas; often found growing on Small clusters on rocky kopjes, outcrops, or plains	Loamy Sand	7.88	East	20m	Single-stemmed tree, 5-9m high
Aloe hereroensis Aloaceae Sand Aloe	698m, S 22.39195, E 15.08201	Growing out of granite rock	n/a (rock)	n/a (rock)	East	<1m	1 m tall plant
Aloe littoralis Aloaceae Windhoek Aloe	744m, S 17.40876, E 13.91681	Granite and metamorphic rocky valley	Coarse Loamy Sand	7.68	North	3-5m	3-4 m tall
Boscia albitrunca Capparaceae Shepherd's Tree	823m, S 22.85414, E 15.47377	Large stand of Boscia, mixed community, in valley	Sandy Loam	7.44	East	n/a	Shrub or tree up to 10m high

Latin Name Family Common Name	Location	Location Notes	Soil Texture	Soil pH	Aspect	Average Distance Between Plants	Size
Colophospermum mopane Fabaceae Mopane	744m, S 17.40876, E 13.91681	Hills, valleys, along dry rivers Dominant tree in northwestern Namibia, forests of trees are common	Coarse Sandy Loam	7.17	East	10m	Deciduous to semi-deciduous shrub or tree 1-15m high
Commiphora glaucescens Burseraceae Elephant Tree	727m, S 17.0 0439, E 13.24464	Top of hills, extremely rocky; widely distributed, covering most vegetation and soil types in Namibia	Sandy Loam	6.57	North	1000m	Deciduous tree 2-8m high or a shrub branching near the ground
Cyphostemma currorii Vitaceae Kobas	753m, S 22.71751, E 16.08208	Granite slopes in mountainous areas; single plants found growing out of rocky crevices	Fine Sandy Loam	7.55	West	1000m	Deciduous tree up to 5m high
Euclea pseudebenus Ebenaceae False Ebony	319m, S 20.23338, E 13.8721	Flat, sandy valleys, commonly found along dry washes	Loamy Sand	8.10	North	n/a	Evergreen tree/shrub, 3-9 m high with drooping branches
Euphorbia demarana Euphorbiaceae Damara Euphorbia	744m, S 17.40876, E 13.91681	At crest of hill between metamorphic wash, next to dry wash; found mostly on rocky plains and slopes	Coarse Sandy Loam	7.73	East	3m	Many stemmed, succulent shrub 2.5 m high
Euphorbia eduardoi Euphorbiaceae Kaoko tree-euphorbia	319m, S 20.23338, E 13.8721	On granite and sand hillsides	Coarse Sandy Loam	7.84	East	500m	Single-stemmed up to 10m high
Faidherbia albida Fabaceae Ana Tree	319m, S 20.23338, E 13.8721	Rocky, sandy slope; in dry river courses and floodplains	Sandy Loam	8.21	East	10-20m	Up to 15m high
Hoodia currorii Asclepiadaceae Namib hoodia	744m, S 17.40876, E 13.91681	Found in plains and occasionally rocky places; found clustered with Mopane, Euphorbia, and Aloe	Coarse Sandy Loam	7.17	East	8-10m	Grows up to 1m high with thick, showy flowers present after rain
Lithops ruschiorum Aizoaceae Lithops	437m	hidden among rocks on small granite plateaus in vicinity of Swakopmund	n/a (rock)	n/a (rock)	Flat	5m	Grows only a few centimeters high
Moringa ovalifolia Moringaceae Phantom Tree	589m, S 20.74810, E 14.37180	Base of granite hill and other rocky areas, can also be found on plains	Sandy Loam	7.64	East	1000m	Specimens encountered were up to 7m high

Latin Name Family Common Name	Location	Location Notes	Soil Texture	Soil pH	Aspect	Average Distance Between Plants	Size
Pachypodium lealii Apocynaceae Bottle Tree	319m, S 20.23338, E 13.8721	Steep granite ridges and hilltops	Coarse Sandy Loam	7.88	East	10m	Deciduous, short-branched tree 4-6m high
Parkinsonia africana Fabaceae	698m, S 22.39195, E 15.08201	Scattered along granite slopes in arid areas with any soil type	Fine Sandy Loam	7.64	Flat/North	Usually only 1 or a couple trees per acre	Many-stemmed, deciduous shrub rarely reaching 4m high
Salvadora persica Salvadoraceae Mustard Bush	698m, S 22.39195, E 15.08201	Arid regions near ephemeral watercourses in central and northern Namibia	Fine Sandy Loam	7.64	West	Found clumped together - 10m apart with overlapping foliage; thick vegetation	Many-stemmed shrub 2-4m high with canopy reaching 6m in diameter
Welwitschia mirabilis Welwitschiaceae Welwitschia	329m, S 22.59835, E 14.94202	Typically found on flat sand; found almost exclusively in central and northern Namib desert	Fine Sandy Loam	7.95	Flat	1 – 20 m	Spreading evergreen, woody plant up to 2m high with leaves reaching 4m in diameter

Appendix 2: Cultural Plant Use

Acacia albida / Faidherbia albida	Food	Seeds: boiled and eaten Pods: eaten by people and animals
	Medicine	Bark: boiled for diarrhea
	Other	Green bark: used to dye skins Large hollow trunks: used as drinking troughs Wood: used in construction
Acacia erioloba	Food	Seed pods, flowers, young shoots: eaten by game and livestock Seeds: burnt, coffee substitute Pods: finely ground, eaten as a porridge
	Medicine	Resin: ease stomach complaints Roots: boiled in water to produce a cough syrup Plant: used to treat cuts and wounds Tree gum: dissolved in hot water for flu symptoms Bark: extract dissolved in water for diarrhea Root: ground powder prevents nosebleeds Pods: pulp used to treat ear infections Bark: finely ground and burnt; used for headaches
	Other	Wood: hard, resistant to termites and borers, used in construction and for weapons/tools
Acacia karroo	Food	Resin: edible and sweet; sometimes used as a sugar substitute Leaves and pods: eaten by game and livestock Flowers: rich in nectar Seed: coffee substitute
	Other	Bark: 19.7% tannins; used to tan leather Resin: used as an adhesive Wood: hard and used for fencing
Acacia mellifera	Food	Leaves and pods: eaten by game and livestock Resin: edible, easily stored for long periods without going sour Root: debarked pieces used to curdle milk
	Medicine	Roots: boiled and consumed to treat venereal diseases Various plant parts: used as an antidote to snake venom
	Other	Trunk: used to carve pick and axe handles Wood: used for fencing
Acacia nilotica	Medicine	Leaf and root: extract is used to treat colds, menstrual disorders, eye diseases, to stop bleedings, and as a stimulant Flowers: used in ointments for open wounds Roots: cure tuberculosis and impotence Bark extracts: sedative, stimulant, and sex-stimulant
Acacia polyacantha		Roots: influenza, sore throats, and snakebites
Acacia senegal		Roots: used to treat gonorrhea Bark and leaves: colds, eye infections, diarrhea, stop bleeding
Acanthosicyos horridus (!nara)	Food	Fruits and seeds: eaten raw or cooked
Adansonia digitata (baobab)	Food	Fruit: eaten raw or cooked in dishes; stakes driven into trunk to climb tree and obtain fruit Young leaves, twigs: boiled in soups Large larvae: commonly found on the leaves and eaten. Seed: eaten raw or used as a coffee substitute Roots: eaten
	Other	Bark: young, used as a rope or string
Adenium boehmianum	Other	Milky sap: used in the past as an arrow poison Poison meat: used to eliminate predators that prey on livestock or misbehaving dogs; meat placed as bait over cut Adenium stalks or soaked in water with Adenium pieces
Aloe dichotoma	Other	Stems: hollowed out in past and used as arrow quivers

Aloe littoralis	Medicine	Sap: spread over nipples to ease after breastfeeding, also stops continued feeding Sap: dropped into eyes to cleanse and heal Sap: rubbed under stomach when pregnant Plant: boiled into a drink for fever and stomachache
Boscia albitrunca	Food	Leaves: nutritious, high in protein and vitamin A, browsed by game/livestock Roots: consumed for protein, calcium, potassium, and magnesium Roots: thin, young lateral: debarked and finely ground, left in the sun in a plastic bag until sticky, dried and roasted with brown sugar and fat, ground again and brewed as a coffee substitute known as gat Roots: soft and raw, chewed for the fluids then spat out Roots: softer inner parts: crushed and sun-dried to form a flour for porridge and bread Roots: fresh, boiled in water to produce a thick sweet syrup for porridge or coffee Roots: a small amount powdered, boiled, and cooled to drink Roots: small pieces are used to curdle milk Fruit: edible when fresh and ripe but possesses a slimy texture Fruit: mixed with milk to produce a yogurt Fruit: used to produce alcoholic and non-alcoholic drinks Flower buds: young, green; eaten raw or cooked Trunk: center becomes hollow, collects water
	Other	Wood: fine grained, used to make household utensils
Colophospermum mopane	Food	Mopane worms or emperor moth larvae (*Imbrasia belina*): feed on the leaves and are a delicacy among the local people. May be served dried and fried in oil. bv Leaves: eaten by game and livestock Bark: chewed like a bubble gum Seed pods: oily pods are used as an oil or fat replacement
	Medicine	Leaves: wound disinfectant Leaves: stop excessive bleeding; the fibers absorb blood and promote clotting Leaves: boiled for cough and stomach ailments Leaves: Chewed to suppress nausea Bark: Soft bark is used to wrap the head to alleviate headaches
	Other	Bark: strips twined together into a rope Bark: 8.7% tannins, used to tan leather Wood: firewood and construction- huts, fences, kraals, etc .
Cyphostemma currorii	Food	Entire plant: regarded as toxic, high oxalic acid content in fruits
	Medicine	Seed sap: treats skin disorders and flesh wounds for both humans and livestock
	Other	Trunk: Hollowed out and filled with water to bathe/soak sick goat
Euclea pseudebenus	Food	Fruit: edible but not palatable
	Other	Wood: often used for carving
Hoodia	Food	Plant: strong, unpleasant smell suppresses appetite
	Medicine	Plant: spines removed; eaten for fever, headache and other common sickness
Moringa ovalifolia	Food	Bark: somewhat succulent bark, eaten by game.
Pachypodium lealii	Medicine	Plant: used for any common ailment Sap: dress infected wounds
	Other	Trunk: hollowed out and covered with animal skin to make a drum
Parkinsonia africana	Food	Leaves and branches: browsed by animals Seeds: used as a coffee substitute Green pods and leaves: cooked as vegetables (uncommon)
	Medicine	Leaves are used medicinally
	Other	Wood: does not crack when heated, often used for tobacco pipes
Salvadora persica	Food	Fruit and leaves: eaten by animals Fruits: boiled in water to make a concentrated syrup
	Medicine	Crushed roots tea: sick cattle, diarrhea, bleeding, infection, and other ailments
Welwitchia mirabilis	Food	Core of female cones: are collected and eaten raw or roasted Leaves: chewed on by animals
Weaver bird nest		Droppings underneath used to ferment beer

The Desert Legume Program – a Brief History

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The Desert Legume Program (DELEP) was established in June 1988 by Dr. R. Phillip Upchurch as a joint project of the University of Arizona College of Agriculture and Life Sciences, and the Boyce Thompson Arboretum. DELEP is unique in its' focus on wild species of legumes from the world's dry regions. The decision to concentrare on the Fabaceae (legume, bean, or pea family) was made for several reasons. Legumes are the most important group of plants in human nutrition after the cereal grains. Many species of legumes have the ability to convert atmospheric nitrogen into a usable form, a process called nitrogen fixation, allowing them to grow in soils with low fertility. In addition to food crops, legumes are utilized as forage, forestry, medications and landscape plants. The goals of the program are outlined in the Mission Statement:

1. To acquire and preserve in perpetuity seed of legumes native to the arid and semiarid lands of the world;
2. To learn more about the nature and utility of these unique species;
3. To share this germplasm with professionals and laypersons having a legitimate interest; and
4. To aid in the preservation and conservation of desert legume biodiversity through both *in situ* and *ex situ* means.

Maintaining biological diversity is a growing concern worldwide as human populations continue to increase and more natural areas are diverted for human use. As conversion of native habitats continues, it is inevitable that some species may be lost without conservation efforts. Collecting seeds and maintaining these in a seed bank is a basic and important means of preserving species in the face of habitat loss. DELEP plays an important role in conserving legume biodiversity.

DELEP has developed a unique and valuable collection of legume germplasm from around the world, with seeds originating in 57 countries on 6 continents. The seed bank currently includes 3523 individual seed accessions representing 1356 species (1440 taxa) in 221 genera. No other seed bank has focused on the Fabaceae which includes an estimated 17,000 species worldwide and is the third largest family of flowering plants. The program has had a long affiliation with the USDA-ARS National Plant Germplasm System, and a portion of the seed collection is maintained as a back-up collection at the National Center for Plant Genetic Resources, in Fort Collins, Colorado. The program has provided seeds to hundreds of individuals and organizations across the U.S. and around the world for a wide variety of purposes. Samples of seeds are available without cost to individuals and organizations around the world. An Index Seminum listing seed availability and instructions for requesting seeds is maintained on the DELEP website: http://cals.arizona.edu/desertlegumeprogram

The program supports researchers at the University of Arizona, participates in collections development at Boyce Thompson Arboretum, the UA Campus Arboretum and the Wallace Desert Gardens, and has collaborated with the Arizona State Land Department and the U.S. Fish and Wildlife Service. DELEP has hosted international researchers, and staff have given presentations at numerous local and several international conferences.

DELEP maintains three field evaluation sites at the UA Campus Agricultural Center in Tucson and an additional site for relatively frost-sensitive species at the UA Mesa Agricultural Center, in Yuma. Since the first plantings in 1989, over 600 species have been evaluated in these fields. Plants are evaluated for adaptability to local climate conditions and individual characteristics are noted. A summary of the survival and performance of plants that have been grown in these fields is available on the website. Through DELEP's field evaluation efforts, over a dozen species of low water-use trees and shrubs have been introduced into the landscape nursery trade in Arizona. The fields provide a source of additional seeds for the seed bank, as well as seeds and plant material for a variety of research purposes.

In addition to field grow outs, DELEP was involved in a project to propagate and establish plants of *Acacia angustissima* on the Buenos Aires National Wildlife Refuge in southern Arizona. Seeds of this species serve as a source of winter food for the endangered masked bobwhite quail. Many of the plants that were planted on the refuge established successfully. Working with International Floratech, and a farm operator in Wellton, Arizona, DELEP personnel produced and planted a field of desert smoke trees, *Psorothamnus spinosus*, to evaluate possible production of aromatic resins from the calyx glands that could be used as a fragrance in household cleaning products and cosmetics. The program has participated in several projects with the UA Southwest Center for Natural Products Research and Commercialization to provide plant material for biomedical screening. DELEP also provided plant material for biomedical research to Sankyo Corporation of Japan over a ten year period. For several years, DELEP produced an average of 25,000 tree seedlings per year, including several legume species, for the Arizona State Land Department tree release program.

During the 22 years that the program has existed, 47 University of Arizona students have been employed on a part-time basis, providing valuable assistance in a variety of capacities. Since 1989, DELEP has had an active volunteer program. To date, 254 people have volunteered their time and talents with DELEP. These people come from many walks of life and include retired UA professors. Many volunteers participate at monthly seed cleaning sessions. Other volunteers have assumed important roles in plant propagation and maintenance in the greenhouse and fields, office projects and computer support, and have participated on seed collecting trips. In 1994 the Desert Legume Advisory Board was formed. The Board meets twice yearly to review progress and provide recommendations on current activities and future directions. We are grateful to each of these individuals for their involvement with the program. These special people have helped in large measure to bring the program to the level of success that it has achieved.

A major undertaking begun in 2006 by DELEP and BTA has been the production of *Legumes of Arizona – an Illustrated Flora and Reference*. This treatment will serve as a comprehensive reference for all of the native, naturalized and commercially grown Fabaceae found in Arizona. The completed book will consist of identification keys and written descriptions of each taxon, supplemented with photographs and/or line illustrations and distribution maps. Information on known or potential uses will be provided for each plant. Conservation status of rare taxa will be highlighted. The completed work will be valuable for a wide audience including naturalists, resource managers, educators, horticulturists, ranchers, and gardeners. The treatment for Fabaceae for *Vascular Plants of Arizona* will be developed from *Legumes of Arizona*.

Bauhinia grandidierii DELEP greenhouse (K. Coppola)

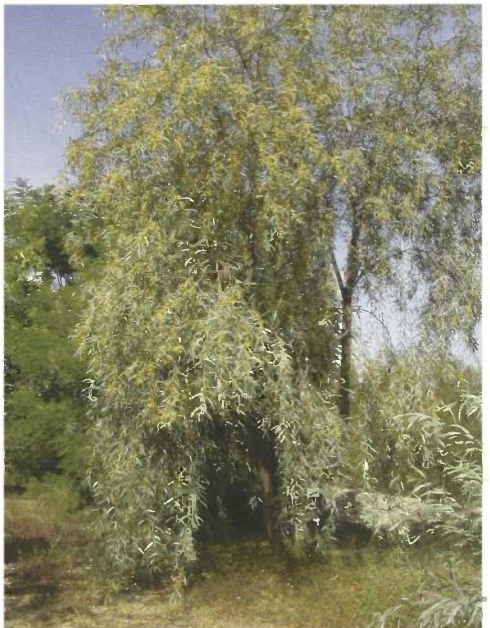
During the last year, *Legumes of Arizona – an Illustrated Flora and Reference* has made good progress towards production of taxonomic treatments. Several treatments were submitted by authors and are now under review. Additionally, we reviewed our list of unassigned taxa and potential authors have been identified. We are currently in the process of confirming these authors. The majority of introductory chapters have been assigned to experts in their respective fields. Two draft chapters have been completed and are currently under review. In response to input by authors, as well as new information, the project taxa list was updated. Artists at the Art Institute at the Arizona-Sonora Desert Museum continue to produce illustrations for the flora. An exhibit of completed illustrations has been planned for May 2011 at Boyce Thompson Arboretum. An opening party will be held to introduce the project and artists to Arboretum members.

Yuma DELEP volunteers Glenn Branham, Pamela Honaker, Terry Donovan and Gail Culver (M. Johnson)

The archive of digital photos of plants in our field sites continues to expand. Propagation of plants for the living collections at BTA and of new releases through the BTA plant sales continues at DELEP's Tucson facilities.

Several seed collecting trips were made in the fall of 2009 in southern Arizona, and a joint DELEP/BTA expedition to northern Arizona was made in June 2010 to collect seeds for both organizations, and herbarium voucher specimens for the *Legumes of Arizona* project. Additional herbarium specimens have been collected from cultivated plants in DELEP's Tucson and Yuma fields to document those species.

Trunk of *Havardia sonorae*, Yuma (K. Coppola)



Acacia citrinoviridis, Campus Agricultural Center (K. Coppola)

DELEP Seeds will go to the Arctic

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The DELEP seed collection has increased steadily over the 22 years that DELEP has existed. Today there are over 3500 accessions representing 221 genera and 1356 species. Several years ago the importance of duplicating this unique collection was recognized and arrangements were made to establish a back-up collection at the National Plant Germplasm System (USDA) seed bank in Fort Collins, Colorado.

Now another opportunity has come about for the DELEP collection. A list of 76 species of crop and potential crop legumes was submitted to the administrators of the Svalbard Global Seed Vault and has been accepted for deposit in this seed bank. The deposit will contain 200 to 500 seeds of each of the 76 species. The seeds are first stored in sealed bags which are placed in sealed boxes on high shelves in one chamber of the seed vault.

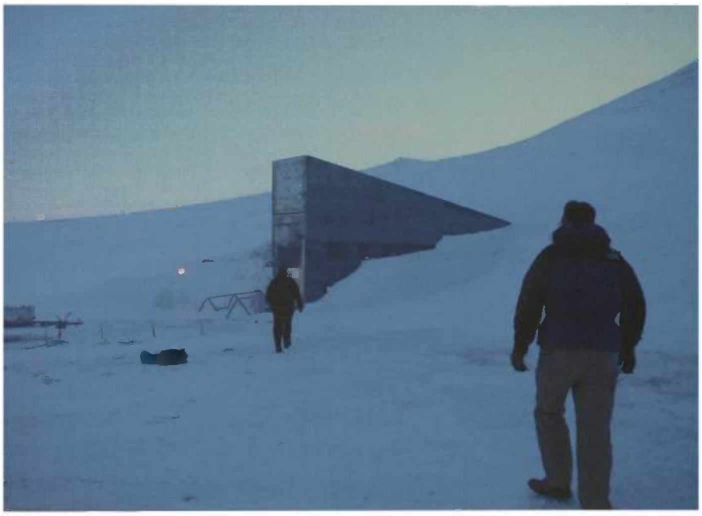
The Svalbard Global Seed Vault opened in February 2008. The concept of the vault is to ensure genetic diversity of the world's food crops. The facility is entirely underground except for the entrance. The vault was blasted out of the permafrost (–3 to –4 degrees C) and is located very deep in the mountain. The vault consists of three chambers each with the capacity to store 1.5 million different seed samples at a constant temperature of –18 degrees C. The chambers can be reached from an access tunnel 100 m long. An entrance of brushed steel is the sole above ground portion of the vault.

The seed vault was constructed by Norway at a cost of 45 million NOK. Svalbard is a Norwegian territory located at 74-81 degrees N, only 1000 km from the North Pole. Three partners manage the seed vault:

Royal Norwegian Ministry of Agriculture and Food
Global Crop Diversity Trust
Nordic Genetic Resource Center (NordGen)

The objective of the seed vault is to store duplicates of seeds from seed collections around the world. Many of these seeds are from developing countries. In the case of natural disasters or war, seeds from a particular area of the earth could be lost.The collection could be re-established using seeds from Svalbard.

To date 25 national and international institutions have deposited more than 400,000 unique seed samples from 198 countries at Svalbard. Two organizations from the U.S., National Plant Germplasm System (USDA) and Seed Savers Exchange have made deposits at Svalbard. DELEP is the third U.S. organization to deposit at Svalbard. This opportunity allows DELEP to back up part of its collection in a facility that is secure from agricultural disaster. This opportunity significantly raises the profile of DELEP nationally and internationally. The DELEP seed will be delivered to Svalbard early in 2011. Stay tuned for more on this topic.



Entry to vault on opening day, February, 2008. (Dave Ellis)

Drawing:Global Crop Diversity Trust