Desert Plants

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Cattail (Typha domingensis) at La Salina in the Gran Desierto of northwestern Sonora. Photo by Miguel Equihua. See article on page 3.

Desert Plants

A quarterly journal devoted to broadening knowledge of plants indigenous or adaptable to arid and sub-arid regions, to studying the growth thereof and to encouraging an appreciation of these as valued components of the landscape.

Frank S. Crosswhite, editor

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The Moral Element in the March of Science, Technology, and Agriculture.

A human being is a multicellular organism with tissues and organs highly differentiated and specialized to perform specific functions for the benefit of the whole individual. A single cell of a eukaryotic organism has been likened to an integrated community of prokaryote-like organelles which function for the benefit of the whole cell. Likewise, our modern society can be viewed as an evolving multi-person organism with individuals highly specialized to perform specific tasks in a division of labor to benefit the whole of society. Efficiency is the guiding force by which our *sapiens* aspect has imposed the social structure on us; we are forced to abide by the division of labor which allows the organism or "animal" of society to function. The individual, once independent, becomes dependent.

We usually think of our social structure as having been largely shaped through civilization, government, religion, war—all powerful forces indeed, but all clearly secondary to the primary genesis of society as a division of labor brought about by the success of science, industry, technology and agriculture. Science did not begin with recorded history. It began with that aspect of *Homo* that gave rise to the designation *sapiens.*

In looking at society as a higher level organism-like being, we should be concerned as to whether it is apt to become a lamb or a beast. Certainly it is rapidly evolving, far from perfect, and still subject to what we make it. Whereas there is a genetic basis for the differentiation of tissues and organs in the multicellular organism, there is as yet much less of a genetic basis for the division of labor in society. Nevertheless, when society allows persons to find their own jobs, individuals settle out in large degree with occupations to which their physical and mental bodies are pre-adapted. Evolution of society would be most efficient if mate selection resulted in the birth of children adapted to efficiency and success in specific occupations within an overall matrix, like stars in a heaven, the voids representing non-adapted combinations. Certain families have indeed become well-known as consisting of genealogic chains of persons with similar occupations. The Patels are innkeepers, the Rothschilds bankers, etc. But selection for such fitness would be counterbalanced by the need for flexibility (variation or diversity) when conditions change. From the humanist viewpoint, perhaps we are lucky that society has brought on so many changes that flexibility has thus far been favored as new occupations have arisen and old ones have disappeared. Thus far we can be content that *Homo sapiens* retains humanistic traits that are of negative or neutral value in the evolution of efficiency of labor, the guiding force of our social system. We have not yet evolved a race of taxi drivers with heavy right feet for pressing on the gas pedal; or factory workers with lungs adapted to breathing industrial waste; or policemen with thick skins to repel bullets.

The animal nature of the organism which is society would actually favor the establishment of such genetic adaptations. But thus far in history there have been humanists who have successfully caused society to emphasize the compensations needed in individual lives to resist the warping influence of the division of labor which is the base upon which society rests.

A normal, living, breathing, human animal is attuned to a balanced pattern of functions whereby in the regular course of the day a variety of work, play, rest, enjoyment, and other activities are intermeshed, allowing a wide variety of inborn genetic adaptations to be exercised. It is still possible, although unlikely, for most of us to live in such a pristine way—to pick fruit from a tree for breakfast, to till a small field in the morning, to weave cloth, to eat hot rabbit stew in the cold of winter, to watch the habits of migrating waterfowl, to pick herbs for tea, to add some thatch to a leaky roof, to make a stone wall, to milk a cow, and then the next day to do different things. A person having such a life would be a social misfit. For the good of society this person would be expected to specialize—perhaps do nothing all day long other than remove staples from checks sent to the IRS, or sit in a factory gluing rubber soles to left size 7½ shoes, or sort mail in a post office, or sweep floors in a downtown skyscraper, or operate a bottle-capping machine.

Our society thrives on such a division of labor even though each individual has had to deviate from the regular course of life to which his human organism is genetically adapted. In the dictionary sense of the verb *pervert,* society is truly guilty of perverting the individual by "causing deviation from the right, true, or regular course" of the individual's biologically adapted life. In a sense the individual human is to society what a milk cow is to a farmer.

Society has both produced and been nurtured by science, industry, technology, and modern agriculture. These all owe their power to being near the control point of society—the brain so to speak of the organism that is society. This is because they are all based on rational, detached, systematic study, planning, and execution. Society gives the leaders in these fields the right to substitute their brains for those of the masses. All the animal of society wants in a woodcutter is a strong arm, a good aim, and plenty of endurance. It doesn't want him to start thinking about how tax funds should be used, or what should be taught in school, or how many hours should constitute a work week—

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Freshwater Islands in a Desert Sand Sea: the Hydrology, Flora, and Phytogeography of the Gran Desierto Oases of Northwestern Mexico

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Abstract

The Adair Bay pozos (water holes) are small artesian springs scattered along the saltflats of the Gran Desierto near the coast of the Gulf of California in northwestern Sonora. The pozos provide essential fresh water for the rich bird fauna and some of the mammals, and were also utilized earlier by native people.

The Gran Desierto aquifer appears to consist of sand and gravel deposited in ancient river beds which were subsequently overlain by dunes. Toward the coast, the alluvial aquifer becomes confined, or buried, beneath the relatively impermeable clays of the saltflats. These clays act as a barrier which causes artesian pressure to develop within the underlying aquifer. Pozos appear to develop at locations in which the permeability of the clay is increased, possibly by desiccation cracking or by flocculation due to ion exchange. The hypothesized existence of a buried fluvial system may explain the occurrence of clusters of pozos in some saltflats and their absence in many others, *i.e.*, pozos only occur in saltflats with an underlying waterway.

Alkali Weed (*Nitrophila occidentalis*) is the first plant to colonize places where the aquifer has broken through the overlying clays and reaches the surface or near the surface. This plant is a good indicator of fresh water. Coyotes seek fresh water in these places. Such action of coyotes and perhaps other animals seems to be related to the formation of smaller pozos. Saltgrass (*Distichlis spicata*) is the second plant to colonize a pozo and larger oases are colonized by a more diverse flora.

The flora of the pozos is markedly different from that of the rest of the Sonoran Desert, both in life-form spectrum and geographic origin. The pozos support 26 species of vascular plants, many of which show temperate affinities. Several members of this flora are new geographic records: Indian Hemp (*Apocynum cannabinum* in the Apocynaceae), new for Sonora and the Sonoran Desert; *Lythrum californicum* in the Lythraceae, new for Sonora; Greasewood (*Sarcobatus vermiculatus* in the Chenopodiaceae), a new generic record for Mexico.

The pozos are island-like relicts of the delta of the Colorado River. With the delta ecosystem now virtually destroyed, the local extinction of any wetland species in the pozo flora will most probably not be followed by new immigrants of the same flora, but by introduced weed species such as Salt Cedar (*Tamarix ramosissima*).

The species-area relationship of the pozo flora is similar in value to that for other island ecosystems, although the exponential parameter ($z = 0.263$) is significantly higher than Preston's "canonical" value and the scale coefficient is significantly higher ($k = 0.75$) than those for other small island ecosystems. The species richness of a pozo is nearly four times higher than that of dry terrestrial islands of comparable size. Based on a projection of a biogeographical model fitted to the floristic richness of the pozos, we estimate that the original flora of the Colorado River delta supported 200 to 400 species of wetland vascular plants. Most of these populations have met local extinction with the destruction of the delta ecosystem of the Colorado River earlier in this century.

Figure 1. *La Soda. Alkali Weed, Nitrophila occidentalis, surrounding a small, young pozo. Photo by Ann Russell, January 1984.*

Figure 2. *La Salina. Exterior of one of the larger pozos. The shrubs are Screwbean, Desert-broom, and Salt Cedar. Bulrush (Juncus acutus), Coast Saltbush (Atriplex barclayana), and Rabbitfoot Grass (Polypogon monspeliensis). Photo by R. S. Felger, December 1986.*

Figure 3. *Alkali Weed, Nitrophila occidentalis. La Salina. Photo by Miguel Equihua, June 1982.*

Figure 4. *La Salina. Interior of one of the larger pozos. Background with Screwbean (Prosopis pubescens), Salt Cedar (Tamarix ramosissima), Reedgrass (Phragmites australis), and Desert-broom (Baccharis sergiloides) with ripe fruit. Wild Hemp (Apocynum cannabinum) in middle. Hierba de Manso (Anemopsis californica) and Saltgrass (Distichlis spicata) in foreground. Photo by R. S. Felger, December 1986.*

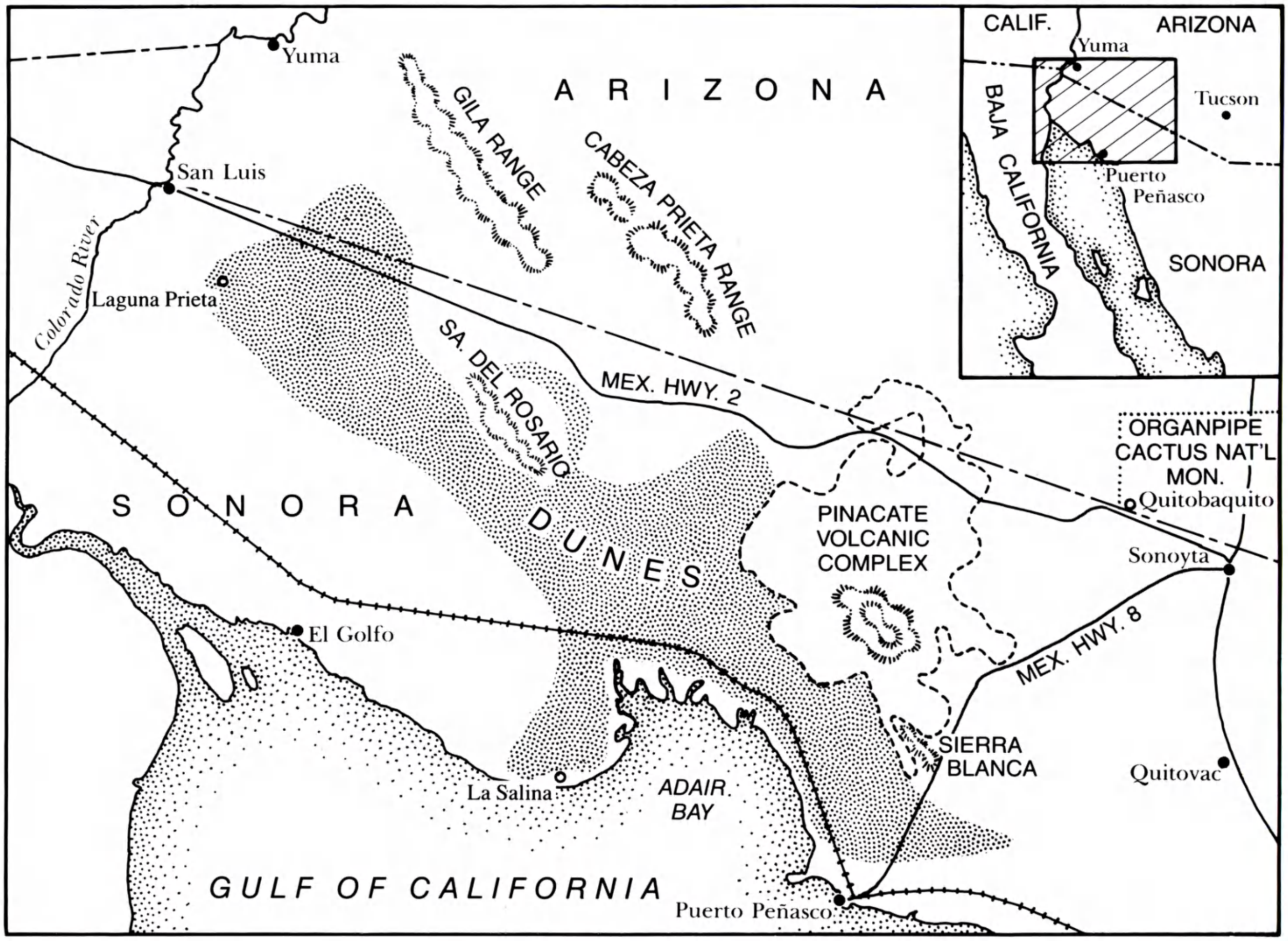

Figure 5. *The Gran Desierto of northwestern Sonora and adjacent regions.*

Introduction

The Gran Desierto of northwestern Sonora is one of the driest areas of the Sonoran Desert. Seemingly out of place are spring-like fresh water sources at various points in the saltflats at Adair Bay in the southern part of the Gran Desierto, approximately 80 km ESE of the delta of the Colorado River (Figures 5 and 6). These small oases occur in the midst of highly saline flats, in areas where salt crusts may be caked several centimeters thick and no vegetation grows. Known locally as "*pozos*," the Spanish term for "hole" or "well," these island-type formations support a vegetation entirely different from that of the desert surrounding the saltflats.

In this region where places with potable water are few and far apart, the pozos were especially important to the indigenous people well back into prehistoric times. The dunes that surround the pozos are frequently littered with modest quantities of shells and artifacts, including prehistoric pottery fragments, flakes from stone tool manufacture, and manos and metates. The water from these pozos no doubt made possible the intensive exploitation of the littoral, seen in the much larger "concheros" (shell-midden dune sites) that flank several of the beaches and esteros of the region. These sites, seldom more than a few kilometers from a pozo, are as much as 2 km in extent and contain shells probably numbering in the millions, the product of countless meals over great spans of time. The pottery at these sites, mostly Patayan types brought in from the Colorado River area, indicate that native people have been exploiting resources on a continuous basis since at least A.D. 700. The few chronologically sensitive stone artifacts show that humans were in the area as early as the first millennium B.C., and there are indications that sporadic use of the region may go back thousands of years before that.

In historic times the pozos were used by western Tohono O'odham (Papago) during annual, sacred pilgrimages to the sea to gather salt (*e.g.*, Lumholtz, 1912). There were well-known trails leading to the pozos. On March 21, 1701, local Indians guided Padre Eusebio Kino, Captain Juan Mateo Manje and their companions to one of the Adair Bay pozos. Manje wrote in his journal that "llegamos a 3 ojitos de agua que yntitlan Cubo Cuasibabia" (Burrus, 1971:503). Ives (1971) labelled it as Tres Ojitos on his map and it seems to be the same place as the water hole also known to us as Tres Ojitos.

The explorers were seeking an overland route to Baja California and were hoping to reach the Colorado River by crossing the desert along the coast. However, Manje (Burrus, 1971:270) recorded that their "plan could not be put into effect because the three small water holes which on the previous day [March 21] seemed to contain water

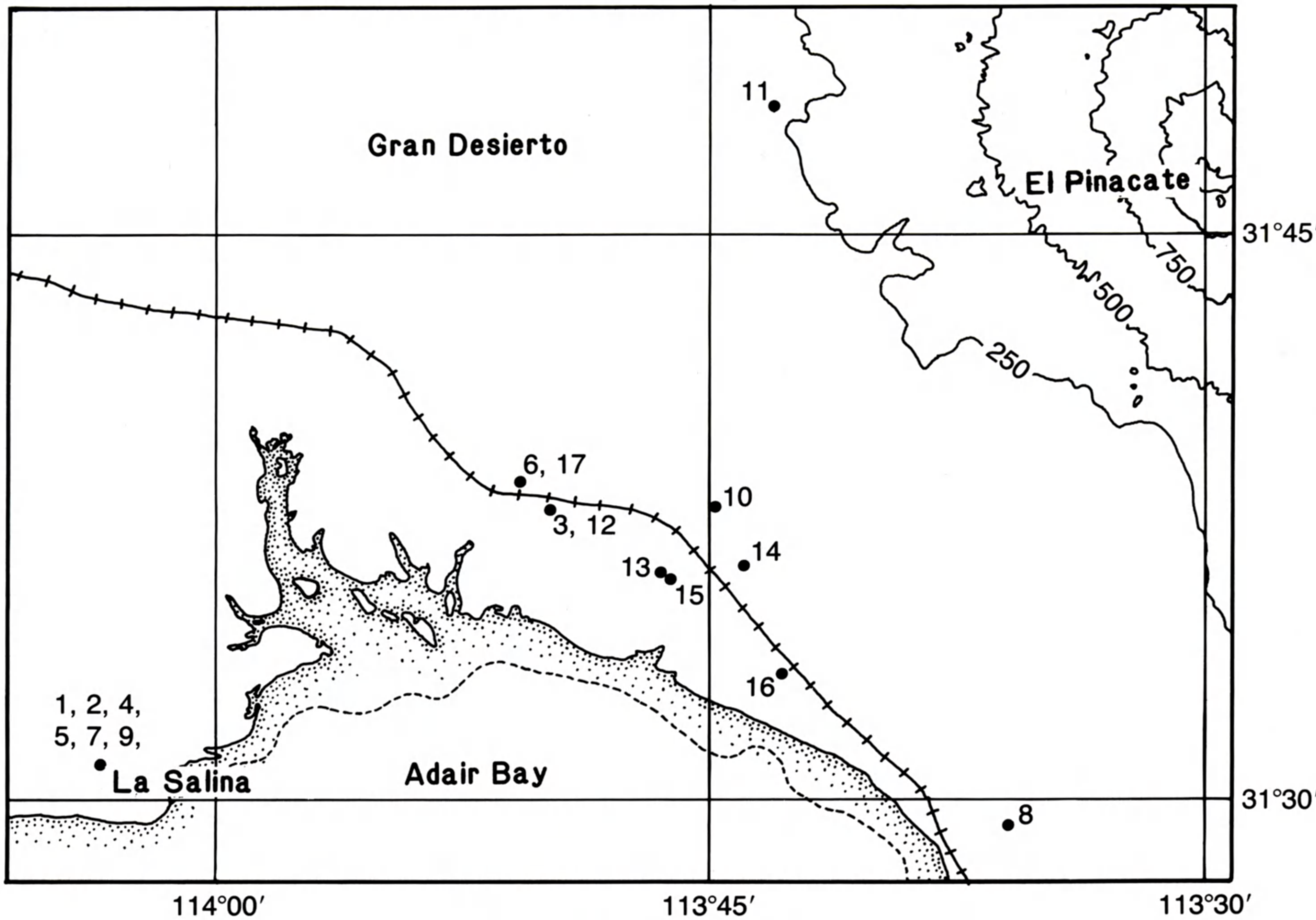

Figure 6. *Adair Bay area, showing locations of sampling sites. The location, name, collection dates and sampling procedures are given in Table 1.*

in abundance gave out when the horses drank from them and did not refill during the entire night. This lack of water forced us to send one of our group to investigate another water hole, called Tucaboricabavia, ten miles away; he reported on his return that it had very little water." Did their companion find Tucaboricabavia, or did he find another, much smaller pozo? Is Tucaboricabavia the same place as La Salina? Certainly there was sufficient water at La Salina. (We presume that La Salina, which one hundred years ago looked much like it does today, was similar when Kino was in the region about two centuries before Lumholtz. The smaller pozos undoubtedly have changed considerably in the intervening centuries.) But the horses also needed forage and water holes were far apart. It is no place for horses. Lumholtz (1912:268) found out that his guide was correct when he said that "the horse that enters the médanos [dunes] never comes back."

The pozos provide essential water for the rich bird fauna and for some large mammals such as the coyote and kit fox. These water holes are in the center of vegetated mounds that are formed by accumulation of undecomposed roots and blown sand. In some instances these hummocks can reach heights of 1.5 m. The highest hummocks occur at La Salina (Figure 2) and show an organic matter content ranging from 36% to 45%. This value contrasts with the normal carbon content in saltflats which ranges from less than 0.1% to 0.5%. The peaty mounds of the pozos provide an interesting substrate for future palynological and carbon-dating studies.

The water holes in the center of the mounds of the smaller pozos are dug and maintained by coyotes searching for water (Lumholtz, 1912; May, 1973). May (1973) noted that new pozos can originate in a relatively short time. Indeed, particularly after a rainy season, a partial dissolution of the salt crust can often be seen in distinct patches along the saltflats. Most of these wet patches occur in small hillocks where Alkali Weed (*Nitrophila occidentalis*) grows, and some of them are dug by coyotes in search of fresh water. In many cases fresh water upwells from the freshly-dug hole, which is then maintained by the drinking and digging activities of birds and mammals (see Lumholtz, 1912; May, 1973).

The research described in this paper was directed towards (a) analyzing the dynamics of the water system that feeds these sites, (b) describing the biogeographical origin of the freshwater flora, and (c) relating the species-richness of these sites to existing biogeographical models. To fulfill these goals we studied the hydrology of the Gran Desierto and the vegetation of the pozos, including distributions and biogeographical affinities of its plants.

Lumholtz (1912) described and photographed several large springs very near the coast (his Salina Grande is La Salina) and stated that potable groundwater could be obtained near the coast by digging through a shallow layer of highly saline clay. Larry May (1973) discussed the pozos at length, speculating that the saltier ones may occur at the interface between fresh continental groundwater and seawater. Ives (1964) referred briefly to poisonous springs in the dunes west of the Pinacate volcanoes in a warning to would-be travellers of the unreliability of water sources in the area.

The Pinacate volcanic complex or shield is composed of many peaks and calderas of basalt, tuff, and ash, flanked by extensive basalt flows (Ives, 1964; Lynch, 1981). Huge dune fields, banked up against the western edge of the volcanic complex, extend nearly to Adair Bay. Because of the relatively low permeability of the volcanic shield and because the land surface slopes toward the bay (and the groundwater surface often gently parallels the land surface), it is likely that runoff from the lava fields provides recharge to an aquifer underlying the dunes.

Hydrogeology and Water Chemistry

Our objectives in the hydrologic portion of the study were to ascertain the source of the water discharging from the pozos, and to explain the dynamics of the hydrologic system supporting them. To our knowledge the hydrogeology of the region between the Pinacate volcanic field and Adair Bay has not previously been seriously studied.

Between June, 1982 and January, 1983 three field trips were made to collect water samples and samples of clay and salt crust from the mudflats surrounding the pozos, as well as other hydrologic data. A fourth trip was made in January, 1984 to drill test holes and collect samples of aquifer materials for permeability testing. Water samples were collected between June, 1982 and January, 1983 from (a) pozos, (b) shallow holes dug in the saltflats, and (c) hand-dug ranch wells located in different parts of the Gran Desierto. The number of samples was limited by the accessibility of pozos and wells and by our limited knowledge of the area. Some of the pozos described by May (1973) were not found in the reported location, while others were extremely difficult to reach because of flooding of the coastal saltflats.

Pozo samples were usually taken in the early morning when evaporation was low and the flows were at a maximum. Groundwater samples in the saltflats were obtained by digging the highly clayey substrate until water-saturated soil was found. The hole was left to fill overnight and the samples were taken the next morning. Samples from wells were collected by bailing. The depth to water was also measured at the wells. The locations of the sampling sites are shown in Figure 2 and origin and collection dates are summarized in Table 1. The samples were analyzed for eleven physico-chemical parameters, including major cations and anions (calcium, magnesium, sodium, potassium, sulfate, bicarbonate, carbonate, chloride, and nitrate), pH, and electrical conductivity. The results of the analyses are given in Table 2.

The resulting data matrix was subjected to a multivariate analysis of variance (MANOVA), in which the eleven parameters were taken as statistical variates and the seventeen samples were divided into four categories. These were (a) saline samples (from waterlogged soil in the saltflats); (b) pozo samples (from potable pozos); (c) transitional samples (from boundaries between saltflats and potable pozos or from saline pozos); and (d) well samples (from hand-dug wells tapping the Gran Desierto aquifer). The Wilks and Pillai multivariate F-tests (Morrison, 1976) showed that saline samples differed significantly ($P < 0.001$) from samples in the other three categories. Transitional samples differed significantly ($P < 0.01$) from pozo and well samples. No significant multivariate differences were found between the latter two categories. Univariate (one-way) ANOVA's on the individual variates showed that the multivariate differences are due to the effects of sodium, potassium, sulphate, bicarbonate, chloride, and electrical conductivity, which varied significantly between sample categories. In all cases, subsequent multiple-range tests failed to detect significant differences between pozo and well samples, indicating that the variation of the selected parameters in pozo water is within the expected range of variation of groundwater from the continental aquifer.

A Principal Components Analysis (Kendall, 1975) on the entire data matrix confirmed these results and gave some additional information (Ezcurra, 1984). All samples from saline sites (samples 1, 2, and 12) were separated from the rest of the cluster along axis 1 (explaining 51% of the dispersion in the data). This axis was strongly correlated with conductivity, sodium, and sulphate concentration and separated highly saline samples from less saline ones. The second axis, explaining 18% of the dispersion in the data, was positively correlated with calcium con-

Table 1. Origin and Collection Dates of Water Samples.

1. La Salina (sampled 28 June 82), sample taken from water-saturated soil in a 0.2 m deep hole bored in bottom of saltflat.
2. La Salina (sampled 28 June 82), from hole bored as in sample 1, fifty meters away from vegetated patch of a large pozo.
3. Pozo Zopilote (sampled 29 June 82), sample drawn directly from water hole.
4. La Salina (sampled 28 June 82), hole bored as in sample 1, one meter away from vegetated patch of a large pozo.
5. La Salina (sampled 28 June 82), sample from hole dug in side of 1.5 m peat mound, from root zone of *Typha domingensis*.
6. Tres Ojitos (sampled 15 Jan. 83), water hole 1.
7. La Salina (sampled 28 June 82), sample from water hole in the center of 1.5 m peat mound (same mound as sample 5).
8. Abandoned well (sampled 8 Nov. 82), 12 km SW of Sierra Blanca, elevation 20 m; water table 8 m below surface.
9. La Salina (28 June 82), hole bored as in sample 1, at edge of vegetated patch beneath root zone of *Distichlis spicata*.
10. Abandoned well (sampled 8 Nov. 82), 15 km NW of Gustavo Sotelo, elevation 28 m; water table 6 m below surface.
11. Well (sampled 6 Nov. 82), Rancho Solito, 5 km S of Sierra Extraña, near western edge of Pinacate volcanic shield, elevation 80 m; water table 5 m below surface.
12. Saltflat adjacent to Pozo Zopilote (sampled 9 Nov. 82), from a 0.6 m deep hole dug at the bottom of the saltflat.
13. Pozo Muerto at La Soda (sampled 15 Jan. 83), drawn directly from water hole; water flow in this pozo has apparently slowed down and the water hole is salinized.
14. Abandoned well (sampled 8 Nov. 82), 8 km N of Gustavo Sotelo, elevation 28 m; water table 6 m below surface.
15. Pozo Metate at La Soda (sampled 14 Jan. 83), sample drawn directly from water hole.
16. Well at Gustavo Sotelo (sampled 8 Nov. 82), elevation 25 m, water table 5 m below surface.
17. Tres Ojitos (sampled 15 Jan. 83), water hole 2.

centration and negatively correlated with potassium concentration. Sample 8, which had a relatively high concentration of calcium and magnesium, was differentiated from the rest of the cluster along this axis. It is interesting to note that this sample came from a well south of the Sierra Blanca, a pre-Tertiary gneiss and granite formation. Water flowing from this formation would be expected to differ chemically from that flowing from the basaltic volcanic field; however, water level and lithologic data in the area are too scant to verify that this well is located in a different groundwater basin than the others.

The statistical analysis of the absolute ionic concentrations showed that water from wells is chemically similar to water from pozos, and that these waters in turn are different from the saline water of the saltflats. However, absolute concentrations may not indicate the source of the water, because evaporation can increase absolute ionic concentrations in water from a single source. In other words, the analysis based on absolute concentrations does not determine whether the salinity of water from the saltflats is due to evaporation of continental groundwater or to seawater intrusion. One way to distinguish between possible sources of water is to compare the relative percent of total cations or anions represented by a particular ion, a parameter which does not change substantially with evaporation. MANOVA and Principal Components Analysis were performed on relative concentrations of the major cations and anions. The MANOVA did not show significant differences between pozo, well, and saltflat waters ($P = 0.15$ for Pillai's F-test and $P = 0.20$ for Wilks' approximation); however, because the relative concentrations of some ions are highly intercorrelated, the Principal Components Analysis was able to detect differences (Figure 7). Axis 1, explaining 55% of the variability in the cluster, had high positive loadings for sodium and high negative loadings for calcium, potassium, and bicarbonate. The saline and transitional samples (samples 1, 2, 4, 9, 12, and 13) occupied the more sodic extreme of this gradient. A Mann-Whitney U-test showed that their loadings were significantly higher ($P < 0.01$) than those of pozo and well samples pooled together. Axis 2, explaining 16% of the dispersion, had high loadings for chloride. With the exception of sample 8, which was an outlier in the absolute-concentration analyses as well, all pozo samples had a significantly higher proportion of chloride than well samples ($P < 0.05$), but the two subsets did not differ significantly along the first axis. The higher proportion of chloride in pozo water may be due to mixing with the salty clays of the saltflats.

The position of the average concentration of seawater (Horne 1969) in Figure 7 shows that the relative ion content in samples from the extensive mudflats of Adair Bay is more similar to that of fresh groundwater than to that of marine waters. This suggests that the origin of the water in both the potable and saline pozos and the mudflats is the continental freshwater aquifer, and that the salts are concentrated in the mudflats mostly by a process of long-term migration of ions and subsequent evaporation. These data do not support May's (1973) hypothesis that saline waters of the pozos derive their salts directly from seawater intrusion.

Surface salt crystals, collected at La Soda playa and analyzed by x-ray diffraction, were a mixture of halite or common salt (NaCl), and trona ($Na_3H(CO_3)_2 \cdot H_2O$), a bihydrated form of sodium carbonate. Trona is more abundant on the higher parts of the saltflats, forming powdery and rounded "popcorn" clusters of crystals. Halite, a more soluble salt, was present in higher proportion at the bottom of the flat. The absence of sulfate salts on these flats supports the hypothesis that the origin of the salts is not marine.

Piezometric Studies. The results of the water chemistry survey suggest that the fresh water emerging at the pozos comes from a large aquifer underlying the Gran Desierto. In order to confirm this hypothesis and to analyze the characteristics of the aquifer, a detailed drilling study in two sites within a single saltflat was carried out.

Pozo Muerto and Pozo Metate occur at La Soda in the same saltflat along with a third (unnamed) pozo and sev-

Table 2. Water Samples From the Gran Desierto[1]

Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Seawater
Source	Saline	Saline	Pozo	Trans.	Pozo	Pozo	Pozo	Well	Trans.	Well	Well	Saline	Trans.	Well	Pozo	Well	Pozo	—
Calcium	—	—	—	0.5	1.9	0.4	0.7	3.4	0.7	0.4	0.9	—	0.5	0.4	0.6	0.5	0.8	5.2
Magnesium	0.6	0.7	2.5	1.0	1.1	0.4	2.2	6.2	0.8	0.5	0.4	1.1	0.3	0.6	0.7	0.5	1.2	26.6
Sodium	2336.6	4034.0	56.9	924.8	37.0	51.4	36.5	30.4	891.2	81.3	4.2	6156.8	476.3	49.7	42.4	47.9	58.4	468.0
Potassium	19.3	15.7	0.2	5.9	0.6	0.4	0.7	0.4	4.8	0.3	0.2	0.9	1.0	0.3	0.6	0.3	0.4	9.9
Sulphate	760.7	1304.1	—	204.3	8.9	10.0	10.0	10.0	234.7	14.3	0.4	3347.2	200.0	12.6	10.0	12.2	13.0	14.1
Bicarbonate	—	—	—	17.9	5.7	9.3	4.8	4.8	36.8	11.7	4.2	—	39.0	9.2	8.2	11.8	11.6	2.3
Carbonate	116.0	72.0	19.0	6.0	—	2.0	—	—	28.2	12.0	—	800.0	96.0	6.8	1.8	3.8	2.8	—
Chloride	1350.0	2440.0	39.0	704.0	25.1	30.0	24.0	23.0	550.0	40.0	0.5	1220.0	120.0	20.5	22.5	18.5	31.0	544.5
Nitrate	0.2	0.1	0.2	—	0.1	0.1	3.0	1.4	0.6	1.4	0.4	8.0	0.4	1.4	1.6	3.5	—	—
Charge balance error (%)	2.8	3.0	1.2	0	1.0	1.2	2.1	1.1	2.7	1.9	1.8	6.8	2.4	0.5	0.2	−0.6	2.0	−4.8
pH	9.8	9.7	8.8	9.1	8.7	9.0	8.6	8.6	8.2	9.2	8.5	10.0	9.8	8.2	9.1	9.2	10.1	8.0
Conductivity	233.0	402.7	5.8	99.0	4.1	5.4	4.1	4.1	84.5	7.3	0.6	582.5	43.1	4.7	4.4	4.8	6.1	47.9

[1]Anions and cations are measured in meg/1, conductivity is measured in mS/cm (S = Siemens = ohm−1). The sources of the samples are shown classified into four categories: (a) *saline* areas (water samples from saltflats), (b) *pozos* (water samples from freshwater oases), (c) *transitional* areas (briny water samples from the edge of a pozo or from closed pozos which do not outspring at present), and (d) *wells* (samples taken from the underground aquifer of the desert through existing wells). The average composition of seawater was extracted from Horne (1969). The charge balance error, which provides an indication of the quality of the analysis, was calculated by

$$\frac{\text{sum cations} - \text{sum anions}}{\text{sum (cations and anions)}}$$

A charge balance error of 5% or less is considered acceptable, although higher errors may be expected from very saline water samples.

eral smaller mounds with *Nitrophila*. Pozo Muerto, an inactive and salinized water hole, is located about 60 m from the western edge of the saltflat, near sand dunes that are littered from shell fragments, painted and bare pottery remains, mortar-stones and pestles, bones, stone flakes and other archaeological remains. A hummock of dead and living Saltgrass (*Distichlis spicata*) and *Nitrophila occidentalis*, approximately one meter high, surrounds an inner pool, which opens out into a small pond about 1.5 m across. The water at Pozo Muerto is brackish and usually stained red-brown. Pozo Metate is located across the saltflat, east of Pozo Muerto. The water is clear and potable, and spills constantly into the surrounding saltflat. This water hole is surrounded by a ring of Flat Sedge (*Cyperus laevigatus*) with a wide outer ring of *Nitrophila occidentalis*. The saltflat clay is covered with a crust of hard and crackly salt crystals (mostly halite) in the lower parts, and powdery crystals forming rounded clusters (mostly trona, with a typical "popcorn" texture) in the higher places.

Two piezometers were installed near each pozo to measure the water pressure and to enable water to be sampled at different depths. A hand-driver bucket auger 9 cm in diameter was used to drill the holes. At each site, one piezometer was installed at a depth of approximately 1.2 m, in contact with the saline aquifer of the saltflat. The boring for the second piezometer was continued until an underlying freshwater aquifer was found. At both sites, fresh water was encountered in a matrix of sand and rounded gravel at a depth of approximately 3.0 m. Owing to the strong artesian pressure of the aquifer, water flowed freely from the deeper-drilled hole. The piezometers were made from 5 cm PVC pipe, with a 46 cm screened section made by drilling rows of 0.6 holes and wrapping the pipe with 1 mm nylon mesh. Dune sand was poured into the annulus between the boring and the pipe to about 60 cm above the top of the screened section. The piezometer was then sealed off by pouring concrete into the annulus, and clay was packed into the top to prevent leakage of surface water into the boring.

Once installed, the piezometers were bailed twice to clean the fine materials away from the screen. After 15 days, the head differences between the shallow and the deep piezometers were measured, and water samples were taken from each piezometer for major cation and anion analysis. Salt crusts were collected for mineralogical analysis. An additional water sample was taken beneath a *Nitrophila* patch, at a depth of about 20 cm below the soil surface.

Water in the two deep piezometers was chemically similar to that of the pozos and the Gran Desierto aquifer, with conductivities of 3.5 and 3.3 mS (around 0.3% of total dissolved solids). Water saturating the soil beneath the *Nitrophila* patch was also non-saline and similar to that of the deep piezometers, with a conductivity of 2.3 mS (ca. 0.2% TDS). On the other hand, the two shallow piezometers contained the typical hypersaline water of the saltflat, showing conductivities above 100 mS (more than 8% TDS).

The vertical hydraulic gradient (with heads corrected to a standard density of 1 g/cm^3) was 0.43 m/m at Pozo

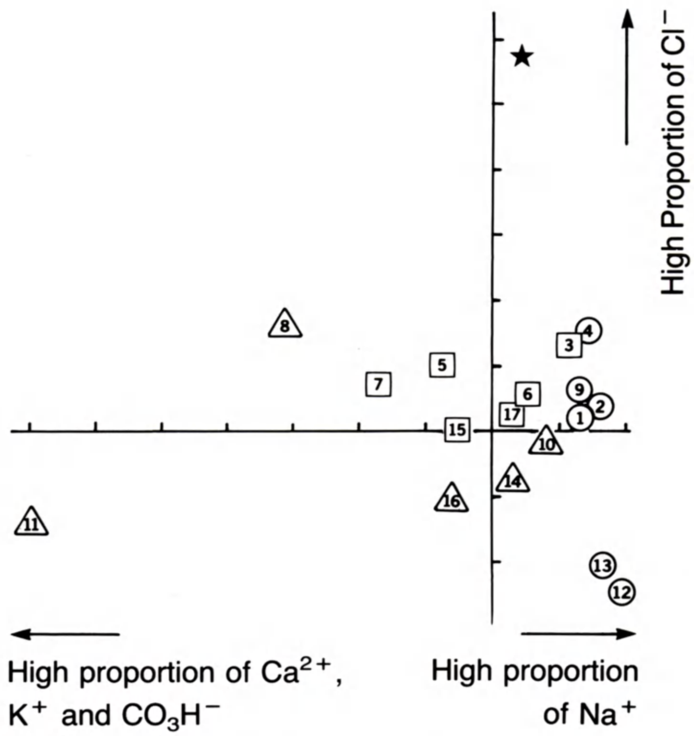

Figure 7. *Principal components analysis of the eleven samples characterized by their relative ion content. ○ = saline and transitional samples; □ = pozo samples; △ = well samples; ★ = standard seawater (Abscissa: axis 1; ordinate: axis 2)*

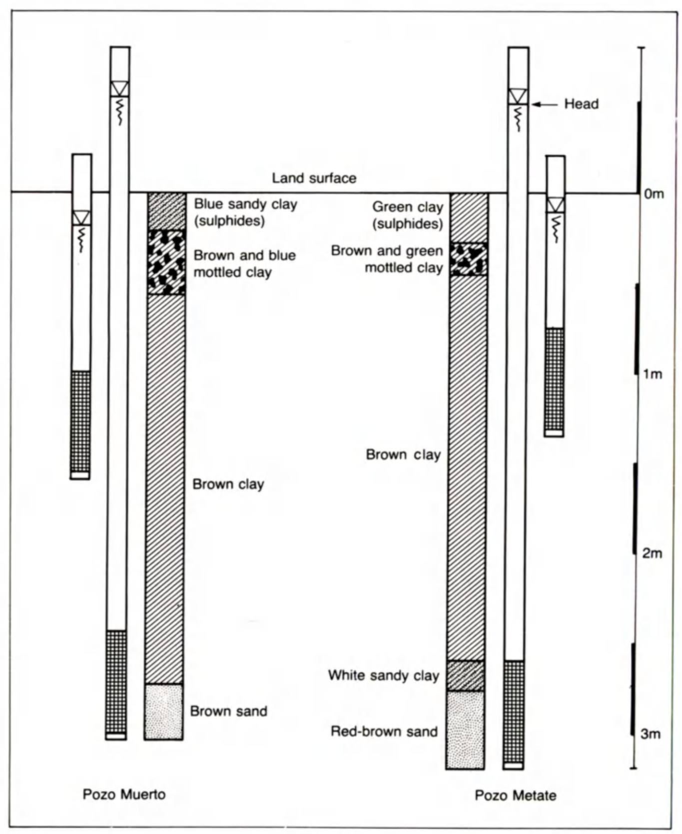

Figure 8. *Piezometric diagram.*

Muerto and 0.36 m/m at Pozo Metate (Figure 8) indicating that a strong driving force for upward vertical flow exists at both sites (hydrological pressures were measured as the height of a water column, a standard unit in hydrology: one meter of water pressure is equivalent to 98 mbars, a unit more familiar to biologists). At both sites the deep piezometers became flowing wells, i.e., the water level inside the piezometer was higher than the land surface.

Samples of clay from the bottom of the playa at La Soda and of sand from the freshwater aquifer were collected and tested for permeability. Under a pressure gradient of 1 m/m (approx. 1 mb/cm) the permeability (or hydraulic conductivity) of the clay was 0.001 cm/hr and that of the sand was 243 cm/hr. In the time that water takes to move 1 mm in the clay, it will move 2.4 km in the sand! Clays sampled during an earlier field trip were found to be highly expansible, with mean differences of 42% in volume between wet and dry clay.

Conclusion. The information presented here indicates that a confined aquifer with a strong upward component of flow near the coast is the source of water discharging in the pozos. The aquifer probably receives recharge from the Pinacate volcanic shield and becomes confined toward the coast beneath the relatively impermeable clays of the saltflats. The permeability of the clay may increase in some places initially because of cracking caused by desiccation and contraction, allowing the flow of fresh water from the confined aquifer. As the fresh water flows through the clay, the permeability may further increase because of flocculation due to replacement of sodium by calcium at exchange sites. Finally, root activity of plants may also increase the clay permeability and help to maintain spring flows.

The geologic origin of the Adair Bay saltflats is not well known. Some authors (May, 1973; J. Hayden, pers. comm.) think that the Adair Bay saltflats might be a paleo-deltaic formation. If this hypothesis is correct, the clayflats would have originated from old estuarine sediments. The sand and the rounded gravel (of apparent fluvial origin) that underlie the clay barrier indicate the existence of former fluvial activity in the area. We hypothesize that the deep sandy aquifer underlying the pozos consists of old waterways now buried under the moving dunes. If correct, this buried fluvial system would account for the occurrence of clusters of pozos in some saltflats and no pozos in many others; *i.e.*, pozos occur only in saltflats with an underlying waterway. More detailed drilling studies in the saltflats and in the Gran Desierto are necessary to confirm this hypothesis.

The water chemistry survey indicates that the confined freshwater aquifer is only the coastal edge of the large Gran Desierto aquifer which, as it reaches the sea, becomes buried under the Adair Bay clays. At the edge of the Pinacate shield, some 50 km north, the head of the Gran Desierto underground aquifer is 75 m above sea level (Table 2, sample 11, "Rancho Solito"). In the wells that are nearer to the coast, the head of the aquifer lies approximately 3 m above the mean tide level. The data presented here indicate that the underground aquifer of the Gran Desierto slopes toward the sea and is periodically fed by runoff from the extensive Pinacate volcanic shield and other local mountain ranges. The water is slowly transported toward the coast beneath the moving dunes of the Gran Desierto. The clays of Adair Bay saltflats act as a barrier which causes artesian pressure to develop within the underlying sand aquifer.

Table 3. Geographic distribution of pozo plant species and similarity with neighboring waterholes in the Sonoran Desert (CO = cosmopolitan; AM = Americas (North, Central and South America); NA = North American; WA = western North American; SW = southwestern North American (northwest Mexico and the southwest United States); QB = Quitobaquito, Arizona; QV = Quitovac, Sonora; LP = Laguna Prieta, Sonora).

	Major Geographic Affinity					Occurrence in Other POZOS		
SPECIES	CO	AM	NA	WA	SW	QB[1]	QV	LP
Allenrolfea occidentalis					SW			LP
Anemopsis californica					SW	QB	QV	LP
Apocynum cannabinum			NA					
Aster intricatus					SW	QB	QV	
Atriplex barclayana					SW			
Baccharis sergiloides					SW			LP
Cyperus laevigatus	CO					QB	QV	
Distichlis spicata		AM				QB	QV	LP
Eleocharis rostellata		AM				QB		
Heliotropium currasavicum		AM				QB	QV	
Juncus acutus	CO							
Lythrum californicum					SW			
Nitrophila occidentalis				WA		QB	QV	LP
Phragmites australis	CO					QB		LP
Pluchea odorata			NA			QB		LP
Pluchea sericea					SW	QB	QV	LP
Polypogon monspeliensis				WA *		QB	QV	
Prosopis pubescens					SW	QB	QV	LP
Ruppia maritima	CO							
Sarcobatus vermiculatus				WA				
Salix exigua			NA					
Scirpus americanus		AM				QB	QV	LP
S. maritimus	CO							
Sporobolus airoides				WA		QB		LP
Tamarix ramosissima				WA *		QB	QV	LP
Typha domingensis			NA			QB	QV	LP
TOTALS	5	4	4	5	8			

* Native to the Old World, naturalized in western North America.
[1]Includes adjacent Burro Spring (see Bowers, 1980).

Phytogeography

Distribution and Affinities of Pozo Species. Twenty-six species of vascular plants were collected at the various pozos at Adair Bay in four trips: June, 1982; November, 1982; January, 1984; and December, 1986. The flora is discussed below and the distributions are summarized in Table 3. The flora is composed mostly of wetland plants with temperate affinities. Five species (19% of the flora) are cosmopolitan, four (15%) are widespread in the Americas, four (15%) are widely distributed in North America, five (19%) are from western North America, and eight (31%) are from southwestern North America. While the typical Sonoran Desert flora has a high number of genera and species of tropical or southern affinity or origin (Axelrod, 1979; Shreve, 1951), few taxa of tropical or southern affinity occur among the pozos flora (*Prosopis* is widespread but generally has a semi-tropical affinity). The species present have wide distributions or tend to be associated with geographic ranges primarily west or north of the Gran Desierto.

There are three other large springs in relative proximity to Adair Bay: Laguna Prieta (120 km NW) and Quitovac (100 km NE) in Sonora, and Quitobaquito in Arizona (90 km NNE). The flora of Laguna Prieta has

Table 4. Life form spectra of the floras of the Adair Bay pozos and the Gran Desierto.

	Pozos		Gran Desierto (from Felger, 1980)
Microphanerophyte (Shrubs or trees, 2–8 m tall)	3 (11%)	*Baccharis sergiloides* *Prosopis pubescens* *Tamarix ramosissima*	6 (4.1%)
Nanophanerophyte (Small shrubs, 0.3–2 m tall)	5 (19%)	*Allenrolfea occidentalis* *Atriplex barclayana* *Pluchea sericea* *Sarcobatus vermiculatus* *Salix exigua*	24 (1.6%)
Chamaephyte (Perennating bud less than 0.3 m above ground)	0	—	14 (9.7%)
Hemicryptophyte (Perennating bud at soil surface)	15 (58%)	*Anemopsis californica* *Apocynum cannabinum* *Aster intricatrus* *Cyperus laevigatus* *Distichlis spicata* *Heliotropium currasavicum* *Juncus acutus* *Lythrum californicum* *Eleocharis rostellata* *Phragmites australis* *Pluchea odorata* *Scirpus americanus* *Scirpus maritimus* *Sporobolus airoides* *Typha domingensis*	11 (7.6%)
Geophyte (bud below soil surface)	1 (4%)	*Nitrophila occidentalis*	3 (2.1%)
Therophyte (ephemeral or annual)	1 (4%)	*Polypogon monspeliensis*	79 (54.4%)
Parasitic plants	—		3 (2.1%)
Stem succulent (e.g., cacti)	—		5 (3.4%)
Submerged aquatic	1 (4%)	*Ruppia maritima*	—
TOTAL	26		145

been studied by Felger (in prep.), that of Quitobaquito by Bowers (1980) and Felger *et al.* (in prep.), and that of Quitovac by Nabhan *et al.* (in prep.). A large percentage of the wetland plant species of the Adair Bay pozos, particularly those at the larger water holes at La Salina, also occur at these other oases (Table 3).

The wetland flora of all these sites probably came mostly from northern temperate areas, via the Colorado and Gila Rivers that flowed in the region until the beginning of this century. The Colorado River delta embraced approximately 300 km^2 with abundant wetland and aquatic vegetation maintained by periodic floods. Unfortunately its flora was not adequately studied before the delta dried up and salinized due to construction of Hoover Dam and other dams earlier in this century, and the development of the Lower Colorado irrigation projects in Mexico and the United States.

The life-form spectrum of the flora of the pozos is shown in Table 4. In drastic contrast with the surrounding desert vegetation, the pozo flora contains only one annual, Rabbitfoot Grass (*Polypogon monspeliensis*). Winter-dormant root perennials are a common growth form. Nine species, *Hierba de Manso* (*Anemopsis californica*), Indian Hemp (*Apocynum cannabinun*), *Lythrum californicum*, Reedgrass (*Phragmites australis*), *Pluchea odorata*, Bulrush (*Scirpus spp.*), Alkali Sacaton (*Sporobolus airoides*), and Cattail (*Typha domingensis*) are winter dormant, while Screwbean (*Prosopis pubescens*), Sandbar Willow (*Salix exigua*) and Salt Cedar (*Tamarix ramosissima*) are winter deciduous. Adaptation to low winter temperatures and the marked seasonal pattern of phenological change indicates temperate or northern affinities. *Tamarix ramosissima* and *Polypogon monspeliensis* are the only non-native species present. Both are widespread and the *Tamarix* is a highly successful invader occurring in riparian and semi-riparian alkaline soils in the Sonoran Desert and elsewhere.

Nitrophila is the first freshwater species to colonize places where freshwater penetrates the saltflat surface. Although generally regarded as a halophyte (*e.g.*, Wiggins 1964), we found it in salt-encrusted sites overlying soils with fresh water. A water sample taken from the rhizosphere of a *Nitrophila* colony showed electrical conductivity (2.3 mS) similar to that of the pozos and the confined underground aquifer, indicating *Nitrophila* grows where the underground aquifer has broken through the overlying clay horizon and is reaching the surface. This plant is therefore a reliable indicator of fresh and potable water 20 to 50 cm below the surface, which explains why coyotes often dig holes in the greener, more luxuriant *Nitrophila* colonies.

Species-area Relationships. It is a well known fact (*e.g.*, Preston, 1962; MacArthur and Wilson, 1967; Strong, 1974; May, 1975) that the species richness of a given site is an exponential function of the area of that particular site. This relationship is usually expressed as:

$$s = kA^z$$

where s is the species richness, A the area, z the exponential parameter (also known as the slope parameter when log-log transformations are used), and k the scale coefficient. For biogeographical data, the exponent z usually presents values near 0.25, a fact that has lead to much theoretical speculation (*e.g.*, Preston, 1962; May 1975). Increasing habitat diversity associated with increasingly large areas may partially explain this mathematical relationship. The species-area function is possibly also determined by the properties of passive sampling; larger areas represent larger samples from the species pool, and will contain more of the rarer species (Conner and McCoy, 1979). Finally, there is an "area per se" hypothesis, developed by Preston (1960, 1962) and by MacArthur and Wilson (1967), which has been used to explain this relation. Originally derived from the equilibrium theory of island biogeography, this hypothesis explains species richness as a function of the community structure, and of immigration and extinction rates. The three hypotheses are not mutually exclusive and possibly intervene simultaneously in defining the species-area relationships of particular biota in particular environments.

Preston (1962) and MacArthur and Wilson (1967) have shown that, given a "canonical" lognormal species-abundance distribution, the expected exponent for the species-area relationship is $z = 0.263$, if the number of species is large. MacArthur and Wilson (1967) however, have noted that when the species counts are made from sample plots of increasing area from the *same* continent, the z-values tend to be smaller (0.12–0.17). They think that this deviation from the canonical value can at least be partially explained as a result of the flooding of small plots by transient species that maintain themselves in nearby but ecologically different areas. By a similar argument, MacArthur and Wilson (1967) support the idea that isolation and the resulting absence of transient species will increase intra-community differences in islands, leading to higher slopes in the species-area relationships. However, some authors (*e.g.*, see Connor and McCoy, 1979) present evidence that contradicts the idea that increased isolation leads to higher *z* values.

Wetland vegetation in an extremely arid environment provides an intriguing example of island-like communities. To test species-area theory against the real world, we used information from eleven of the most accessible pozos. The vegetated areas at these pozos were measured, and the number of species colonizing the patch around the water hole is given in Table 5. (See Table 1 for descriptions and locations of the pozos). The resulting species-area pairs were fitted to the above species-area equation through a numerical optimization method (direct search, Himmelblau, 1972) and a major-axis fitting procedure on the the log-log transformed data (Sokal and Rohlf, 1969).

Table 5. Size, species richness, and species composition of the eleven sites used for the species-area analysis.

POZO	SIZE (M2)	NUMBER OF SPECIES	SPECIES
Patch 1	2	1	*Nitrophila occidentalis*
Patch 2	4	1	*Nitrophila occidentalis*
Zopilote 2	7	2	*Cyperus laevigatus* *Nitrophila occidentalis*
Zopilote 3	10	2	*Cyperus laevigatus* *Nitrophila occidentalis*
Tres Ojitos 1	13	2	*Cyperus laevigatus* *Nitrophila occidentalis*
Metate	19	2	*Cyperus laevigatus* *Nitrophila occidentalis*
Zopilote 1	28	2	*Cyperus laevigatus* *Nitrophila occidentalis*
Tornillo	28	3	*Cyperus laevigatus* *Nitrophila occidentalis* *Prosopis pubescens*
Tres Ojitos 2	80	3	*Cyperus laevigatus* *Nitrophila occidentalis* *Sarcobatus vermiculatus*
La Salina 1	230	6	*Anemopsis californica* *Distichlis spicata* *Lythrum californicum* *Nitrophila occidentalis* *Tamarix ramosissima* *Typha domingensis*
La Salina 2	380	7	*Anemopsis californica* *Apocynum cannabinum* *Distichlis spicata* *Lythrum californicum* *Nitrophila occidentalis* *Prosopis pubescens* *Typha domingensis*
La Salina 3	1500	11	*Apocynum cannabinum* *Distichlis spicata* *Juncus acutus* *Lythrum californicum* *Nitrophila occidentalis* *Phragmites australis* *Prosopis pubescens* *Salix exigua* *Scirpus americanus* *Tamarix ramosissima* *Typha domingensis*

Both alternative methods gave similar estimates for the parameters: $k = 0.75$ and $z = 0.368$. The 95% confidence intervals are $z_{min} = 0.32$ and $z_{max} = 0.42$, and $k_{min} = 0.63$ and $k_{max} = 0.88$. In both cases the fit was significant ($P < 0.001$), with determination coefficients $r^2 = 0.98$ for the direct search method, and $r^2 = 0.95$ for the major-axis fit (Figure 5).

The exponential parameter does not differ significantly from other previously reported values for small islands. Hamilton *et al.* (1963) reported values of $k = 0.22$ and $z = 0.33$ for land plants in the Galapagos Islands. Amerson (1975; see also Gould, 1979) reported data which yield values of $k = 0.2$ and $z = 0.39$ for small (less than 7 ha) sandy, undisturbed islands of the northwestern Hawaiian Islands, while Johnson *et al.* (1968) report $k = 0.25$ and $z = 0.37$ for land plants in the Channel Islands of southern California. However, these exponent values are significantly higher than those for most continental land plant communities. Preston (1962), for example, reports $z = 0.22$ for the flowering plants of the world, and Johnson *et al.* (1968) report $z = 0.16$ for land plants in the California mainland. A revision of the Galapagos species-area relationships by Werff (1983) reports data that yields $z = 0.39$ and $k = 0.12$.

As shown by Gould (1979), when the exponents (z) of two curves are similar, the scale coefficients (k) can be used to compare the expected species-richness of the two data sets for any given area. Taking into account, for comparison purposes, only the islands' data sets which present exponents similar to that of the pozos curve, it can be seen that the scale coefficient (k) is significantly higher for the pozos than for other islands in the literature (to make the comparison valid, the k-values were all recalculated for areas measured in square meters). Compared to Hamilton *et al.* (1963) and to Amerson (1975), for any given area the pozos are expected to be approximately three to four times richer in species. That is, for a given area the pozos wetland communities are floristically much richer than island terrestrial floras.

Conclusions

The extensive dune system of the Gran Desierto covers a large underground aquifer which flows from the Pinacate volcanic shield and other mountains in the north toward the Gulf of California in the south. As it approaches the estuary-like clay deposits of Adair Bay, this aquifer is confined under a relatively impermeable clay-mantle which causes artesian pressure to develop. At some localized points the confined fresh water breaks through the overlying layer and flows to the surface in the form of artesian upwellings.

Nitrophila occidentalis is the first plant to colonize places where the aquifer has broken through the overlying clays and reaches the surface or near the surface. This plant is a good indicator of fresh water and is used as such by coyotes. Larger oases are colonized by a more diverse flora.

The vegetation of the pozos contains only two annuals. It has a large proportion of winter dormant peren-

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Sesbania-Rhizobium Specificity and Nitrogen Fixation

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Abstract

The compatibility of potentially nitrogen fixing associations between ten *Rhizobium* strains and six *Sesbania* accessions (species) was studied under glasshouse conditions. The rates of N_2 (C_2 H_2) fixation (u moles C_2 H_4/plant/h) were determined. The various *Sesbania* accessions responded differently to inoculation with the strains tested. The ANOVA test revealed that there are real accessions ($P = 0.01$) and strains ($P = 0.05$) differences. In general the results obtained indicated that the highest mean rate of N_2 (C_2 H_2) fixation and the highest degree of compatibility with strains under test was shown by *Sesbania bispinosa* (accession BA12). *Sesbania grandiflora* (accession GL 2.02) ranked next. The performance of *Sesbania pachycarpa* (accession PCI), *Sesbania macrantha* (accession MNI), and *Sesbania sesban* (accession SBIO) in the N_2 (C_2 H_2) assay is lower than that of accessions BAI2 and GL2.02, thus indicating the possibility of lack of compatibility between these three accessions and almost all of the *Rhizobium* strains studied. Plants of *Sesbania rostrata* (accession RSI) produced either extremely low or no ethylene (C_2 H_4) quantities in the N_2 (C_2 H_2) assay thus indicative of high specificity or that this legume is not promiscuous at all. However, inoculated and fertilized *Sesbania rostrata* performed quite satisfactorily and formed profuse N_2-fixing nodules on roots and stems when grown in potted soil under Central Saudi Arabia climatic conditions. The results obtained indicated high variability among treatments in nodule number.

Introduction

In recent years species of the genus *Sesbania* have been reported as a potentially important plant group for many tropical and sub-tropical regions (Brewbaker et al., 1981; Rinaudo et al., 1981). In spite of their many possible uses *Sesbania* species have not been widely exploited or researched. Survey of literature (Hussain and Ahmed, 1965; Bhat et al., 1971; Razzaque and Siddique, 1971; Farooqi and Sharma, 1972; National Academy of Sciences (NAS), 1979) indicated that many of the *Sesbania* species can provide a wide range of products: forage, green manure, firewood, gum, pulp and paper, edible leaves and flowers. Moreover, attention to the species of the genus *Sesbania* is widely being emphasized (Brewbaker et al., 1981; NAS, 1979) because of their adaptation to a wide range of soil characteristics. Due to their nodulation (Rinaudo et al., 1981) *Sesbania* species are potentially suitable for improving the fertility and consequently the utilization of salt-affected soils (Khan and Awan, 1967; Abrol and Bhumbla, 1971; Bhardwaj, 1974; Dommergues, 1981). The genus *Sesbania* was recommended, among other leguminous candidates, by the NAS (1979) as a green manure for the fragile ecosystems in the tropics where vast areas remain barren because of the unsuitability for conventional crops due to poor soil conditions and lack of water.

The importance of this investigation stems out from the continuous call for research needs in trees as an indispensable resource (Brewbaker et al., 1981; NAS, 1979) and from the awesome imminent crisis and challenge in finding fuelwood that might face the world by the year 2000

Table 1. *Sesbania* species evaluated.

Accession number	Species name
BA12	*S. bispinosa* (*S. aculeata*)
GL2.02	*S. grandiflora* (white flowered variety)
PCI	*S. pachycarpa*
MN1	*S. macrantha*
SBI0	*S. sesban* (*S. aegyptiaca*)
RS1	*S. rostrata*

Table 2. *Rhizobium* strains evaluated.

Strain code	Species infected	Origin of strain	Agency supplying strain
Tal 1113	Unidentified+	Hyderabad (India)	ICRISAT++
Tal 1115	Unidentified	Hyderabad (India)	ICRISAT
Tal 1137	Unidentified	Cali (Colombia, South America)	CIAT No. 175+++
Tal 1298	Unidentified	Univ. of Wisconsin (Milwaukee)	Allen No. 770
Tal 1042	*S. grandiflora*	Nitragin company ($145 B_1$)	Nitragin company (Milwaukee, Wisconsin)
Tal 1126	*S. macrocarpa* *S. bispinosa* (*S. aculeata*)	Nitragin company (145 A4)	Nitragin company (Milwaukee, Wisconsin)
S. grandifolia	*S. grandiflora*	—	NifTAL+++
S. arborea	*S. arborea*	—	NifTAL
USDA3F4CI	—	USA	USDA, Beltsville, MD.
$USDA3F4A_4$	—	USA	USDA, Beltsville, MD.

\+ The genus is known to be *Sesbania* but the species was not identified.
\++ ICRISAT = International Crops Research Institute for the Semi-Arid, Tropics. Hyderabad, India.
\+++ CIAT = Centro International de Agricultura Tropical. Cali, Colombia.
\++++ NifTAL = Nitrogen Fixation in Tropical Agricultural Legumes Project. Maui, Hawaii, USA.

Table 3. Effect of *Rhizobium* strain on the rate of N_2 (C_2 H_2) fixation by *Sesbania* accessions or species.

Strains	*Sesbania* accessions or species						
	BA12	GL2.02	PCI	MNI	SBIO	RSI	Mean
	μ moles C_2H_4/plant/h						
Uninoculated (control)	0	0.9	0	1.2	1.1	0	0.53
Tal 1113	16.6	N.D	7.3	3.8	4.8	0	6.50
Tal 1115	8.3	10.7	9.1	3.3	0.2	0	5.27
Tal 1126	3.3	5.2	0.6	0.3	1.8	0	1.87
Tal 1137	0.8	6.1	2.9	2.7	0.6	0	2.18
Tal 1042	0.3	N.D	0	1.0	2.7	0.1	0.82
Tal 1298	4.4	3.6	1.0	3.0	0.7	0	2.12
S. grandiflora	16.3	7.5	4.6	0	2.7	0.3	5.23
S. arborea	5.5	N.D	1.0	1.5	0	3.8	2.36
USDA3F4CI	13.8	5.1	4.4	0.6	2.9	0	4.47
USDA3F4A4	3.6	3.7	0.6	2.9	0.7	0	1.92
Mean	6.63	5.35	2.86	1.85	1.65	0.38	

N.D = Not determined
$LSD_{0.01}$ (accessions) = 4.49, SE ± 2.80
$LSD_{0.05}$ (strains) = 3.32, SE ± 2.07

Table 4. Effect of inoculation and N_2-fertilization on nodule number and plant dry weight of *Sesbania rostrata*.

Treatment	No. of nodules/plant	Dry weight (g/plant)
Uninoculated control	0	6.9
+ N (Urea)	10	8.6
Inoculated	200	9.8
Inoculated + N	100	8.2
Mean	77.5	8.4
C.V. (%)	120	14.3

AD, as predicted by the Food and Agriculture Organization (FAO, 1980). Therefore, to assess the future potential of *Sesbania* species in recommended ecosystems, this investigation aims at determining the degree of plant-*Rhizobium* compatibility between *Rhizobium* strains and various species of the genus *Sesbania* using the acetylene reduction technique.

Materials and Methods:

The seed material consisted of six *Sesbania* accessions (Table 1) and was obtained from Mr. Dale O. Evans, Dept. of Agronomy and Soil Science, University of Hawaii at Manoa.

Pretreatment of Seed. Because the seeds of many tropical leguminous plants were found to germinate slowly and irregularly unless the testa was removed and made permeable all the seeds used in this study except accession RSI, were surface scarified in concentrated sulphuric acid for 15 minutes (accomplishing surface sterilization as well). Accession RSI was left in the acid for 30–45 minutes for maximum percentage germination as recommended by Mr. Evans (personal communication). After treatment the seeds were washed with water until all traces of acid were removed.

Rhizobium Strains. Ten *Rhizobium* strains, obtained from the NifTAL collection, together with uninoculated controls were evaluated (Table 2). *Rhizobium* cultures were grown and maintained on sterilized nutrient agar (Vincent, 1970). Then from each culture an inoculum was prepared by growing the culture in a nutrient solution.

Method of Planting Seeds. The sterile seeds were planted aseptically under greenhouse conditions at the NifTAL, Project, Maui, Hawaii during October, 1983, in sterilized vermiculite in self irrigating medium size plastic pots with lids. Six small holes were drilled around a central hole on each lid. The function of the small holes was to allow for inoculum addition, reduce the risk of cross-contamination and vermiculite drying (by exposing a relatively small surface area), and allow seedling emergence at germination. The central hole held the irrigation valve attached to a common timer. Macro and micronutrients were added in a nutrient solution lacking nitrogen (Singleton et al., 1985). Enough inoculum was then applied to bathe the seeds in each hole by adding 1 ml of a one week old turbid suspension of the test culture containing 10^9 cells/ml. Each test was replicated three times and uninoculated controls were kept for comparison. Sterilized dry gravel was spread around the holes on the lids to reduce chance contamination that might occur through the top of the system. Later the plants were thinned to one plant per hole and then allowed to grow in a cooled greenhouse for 5–6 weeks, until the differences between inoculated plants and uninoculated controls were apparent. The plants were then cut at the vermiculite level and their roots, containing nodules, were removed from the vermiculite and incubated in 21 plastic containers with 10% (V:V) acetylene for one hour. Ethylene production was determined by gas chromatography (Varian Aerograph Model 940).

Results and Discussion:

The response or susceptibility to infection by *Rhizobium* of six *Sesbania* accessions (species) inoculated with different strains (Table 2) is shown in Table 3. Examination of the data presented in this table showed that the uninoculated controls, generally gave the lowest estimate of N_2-fixation based on the rate of N_2 (C_2H_2) assay indicating that the increase in the assay rate is mainly due to biological nitrogen fixation. *Sesbania bispinosa* (accession BA12) showed the highest mean rate of N_2 (C_2H_2) fixation. The data presented in Table 3 indicate that there is a compatible association between accession BA12 and most of the *Rhizobium* strains tested; viz. Tal 1113, *Sesbania grandiflora*, USDA3F4CI, and Tal 1115. Similar compatible association between *Sesbania grandiflora* (accession GL2.02) and *Rhizobium* strains tested in this study (Table 3) was only evident in the case of Tal 1115, yet this accession showed the second highest mean rate of N_2 (C_2H_2) fixation. The performance of *Sesbania pachycarpa* (accession PCI), *Sesbania macrantha* (accession MN1), and *Sesbania sesban* (accession SB10), as shown in Table 3, although better than that of *Sesbania rostrata* (accession RSI), yet it is indicative of low N_2 (C_2H_2) fixation rates when compared to that of accessions BA12 and GL2.02. This indicates the possibility of lack of compatibility between these three accessions and almost all of the *Rhizobium* strains tested. On the other hand, plants of accession RSI inoculated with the *Rhizobium* strains used in this study appeared unhealthy and produced either extremely low or no ethylene (C_2H_4) quantities in the N_2 (C_2H_2) assay (Table 3). Previous reports (Dreyfus, 1982) indicated that accession RSI is nodulated only by a specific strain of *Rhizobium* or, in other words, that this legume is not promiscuous at all. However, Rinaudo *et al.* (1981) working under waterlogged soil conditions in the Senegal Valley, reported that accession RSI performed quite satisfactorily and formed profuse N_2-fixing nodules on the roots and the stem.

The analysis of variance (F-test) revealed that there are real accessions ($P = 0.01$) strains ($P = 0.05$) differences. Comparison among the means for accession effect and among those for strain effect (Table 3) also revealed these differences. On the basis of whether significant fixation (C_2H_2) took place or not, the order would be GL202 < BA12 < PC1 < SB_{10} = RSI < MN1.

In addition to the acetylene reduction assay data presented in Table 3, the number of root nodules and the dry weight per plant were also determined for 60-day-old inoculated and fertilized *Sesbania rostrata* grown in potted soil under Central Saudi Arabia climatic conditions (Table 4; see also photos). The coefficient of variation (C.V.) indicates that there is a high variability in the number of nodules arising with the treatments. This implies that growing or intercropping this *Sesbania* species under the widely practiced center-pivot irrigation system could be beneficial in rejuvenating the fertility of these poor soils. In this part of the world where excessive irrigation is practiced, the center-pivot, in most cases, indiscriminately irrigates both cropped and fallow land, thus availing an adequate amount of water to support the growth of the *Sesbania* plants.

In conclusion it may be mentioned that future work along this line is warranted if the various species of *Sesbania* are valued as appreciable landscape components of the drought stricken fragile ecosystems of arid and semiarid regions. Moreover, very little or scanty information, in so far as we have been able to ascertain, is available on *Sesbania-Rhizobium* specificity.

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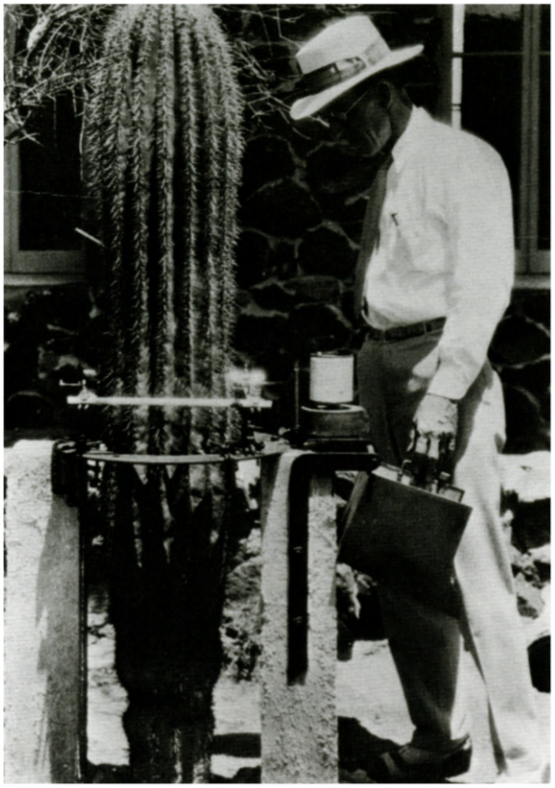

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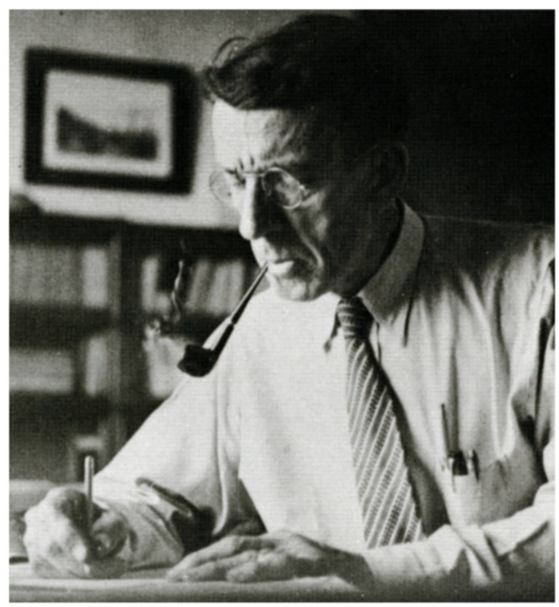

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Piman Indian Historic Agave Cultivation

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Abstract

The lands occupied by northern Piman Indians yet display remains of old ways of life, the hallmark being ruins of massive "casa grande" style architectural complexes within puddled adobe walled compounds. Vestiges of "rockpile" fields occur on desert bajadas that seem to have little potential for traditional hispanic or anglo agriculture.

Evidence has accumulated that critical population pressures once exerted heavy demands on the food supply in this region, with resultant internecine strife and competition, the massive walled architectural complexes functioning as defensible storehouses for food that was harvested from the resource area controlled or exploitable by the inhabitants. The rockpile fields were used for agricultural production of the sweet foodplant *Agave*, using an innovative technology that made use of agriculturally marginal land (see Desert Plants Volume 7, pp. 107–112, 100).

The European encounter of Pimans occurred to the south long before it occurred to the north, at a time when ways of life were rapidly changing. A rare glimpse of southern Piman life about 1613 by Rev. Andrés Pérez de Ribas presents an historic picture of *Agave* cultivation by people living in houses with massive puddled adobe walls. This Piman way of life at that time in the southern region is altogether consistent with the vestiges of what seems to have been the same lifestyle in the north.

Old World diseases brought a general collapse of Native American populations; the pressures that generated casa grande style architecture, earth defensive walls, and *Agave* cultivation in Piman territory diminished, a terminal date for the complex more likely to have been after A.D. 1613 than the traditional date of "Classic Hohokam" demise about A.D. 1450. Introduction of Old World cultivars high in sugar (melons, peaches, apricots, quinces, pears, apples, sugar cane) also reduced Piman demand for sweet pulp of *Agave*. Watermelons were already substituting as a functional equivalent of *Agave* by 1698 among northern Pimans.

Both the casa grande style ruins and the rockpile fields were abandoned by the time European civilization reached the northern Pimans. Both have been classified as "Hohokam" by archaeologists, using the plural of the Piman language word meaning "all used up" or "defunct."

Introduction

Remains of *Agave* plants roasted in valley or nearby mountain *bajada* slope locations have recently been archeologically recovered. Processing areas are associated with rock piles that would have conserved soil moisture for *Agave* plants cultivated on otherwise unirrigated desert slopes (Fish et al 1985:107). Transplanting local wild species or growing cultivars imported from farther south have been attributed to prehistoric early Classic Period Hohokam "between about A.D. 1150 and 1300" (Fish et al 1985:110). This attribution is based upon an "apparent absence of agave as a cultivated staple among peoples of the Sonoran Desert" (Fish et al 1985: 107). The present analysis cites historic documentary evidence that Piman

Indians historically cultivated *Agave* within the Sonoran Desert, and presents an alternative chronology for the remains excavated in southern Arizona.

Historic Evidence

Documentation of Piman Indian historic cultivation of *Agave* appears in the work *Triunfos de nuestra santa Fe entre gentes las más bárbaras y fieras del Nuevo Orbe conseguidos por los soldados de la Milicia de la Compañía de JESUS en las Misiones de la Provincia de Nueva España* written by Rev. Andrés Pérez de Ribas and published at Madrid in 1645. *The Triumphs of Our Holy Faith among the Most Barbarous and Fiercest Peoples of the New World* achieved by the soldiers of the militia of the Society of Jesus in the Missions in the Province of New Spain is basically a Jesuit mission promotional work. It is cast loosely in the form of a history or chronicle, but the author furnished readers with few chronological guides. For present purposes, the most important characteristic of the work is its autobiographical content. The Rev. Andrés Pérez de Ribas relied necessarily upon Jesuit and civil documents to obtain information for writing about missionaries, missions, and events with which he lacked personal experience. Pérez was, however, an active participant in Jesuit missionary efforts on the early seventeenth century Sinaloan frontier. Pérez himself led the Jesuit pioneers who entered Yaqui country in 1617 at Yaqui invitation. Thus, Pérez's account of the Yaqui missions is largely autobiographical.

Both before and after his Yaqui mission began, Rev. Andrés Pérez de Ribas visited the southern Piman Indians living immediately to the north of Yaqui territory. During the 1617–1619 interval between the entry of Jesuit missionaries among Yaquis and their entry among southern Pimans, the latter group sent ambassadors to Pérez soliciting resident priests.

> *Some of them went to see me, while I was converting the Yaqui Nation, saying, that they wanted to begin building a church and house for the time when a Father would convert them. They planned ahead by seeking experts in such works* (Pérez de Ribas 1944:151).

A few years earlier, probably in 1613, Pérez de Ribas accompanied frontier military post Captain Diego Martínez de Hurdaide on a probe through Yaqui territory into Piman country. The modesty of Piman women very favorably impressed the missionary.

> *In confirmation of this, I am able to afirm that one time I accompanied the captain and his troops when he went to visit the Yaqui Nation, and at the request of the Nebome Nation continued onward to see some pueblos of this people, because they are friends and allies, although gentiles. A great number of people of all ages assembled and approached us to greet us, and according to the gestures of peace, we touched our hands to their heads. When the women arrived, especially the young ones, we saw that they were so shy that they hung their hair in front of their faces so they could not be seen* (Pérez de Ribas 1944:150).

In other words, Rev. Andrés Pérez de Ribas personally visited Nebome—southern Piman—towns and himself observed Piman ways of living.

On the basis of personal observation, supplemented probably by information that he gained from the first Jesuit missionaries among the southern Pimans, Pérez de Ribas wrote a summary of southern Piman subsistence activities. He reported that they cultivated the same domesticated plants generally grown by Mesoamericans, adding that "in some appropriate places, they plant irrigated fields, taking water out of the arroyo in canals to irrigate them." Pérez de Ribas continued:

> *In addition to this, they used to plant next to their houses a kind of vineyard of a plant that the Spaniards call lechuguilla, because its form resembles that of lettuce. Its leaves are, however, much stronger. It takes one or two years for it to grow and mature. When it matures, they cut it. Baked with some of its leaves, the root serves them as food that is tasty and sweet. They grind it and make a sort of jelly like a conserve. When one of these roots is cut, it leaves already started other renewals and shoots. Thus, once this type of vineyard is planted, it lasts them for many years* (Pérez 1944:150).

Some of Pérez de Ribas's phraseology may strike the contemporary ear as strange. Yet he penned nearly a perfect description of southern Piman *Agave* cultivation and processing. He mistakenly reported cooking only the root, not the above-ground heart of the plant, and he did not report pit-roasting. Pérez de Ribas may not have witnessed *Agave* harvesting and baking, but he almost certainly watched cooked pulp being processed with stone mullers, and tasted the sweet-tart product, which indeed has the consistency of European jelly or conserves before they "jell." Probably Pérez de Ribas then left without observing processed pulp being sun dried for storage or transport.

Pérez de Ribas's calling the *Agave* fields "a kind of vineyard" may seem strange. It was very logical, however, from his early seventeenth century perspective. Jesuit missionaries had initiated conversion efforts during the final decade of the sixteenth century farther south among Native Americans who tapped *Agave* cultivars for sugar-rich juice to ferment into mildly alcoholic (6%) *pulque* (Valenzuela-Zapata 1985:65). Because *Agave* juice fermented liquid drinking was an aboriginal trait, and because it frequently formed part of traditional Native American rituals, Christian missionaries in Pérez de Ribas's time viewed it as inspired by the Devil. So missionaries strove to stop the practice (Pérez de Ribas 1944:II:130). To the missionary mind, therefore, an *Agave* field was analogous to a European vineyard—where grapes grew that furnished juice fermented into wine, the nearest European analog to *pulque.*

Southern Pimans and Northern Pimans

Recent archeological investigation has located rockpiles that presumably once encouraged *Agave* plants deliberately set out by local Native Americans, plus associated Agave remains, on the San Pedro River, Santa Cruz River, middle Gila River, and upper Queen Creek (Fish et al 1987:108, Fig. 1). These drainages were the habitat of Northern Piman-speaking tribes when Spanish colonial officials and Jesuit missionaries visited them during the final decade of the seventeenth century, the Gila in 1694 (Kino 1919:I:127–28), and 1697 (Burrus 1971:343–46), the Santa Cruz that same year (Burrus 1971:335, 347–49) the San Pedro also (Burrus 1971:359–60, 336–37) and the Papaguería in 1698 (Smith et al 1966:17–19). These colonial frontiersmen failed to venture north of the middle Gila River Valley to visit the lower Salt, Verde, and Agua Fria Rivers where archeologists have also found rockpiles and *Agave* remains (Fish et al 1985: 108, Fig. 1). In the mid-nineteenth century, however, Pimas and Maricopas whose primary residence was in rancherías along the middle Gila River visited fishing camps on lower Salt River, and sought there refuge from contagious disease spreading northward through Sonora (Bartlett 1854:II:241).

The Pérez de Ribas summary of Nebome (southern Piman) culture around 1613 provides an additional key perspective on dating the so-called Classic Hohokam riverine settlements where the people lived who grew and processed *Agaves* in southern Arizona river valleys. The Jesuit missionary wrote:

> *The Nebomes lived along the banks of arroyos with good waters and flows. Their houses were better and more substantial than those of the other nations. They had walls of great adobes which they made of clay, and which they roofed with flat roofs and terraces. Some they built much larger and with embrasures in the manner of forts, so that if enemies should attack them, the inhabitants of the pueblo could assemble in these structures and take advantage of their archery* (Pérez de Ribas 1944:149).

What Pérez de Ribas described as the southern Piman town around 1613 was, in other words, precisely what archeologists have termed "Classic Hohokam" architecture in southern Arizona's riverine oases. Because archeologists in the southwestern United States have relied extensively upon ceramic vessels as chronological markers, they have inferred that certain ceramic types were utilized during Classic Hohokam times. Haury (1976: 203), for example, considered Gila and Tonto Polychromes to be "one of the distinguishing features of the Civano Phase" along with Casa Grande Red-on-Buff vessels. Yet, the fundamental archeological definition of the Classic Hohokam period has clearly been the Blackwater *Casa Grande,* or Big House. As Haury (1976:53) phrased it, "Casa Grande National Monument is the type example of architecture for the Civano Phase." Buildings were massive, made of puddled adobe or coursed clay, protected by external walls even when single storied. *Casa Grande* is a stronghold, multistoried like functionally equivalent structures in the Gila and Salt River basins (Haury 1945:14, 186–92; Hammack and Sullivan 1981). Consequently, the Pérez de Ribas *circa* A.D. 1613 description of "Classic Hohokam" southern Piman towns provides a much more accurate date for such settlements than does ceramic trade ware recovered from Gila-Salt River basin *Casas Grandes.* The terminal date of "Classic Hohokam" from the upper Yaqui River to the Verde River is much more likely to have been after A.D. 1613 than around A.D. 1450 and certainly A.D. 1300.

This chronological revision derives from a simple logical rule. Any chronological interpretation of village remains in Northern Pimería that fails to take into account the historic record of radical changes in housing and settlement patterns in southern Pimería is inevitably erroneous.

Cultural Dynamics

The seventeenth century Piman abandonment of *Casas Grandes* and *Agave* cultivation can easily be accounted for in an historic temporal framework. Both of these Classic Piman cultural characteristics may be viewed as logical consequences of pre-Columbian population growth and resulting human competition for natural resources. Population growth has been identified as having led to populous, defensively wood-palisaded towns in the south-eastern (Larson 1972:391) and walled Puebloan towns in the southwestern United States (Dobyns 1983:333–34). Piman population and settlements went through the same pre-Columbian processes.

When population density reached a critical level in the Sonoran Desert riverine oases, Pimans who had gotten along with one another began fighting over resources. Irrigable oasis fields became so valuable that Piman-speaking tribes fought wars of territorial conquest. Such conflicts led to prompt construction of earthen walled defensive towns throughout Piman territory. Emergency horticultural and processed wild foods were stored in the *Casas Grandes* multistoried bastions that doubled as warehouses.

Evidently territorial warfare cut off or at least restricted access to wild *Agave* by residents of riverine oasis Piman towns. They nonetheless retained their appetite for sweet-tart roast *Agave* pulp. As population density increased, per capita consumption of all available sweets including giant cactus fruit syrup and honey inevitably declined. The predictable result was high demand for scarce sweets. The Piman solution to diminished access to a desired food was to grow it on a type of naturally irrigated sloping field similar to Piman *ak chin* fields for cultivars. Possibly strong military task forces had to invade the uplands to dig up young *Agave* shoots to transplant in the *bajada* slope rock pile beds. On the other hand, shoots might have been obtained from the south by international trade, as were parrots and/or macaws (Nuñez 1904:156; Kino 1919:II:267).

When Native American population collapsed during the sixteenth century under the onslaught of Old World pathogens (Cook and Borah 1971:73–118; 376–429), the population pressure that generated *Casas Grandes,* earth defensive walls, and *Agave* cultivation quickly diminished. Such was the cultural inertia, however, that intertribal warfare persisted for decades. The northwesternmost Pimans, the *Soba'amakam,* fought with the Hímeris tribe until at least the 1680s (Kino 1919:I:124).

The Hímeris inhabiting the upper San Pedro River Valley also fought with the ancestral "Gila River" or Kohatk Pimans on the lower San Pedro River at least until the 1690s (Mange 1954:79; Burrus 1971:337). One archeologist has recognized that Piman residence in massive earthen walled compound villages also persisted on the upper Santa Cruz River into the 1750s (Di Peso 1956:36, 41).

Christian missionaries and Spanish colonial officers strove to impose a *Pax Hispanica* upon Native Americans under effective colonial control (Pérez de Ribas 1944:II:165). They also negotiated peace treaties with and between tribes beyond the colonial frontier. The need for defensive walls and *Casas Grandes* therefore declined.

Piman intertribal competition for wild *Agave* seems to have ended no later than the third decade of the eighteenth century. Rev. José Agustín de Campos (1724:46–47) noted, during a trip northward from his Mission San Ignacio de Xáburic, encountering a party of Kohatk tribesmen processing *Agave* near the San Pedro River.

Historic innovations in Piman horticulture probably diminished demand for *Agave* pulp, because new cultivars furnished functional equivalents. By 1698, the Kohatk tribesmen had already adapted melons to *ak chin* ephemeral stream flood plain horticulture (Smith et al 1966:17). By 1700, the Colorado River Quechan grew watermelons (Kino 1919:I:249). Their seeds necessarily traveled via the Piman *Soba'amakam.*

The northernmost Pimans had, therefore, started growing watermelons earlier in the seventeenth century. Northern Pimans learned to store melons picked before first frost in straw-lined pits (Couts 1961:66–67). Thus, they lengthened watermelon "season" from June–October until November (Emory 1848:82; Turner 1966:107), and December (Cooke 1938:181; Gracy and Ruggley 1965:152). Sweet watermelon flesh furnished a much liked substitute for fresh baked *Agave* pulp that was available for six months or longer, and could be grown in quantity in irrigated riverine oasis fields. It lessened the need to venture far from home after *Agave* or to grow it.

Pimans also quickly imported Old World peaches, planted seeds, and harvested locally grown fruits (Di Peso 1951:19; Pennington 1980:177). Lush, ripe peaches seasonally reduced appetite for *Agave.* By the early eighteenth century, at least some northern Pimans grew not only peaches, but also apricots, quinces, pears, and apples (Di Peso 1956:53; Bolton 1936:573). Pimans also began growing Old World sugar cane during colonial times—by 1710 in Pimería Alta (Di Peso 1956:53; Bolton 1936:573). Chewing mature sugar cane furnished Pimans with another substitute for fresh baked *Agave* pulp. Pimans with access to markets and stores could purchase crudely refined sugar (Pennington 1980:188).

The Rev. Andrés Pérez de Ribas's terminology for *Agave* fields among southern Pimans provides a further clue to additional motivation for abandoning *Agave* "vineyards." Christian missionaries among the Pimans who encountered *Agave* cultivation may well have discouraged it on the premise that cultivated *Agave* sap would be fermented and drunk as part of traditional Native American non-Christian rites.

Other historic dynamics of horticultural change may have been more important than missionary intervention. Ironically, although *Agave* is today not known as a northern Piman cultivar, it is still grown by southern Pimans longest subject to conversion efforts. Indeed, the very variety that Pérez de Ribas saw may still be grown. It could be "An unidentified white maguey" that Pennington (1980:177) reported was "cultivated in at least 50 percent of the Pima gardens" at Onavas, Sonora, in 1968–1971. Pennington concluded that: "This plant may be analogous to a maguey mentioned by Pérez de Ribas." Is it an analog or descendant?

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The Moral Element in the March of Science, Technology, and Agriculture

(Continued from page 34)

society by its nature would want other specialists to deal with these matters. Scientists are allowed to detach from the vicissitudes of life to systematically examine, test, and develop knowledge. From such development of knowledge come the flow charts of industry—the systematic assignment of labor resulting in that "habitual employment in specialized endeavor" which is the dictionary definition of *industry.*

Think of a country of innocent humans living natural lamblike lives in peace and joy. Then consider an adjacent country with scientists, industrialists, and technologists feeding data on the agricultural potential of the adjacent country into their computers. Once the first person ate of the forbidden fruit of knowledge in the Garden of Eden, science was born. The chain of events was begun which would create and govern society. At this point one can't resist comparing the problems of society with the simple good and innocence of pre-society humanity. When society is seen in its inevitable role as an independently evolving being, the negative aspects of the original sin, eating of the fruit of the tree of knowledge, become immediately clear. One can't resist comparing the runaway aspect of society as an organism with that of the Frankenstein monster, the intelligent computer, or perhaps the robot which decided to act on its own. Again we must ask. "Is the organism of society to be a lamb or a beast?" Technology is meaningful to society in the economic sense of yielding ever more advanced improvements leading to greater productivity with elimination of manual operations, the old industries fading into the sunset. We naturally think of the animal of society in the role of the corporate raider using a leveraged buyout to gain control of a company in order to gut it, liquidate the assets, terminate the pension plan, and fire all the workers. Biologically speaking, and ignoring the moral factor and humanity, this might have been the right thing to do, the most efficient course of action for society to take, if more money could be obtained from liquidating than continuing the company. But would the liquidation merely result in instant gratification and negate what might have been better good down the road?

American agriculture is energized by innumerable subsets of science, industry, and technology and by means of complex feedback patterns manages to energize our society itself. War, agriculture, and health care are the three great users of science, industry and technology. Both war and agriculture are land-hungry. Whereas the former kills and maims, providing grist for hospitals and doctors, it temporarily reduces population and in turn the demand on agriculture. Proliferation of agriculture, on the other hand, can kill and enfeeble whole communities of organisms. On the local scene it may result in loss of readily viewable scenery—trees, flowers, wildlife. On the international scale it threatens to extinguish innumerable endangered species of both plants and animals. Yet agriculture is the necessary dynamo of our modern society.

We have now reached the point where the reader wonders if this is essentially an anti-social editorial. It is not. This is because a finite number of humanists have gotten close enough in the past to the control center of society to inject enough serum of humanity into society to keep the animal nature of the beast under control. Such humanists have believed that the steel worker should be allowed to appreciate good music, the postal worker should be allowed to hunt and fish, the taxi driver should be allowed to cultivate a garden. Members of society near the control point routinely substitute their thinking for that of the masses. In the absence of action by humanists, such thinking becomes the automatic response of society. But the individual members of the mass of society still retain brain function which we might style "member-thinking." Whereas the automatic biological forces of society make for fitness, the accessory moral or member-thinking forces demand flexibility. Here is the moral element.

Because people are necessarily used like pawns by society, humanists have insisted on certain standards. The standards have been built up through a series of treaties between the bestially biological nature of society that rewards fitness, and the humanist forces which crave flexibility. Nowhere are all the words of the treaty written down except in the heart and soul of humanity. The time traveler would have seen the reality of the winning, however, on the field at Runnymeade, or in the Roman senate, or in the presence of the Ark of the Covenant, or at Yorktown and Independence Hall. Part of this evolving treaty are the 40-hour work week, women's rights, elimination of slavery, but much more.

Although we are indeed all pawns in relinquishing our labor to society, humanists have required that our pawnships be only part-time (often 40 hours of the 168-hour week), and even more important—we are more and more being allowed to exercise humanistic social responsibility within the pawnship itself. Our evolving society now allows the individual to reconstruct a normal lifestyle with its variations and satisfactions despite the demands of division of labor. Thus, humanity is allowed to thrive on various amendments and enrichments which feed the human spirit itself. The enrichments hearken back to the older, natural, primitive, or pristine lifestyles which are diametrically opposed to the essence of the social structure, division of labor.

In our search for the good life, we unaccountably use the noun *society* and the adjective *social* to describe this alter-ego of society, the Valhalla haven of the spirit where there is theatre, light gardening, live music, museums, hunting and fishing, athletic events, restaurant-going, club work, and other activities, which are the escape from the true bestial essence of society, the division of labor which is sometimes referred to as the rat-race, the salt-mine, or the slaughter of battle. In creating the Valhalla alter-ego, society, in its bestial tendencies toward sophistry, sometimes emphasizes sublimation, whereby supposed improvements are made which prove emininently acceptable to society but are distasteful to the natural adaptations and functioning of the individual. For this condition, we also hear use of the term "rat-race" frequently. Here enters again the moral element. The true humanistic approach in such instances has not been used and we are reminded again that *perversion* relates to "deviation from the right, true, or regular course" of the lifestyles to which we are individually genetically adapted. If we enjoy playing golf because it fills a void, exercises some biologically adapted functions, and provides a feeling of fulfillment, then we have a richer and better balanced life. If we really don't like golf but play it to be socially accepted, we have fallen into a trap and have been diverted from the course that might best satisfy our most basic needs.

Money is the common denominator by which the division of labor in our society operates. Whereas normal genetically based adaptation is the biological payment for efficiency, in our society money becomes the payment. If we need to accomplish six major tasks for the well-being of our family during the next six months and one of those is building a brick wall, it might take the entire six months to learn how to construct the wall and do it in an acceptable manner so that it would serve the needed function. If, on the other hand, we are functioning members of society, well trained in one subset of the division of labor, in the same six month period we might construct not only the brick wall for ourselves but excellent brick walls for five or even more people. Each of these would pay us based on the value we had given them. Payment for five of the brick walls might be sufficient to hire specialists to do the other five jobs we needed accomplished. If our efficiency was such that we built even more than five walls for others, we very well might end up with money to use for other purposes.

The rule of thumb in the theory of money is that whatever produces money is good for society because it has rendered a good, an improvement, an efficiency or a facilitation which has furthered the ends of the system. In actual practice, many money-getters cheat the system not only by simple means such as theft, trickery, deception, guile, but by preying on baser instincts and greed of others. We are openly bombarded with letters in the mail telling how we have won fortunes or vacation trips in large print, whereas the small print requires a purchase of other consideration on our part.

These are highly visible short-circuitings in the cycle by which money is intended to serve as the reward for furthering the social system. But such short-circuitings might be minor in comparison with the flaw in the system by which time and value are not reconciled. We might use up something of little value today to obtain a small amount of money. The used-up commodity might have had a very high value in the future, however. An example would be the extinction of an endangered species of *Zea* which could have been used to breed virus immunity into corn. The petroleum reserves of the world may be used up in internal combustion engines, leaving few raw materials for production of expensive chemicals needed in industry or drugs needed in medicine. Today it may cost much more money to clean up the hazardous materials dumped by a factory than the total profits the factory earned while operating.

Technology may not have yet developed to the point where the real potential value of a commodity can be realized. Should we look for immediate gratification or should we hold exploitation in abeyance until a greater good can be realized? Here again enters the moral element in the march of science, technology and agriculture. Despite the sinister stereotype which movies and television attribute to scientists, the understanding which scientists gain in their work seems to redouble their moral awareness. The awful experiment in China whereby it was attempted to kill the totality of songbirds (so there would be no loss of grain) was immediately repudiated by scientists around the world. Scientists are good at seeing cause and effect; they are not content to follow an action only to its immediate effect. Most scientists we have known are intensely interested in their work and put a good deal of extra time and effort into their studies. The thrill of science is the thrill of discovering the truth. To the scientist, truth has its reality only in its consistency with all other facts and in the full context of its compatibility with every thing else that exists in the universe. To the scientist truth is equivalent to good and right; truth is diametrically opposed to sophistry. According to the dictionary, the essence of morality is conforming to a standard of what is good and right.

Scientists, industrialists, technologists and agriculturists have made some of the very best humanists the world has known. Perhaps this is because truth and good are the same wherever they are found. Agricultural curriculums have long carried courses dealing with conservation—leaving fencerows with trees and shrubs for their aesthetic value and for birds and wildlife to use. This was technology suited for the 1920's and 1930's and did a lot of good. Nevertheless, we have had cumulative losses over the years. In this issue of *Desert Plants*, Exequiel Ezcurra, Richard Felger, Ann Russell, and Miguel Equihua describe plants now limited to small fresh-water islands in the desert of Mexico which bespeak an old flora of the estuary of the Colorado River which exists no more. The Sonoran Desert has yielded quite a bit of land for agriculture and this is good. The yields under irrigation can be very large. Aside from this land, however, diversion of streamflow and overdraft of groundwater have degraded other land. More insidious, however, has been the constant spread of residential communities over vast quantities of land, made possible by Arizona's "Eighteen Wheeler Culture" by which human nourishment flows in from the agricultural bounty of the entire nation. Children of Maricopa County, for example, now see a lot of cement and asphalt and little of the biotic communities that once thrived there. Now again enters the moral element of science, industry, technology, and agriculture in the form of arboretums and botanical gardens. The Boyce Thompson Southwestern Arboretum together with other such plant science "living museums" advocates an industry standard for botanical gardens and arboretums whereby 1) endangered species are preserved, 2) natural biotic communities are retained or reconstructed, 3) the full bounty and importance of the plant kingdom is explained, and 4) visitors come into intimate contact with plants.

—F. S. Crosswhite and C. D. Crosswhite

Freshwater Islands in a Desert Sand Sea: The Hydrology, Flora and Phytogeography of The Gran Desierto Oasis of Northwestern Mexico

(Continued from page 44)

nials. This growth form spectrum contrasts with that of the surrounding Gran Desierto as well as that of the rest of the flora of the Sonoran Desert. These desert regions have a high proportion of ephemerals as well as many species with tropical or subtropical affinities which are limited in their distribution by their poor tolerance to winter freezing temperatures (Felger, 1980; Felger and Lowe, 1967; Hastings and Turner, 1972; Neiring *et al.*, 1963; Nobel, 1980; Shreve, 1914, 1951; Turnage and Hinckley, 1938).

In contrast with the tropical-subtropical affinities of the rest of the Sonoran Desert, the wetland vegetation of these sites is associated with northern and more temperate floras. Many of the pozo species are at the southern or eastern edge of their distribution, and some are new records for the Sonoran Desert or Mexican mainland. These species seem to have reached the pozos through the lower Colorado and lower Gila rivers, which are now mostly dry. The delta of the Colorado River (see Leopold, 1949; Sykes, 1937), which at present supports relatively little freshwater vegetation, was probably a major source of propagules and presumably included all of the native pozo species pool as well as the non-native species. With the delta destroyed, the vegetation of the pozos has become highly fragile. The local extinction of any wetland plant species will most probably not be followed by new immigrants of the same flora, but by introduced weeds such as *Tamarix*.

The species-area relationship (Figure 9) for the pozos species fits the exponential function $s = 0.75\ A^{0.368}$. The exponential parameter ($z = 0.368$) is similar in value to exponents reported in the literature for plants in other island ecosystems, and is significantly higher than Preston's "canonical" value ($z = 0.263$). The scale coefficient ($k = 0.75$) is significantly higher than those reported for small island ecosystems. A comparison of the coefficients indicates that the species richness of a pozo is nearly four times higher than that of dry terrestrial islands of comparable size.

Using May's (1975) development of the lognormal model, the species-area relationships obtained from the pozo data can be projected to the whole area of the delta of the Colorado (for the mathematical details of this procedure see Ezcurra, 1984). If the model is fitted to the pozo data assuming a high degree of dominance by some species, it will estimate a total of 192 wetland/aquatic species for the 300 km² of the delta. The estimated total richness rises to 420 species by more realistically assuming that dominance decreases with increasing oases size. By way of comparison, the entire flora of the greater Gran Desierto-Pinacate region (northwest Sonora from Sonoyta to Puerto Peñasco, westward to the Colorado River) contains approximately 560 species, of which approximately 490 are native (Felger, in prep.). We therefore estimate that the original flora of the delta included between 200 and 400 wetland/aquatic species. Most of these populations have met local extinction since the delta dried up.

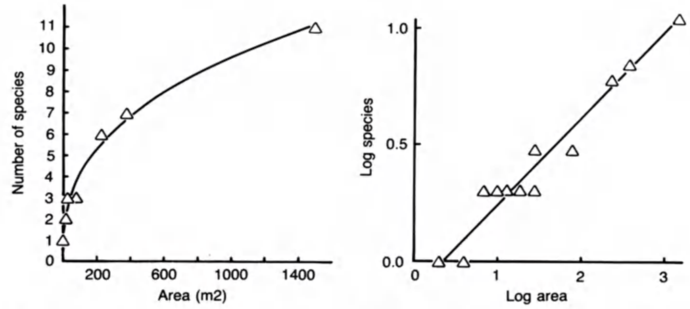

Figure 9. *Species-area relationships of flora of the Gran Desierto pozos: (a) log-log plot; (b) original data and fitted function.*

Flora of the Adair Bay Pozos

The pozos at Adair Bay support a flora of 23 species of wetland vascular plants. The 23 species fall into 21 genera and 14 families. In addition there are 3 species in 2 families which occur at the pozos but are not characteristic freshwater wetland plants, i.e., Iodine Bush (*Allenrolfea occidentalis*), Coast Saltbush (*Atriplex barclayana*), and Alkali Sacaton (*Sporobolus airoides*); a fourth species, *Wislizenia refracta* Engelm., is sometimes present on higher, dryer ground at a few of the pozos but we are not including it among the pozo flora. These four species are much more common in adjacent dryland habitats and only casually extend into the pozo plant communities. By way of comparison, the entire flora of the greater Gran Desierto-Pinacate region contains approximately 49 wetland species (9 are non-native), which represents about 9 percent of the total flora, or about 10 percent of the total flora (native and non-native species).

Herbarium voucher specimens are deposited at the herbaria of the University of Arizona (ARIZ), Herbario Nacional of the Instituto Biología in Mexico City (MEXU), and the University of Texas (TEX). In most cases duplicates will be found at one or the other of the above herbaria. Specimens cited below are from ARIZ unless otherwise indicated. When more than one collector is listed on a label, only the first collector is cited. Specimens cited by collection number only are Felger's. A few synonyms are listed, mostly ones not found in the Flora of the Sonoran Desert (Wiggins, 1964). For more detailed floristic information see Bowers (1980), Correll and Correll (1972), Felger (1980; in prep.), Kearney and Peebles (1960), Mason (1957), Munz (1974) and Wiggins (1964).

Brief ethnobotanical uses are provided to indicate potential influences which earlier people might have had on the history of the flora. *Anemoposis* and *Salix* might be candidates for purposeful introduction, but since they naturally occur in nearby wetland regions it is doubtful that they were introduced by people.

We are using "Río Colorado" for the portion of the river in Mexico and "Colorado River" for that portion in the United States. In general we are necessarily using the past tense in discussing the flora of the lower Río Colorado (Mexico portion of the river system) and its delta, even though some of the species still may be present. The delta flora remains poorly known (although currently being investigated by Felger), and in the general absence of available documented modern data we must assume that most of the original flora has become locally extinct due to extreme desertification in recent decades. Furthermore, most of those few members of the original flora still locally extant exist only in greatly reduced populations and are certainly threatened with local extinction.

APOCYNACEAE—DOGBANE FAMILY

Apocynum cannabinum L. INDIAN HEMP (*A. sibiricum* Jacq.; *A. sibiricum* var. *salignum* (Greene) Fernald; *A. hypericifolium* Ait. var. *salignum* (Greene) Bég. & Bel.)

Winter-dormant perennial, dying back to rootstock, commonly 0.5–1.5 (−2) m tall, with relatively mesophytic leaves often 6–8+ cm long. (Figure 4).

Local distribution: Restricted to wet soil at several pozos at La Salina.

Phytogeography: Widespread from Canada through much of the United States and extreme northern Mexico.

Remarks: This locality is at the geographic margin for the genus. Larger populations undoubtedly occurred in the delta region of the Río Colorado. Wiggins (1964:1103) reports it near "Whitewater and Twentynine Palms" at the northwestern edge of the Sonoran Desert in California. There are no other records for this genus in the Sonoran Desert.

Exsiccatae: La Salina, wet soil at larger pozos, *84-24, 86-555.*

BORAGINACEAE—BORAGE FAMILY

Heliotropium currasavicum L. var. **oculatum** I.M. Johnston. ALKALI HELIOTROPE.

Perennial herbs and sometimes probably facultative annuals, with semi-succulent to succulent leaves and stems.

Local distribution: At one of the pozos at La Soda a few plants were found growing through dense mats of Saltgrass (*Distichlis spicata*). Although not seen at other pozos, it is otherwise common at the edges of many alkaline wetland places in northwestern Sonora.

Phytogeography. This species ranges through much of the warm portion of the Western Hemisphere and has become adventive in the Old World.

Remarks: The La Soda population seemed precariously established. The dense cover of *Distichlis spicata* and lack of suitable open ground may be excluding *H. currasavicum* from becoming more generally established at the pozos.

Exsiccatae: La Soda, rare, with *Distichlis spicata, 86-523.*

CHENOPODIACEAE—GOOSEFOOT FAMILY

Allenrolfea occidentalis (S. Wats.) Kuntze. *CHAMIZO*, IODINE BUSH.

Dense, much-branched shrubs locally about 0.5–1 m in height. Stems succulent, leafless, alternately branched. (Figure 2).

Local distribution: Rare at some of the senescent pozos at La Salina and bordering the saline playas.

Phytogeography. Coastal deserts and inland alkali sinks in western North America.

Remarks: It does not seem to be an established, reproducing member of the "pozo community."

Exsiccatae: La Salina, edge of saltflat and margins of some pozos, *86-534.* Laguna Prieta: *85-744; Ezcurra s.n.* (20 Ap 1985, ARIZ, MEXU); *Roth 4.*

Atriplex barclayana (Benth.) Dietr. COAST SALTBUSH.

Suffrutescent perennial, probably not long lived and sometimes flowering the first year. Herbage semi-succulent, often silvery gray-green. Plants usually dioecious but occasionally monoecious (Figure 2).

Local distribution: A single small colony was found at the margin of one of the La Salina pozos. It is abundant in northwestern Sonora along the shore including sandy beaches and dune habitats and sometimes extends several kilometers inland such as at La Salina.

Phytogeography: Along the shores and near the coast of the islands and both sides of the Gulf of California and along most of the Pacific coast of Baja California.

Remarks: It is not an established member of the pozos community.

Exsiccatae: La Salina, *86-557, 86-558.*

Nitrophila occidentalis (Moq.) S. Wats. ALKALI WEED.

Perennials from thickened succulent roots reaching 2.5 cm in diameter and 15 cm or more in depth. Stems and leaves succulent. (Figures 1 and 3).

Local distribution: Dense colonies in alkaline or saline wet places around many of the pozos, and here and there on slightly raised hummocks on the saline flats throughout the Bahía Adair region. Also at Laguna Prieta, along the margins of Río Colorado, the Río Sonoyta, and at Quitobaquito.

Phytogeography: Widely scattered on saline/alkaline soils in western North America: Oregon to Nevada and south to southern California, northeastern Baja California Norte, and the Gran Desierto in Sonora.

Remarks: Propagation seems to be largely vegetative. On the saltflats surrounding the Bahía Adair pozos it is the first plant to colonize the localized places where the underground aquifer breaks through the overlying clays to reach the surface. It is a good indicator of fresh water. Coyotes dig at these places in order to get to fresh water. Although the plants often sprawl across the salt-encrusted surface, the roots are deeply seated in relatively non-saline mud. The herbage is frost-sensitive and often freeze-killed in winter. It commonly grows intermixed with *Distichlis spicata.*

Exsiccatae: La Salina, *86-539.* La Soda, *84-6.* 6 km NW Gustavo Sotelo, pozo without open surface water, *Lopez-Portillo s.n.* (7 Jul 1984, MEXU). Laguna Prieta: *85-740; Ezcurra s.n.* (20 Ap 1985, ARIZ, MEXU), *85-740; Roth 1.* Muddy banks of Río Colorado, 20 mi N of El Gulfo, *75-60.*

Sarcobatus vermiculatus (Hook.) Torr. GREASEWOOD. (*S. baileyi* Cov.; *S. vermiculatus* var. *baileyi* (Cov.) Jeps.)

Much-branched shrubs 1.2–2.4 m tall with stiff, thorn-tipped woody branches and drought-deciduous succulent leaves. Plants monoecious. Pistillate calyx distinctively winged, the wing developing into a flared collar around middle of fruit; wings becoming dry and papery at maturity (Figure 10).

Local distribution: Common across approximately 100 km in the coastal region between Puerto Peñasco and the delta of the Río Colorado. Low dunes and sandy soils, often adjacent to saltflats. A small colony of shrubs, about 2 m tall, occurs at one of the water holes at Pozos Tres Ojitos; these shrubs are larger than those of the surrounding desert.

Phytogeography: Also in California, Arizona and New Mexico to Washington, Alberta and North Dakota. It is a characteristic element of the Great Basin Desert. The distribution in the Sonoran Desert is limited (see Benson and Darrow, 1982). The closest known population is near the confluences of the Salt and

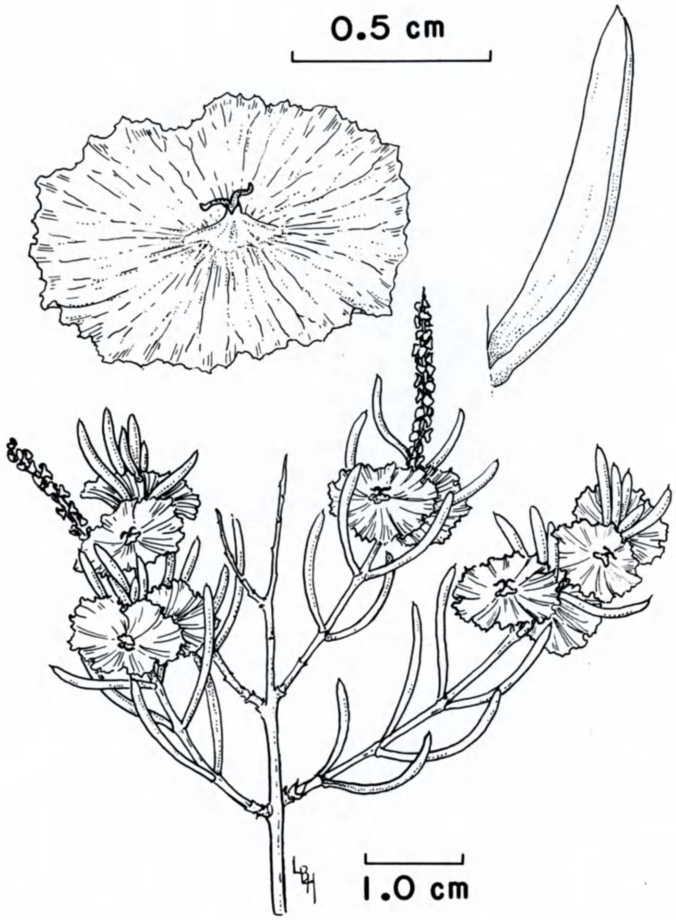

Figure 10. *Greasewood, Sarcobatus vermiculatus, from vicinity of Gustavo Sotelo. Drawing by Lucretia Brezeale Hamilton.*

Gila rivers near Phoenix and Sacaton in Maricopa and Pinal counties, Arizona. Reports of *Sarcobatus* occurring in Texas are erroneous (J. Henrickson, personal communication 1987).

Remarks: This is the first record of *Sarcobatus* in Mexico. It was not reported for the Sonoran Desert by Wiggins (1964).

Heizer and Elsasser (1980) report that the stems were used for arrow shafts and the plants ashes as medicine, but straight stems are seldom seen among the Sonoran plants. Kirk (1970) says that the tender young shoots are edible, but ethnographic documentation seems to be lacking.

Exsiccatae: Gustavo Sotelo, saline soil, *Ezcurra s.n.* (15 Sep 1980, MEXU). Pozo Tres Ojitos, 11.2 mi by road W of Estación Gustavo Sotelo, *84-10.*

COMPOSITAE—DAISY FAMILY

Aster intricatus (A. Gray) Blake. ALKALI ASTER. (*Aster carnosa* A. Gray, not Gilib.; *Bigelovia intricata* A. Gray)

Few-stemmed to bushy perennials, 0.5–0.8 m tall, sometimes dying back to ground during drought. Commonly propagating by rhizomes. Leaves quickly drought-deciduous.

Local distribution: In northwestern Sonora known only from La Soda and Quitovac; also at Quitobaquito. At these oases it grows on alkaline or alkaline-saline soils; at La Soda it is common at senescent pozos and highly localized at some of the immediately adjacent low dunes.

Phytogeography: Northwestern Sonora, Arizona, California, Nevada, and probably in Baja California Norte.

Remarks: It thrives on nearly barren ground where few or no other plants grow.

Exiccatae: La Soda, *86-521.*

Baccharis sergiloides A. Gray. *ESCOBA AMARGO, ROMERILLO,* DESERT-BROOM

Broom-like woody shrubs about 2–2.5 m tall with multiple stems. Leaves reaching 1.5–4 cm long, narrowly elliptic to oblanceolate or obovate, facultatively drought deciduous. Young shoots and leaves dotted with punctate glands. (Figures 2 and 4).

Local distribution: Locally fairly common at La Salina in small but scattered colonies at some pozos and along the margins of the playa. We found three shrubs of this species at Laguna Prieta. There are no other records for it in Sonora, but since it is common at El Mayor along the Río Hardy, it probably was also common on the Sonora side of the Río Colorado.

Phytogeography: California, Nevada, southwestern Utah, Baja California Norte, and central Arizona; mainly in riparian habitats.

Remarks: This species closely resembles and seems to be closely related to *B. sarothroides*, from which it differs in part by having leafier stems, larger, glabrous and oblong-obovate rather than narrowly linear leaves, conspicuously larger and sessile (punctate) glands, smaller achenes, and silky white rather than brownish pappus on mature pistillate achenes. Plants from La Salina and Laguna Prieta have these characters except that the pappus bristles are long, (7–) 10 (–11) mm in length, like those of *B. sarothroides* (*B. sergiloides* is reported to have pistillate pappus bristles only 4–5 mm long). Thus, in all characters except length of pappus bristles, the plants from La Salina and Laguna Prieta fit the definition of *B. sergiloides.* Perhaps the plants from our region represent intermediates or there may have been hybrid intragression. The silky-haired achenes are readily wind-disseminated.

Exsiccatae: Pozos at La Salina, *84-18, 86-553.* E side of Laguna Prieta: *Ezcurra s.n.* (20 Ap 1985, ARIZ, MEXU); *85-755.* BAJA CALIFORNIA NORTE: El Mayor, Río Hardy, *77-7.*

Pluchea odorata (L.) Cass., 1826. (*Conyza odorata* L., 1759; *Conyza purpurascens* Sw., 1788; *Pluchea purpurascens* (Sw.) DC., 1836; *P. camphorata* of various authors, not *P. camphorata* (L.) DC., 1826.)

Perennials in our region from a thick, semi-fleshy root, sometimes with rhizomes. New growth generally emerging in early summer, maturing and flowering in fall, the stems dying in late fall or early winter; winter dormant, the herbage killed by frost. Stems commonly reaching 1–1.5 m tall; leafy, the lower leaves withering as the shoots mature. Fresh green herbage dotted with glands and foul smelling, with sticky (viscid) as well as soft hairs.

Local distribution: Well-established at many of the pozos at La Salina where it commonly grows beneath *Phragmites* and *Tamarix ramosissima.* Also at Quitobaquito, Laguna Prieta, and seeps and swamps along the lower Río Colorado. Not known elsewhere in northwestern Sonora.

Phytogeography: Widespread in wet places in North America, often on alkaline soils.

Remarks: According to the International Rules of Nomenclature our plant must be called *P. odorata* (Gillis, 1977). It is a tangled taxonomic trail. The name *P. odorata* has been widely used for the plant now known as *P. symphytifolia* (Miller) Gillis, a shrubby species widespread in tropical-subtropical America. *Pluchea camphorata* (L.) DC. of southeastern United States and northeastern Mexico, is closely related to *P. odorata* and distinguished from it largely by its elongated rather than flat-topped inflorescence.

Exsiccatae: La Salina ["La Borrascosa"]: *84-30, 86-554. Laguna Prieta: Ezcurra s.n.* (20 Ap 1985, MEXU); *85-754; Roth 12.*

Pluchea sericea (Nutt.) Cov. ARROW-WEED. (*Tessaria sericea* (Nutt.) Shinners)

Woody shrubs, commonly 1.5–3 m tall. Branches willow-like, long, leafy and erect; herbage densely silvery-hairy.

Local distribution: At the margins of some of the pozos and portions of the playa edge at La Salina. Also at Laguna Prieta, in scattered places near the shores of Bahía Adair, and at the Quitovac and Quitobaquito oasis. Often abundant on sandy, silty, and often alkaline soils along riverbed floodplains and riparian habitats. It was especially abundant along the lower Río Colorado and its delta, and is still common along mesas near the river and as a weed in nearby agricultural areas. Also common along the floodplain on the Río Sonoyta.

Phytogeography: Southeastern California to southern Utah and western Texas, Chihuahua, Baja California Norte and northern and northwestern Sonora.

Remarks: The Cocopa esteemed the long, straight stems for house constructions, roofing, and arrow shafts. A prized lac, yellowish in color, was collected from the stems and used as an all purpose plastic adhesive and sealant (Euler and Jones 1956). This lac is common on the extensive stands along the margins of the lower Río Colorado. Heizer and Elsasser (1980) report that the roots are edible, but this seems improbable unless it was used as a condiment.

Exsiccatae: La Salina ["La Borrascosa"], *85-41A, 86-553.* Laguna Prieta, NE side and base of dunes facing laguna, *85-753.*

CYPERACEAE—SEDGE FAMILY

Cyperus laevigatus L. FLAT SEDGE.

Perennials, densely tufted with short rhizomes to mat-forming with creeping rhizomes. Flowering and fruiting at almost any time of year.

Local distribution: Locally dense colonies restricted to wet soil immediately surrounding many of the Adair Bay pozos with open water: La Soda (Pozos Metate and Tornillo), La Salina, Sotelo, and Tres Ojitos. Also common in wet soil along the lower Río Colorado and at Quitobaquito and Quitovac.

Phytogeography: Tropical to warm temperate regions around the world.

Remarks: The plants are often extensively grazed upon by rabbits.

Exsiccatae: Pozos 10 km W of Gustavo Sotelo, *84-5.* Pozo Sotelo, *84-7.* La Soda, *86-552.* La Salina, *84-29; 86-549.*

Eleocharis rostellata (Torr.) Torr. SPIKE RUSH.

Perennials with tough rootstocks; forming dense, grass-like mounded colonies; the stems leaf-like, bright shiny green, at first upright, then arching over as elongating, often reaching 50–100 cm long, oval-compressed (oblong) in cross-section when fresh, becoming flattened although thick and ridged when dry; some stem tips proliferating (rooting from bulbils or plantlets).

Local distribution: Extensive colonies in wet, alkaline soils at margins of some of the larger pozos at La Salina. Also common in swampy places along the banks of the lower Río Colorado and at Quitobaquito.

Phytogeography: Across most of North America from southwest Alaska to northern Mexico and the West Indies, and Andean South America.

Remarks: It is not known elsewhere in Sonora.

Exsiccatae: Quitobaquito, *87-296.*

Observation: La Salina, Felger, 12 Dec 1986.

Scirpus americanus Pers. *TULE,* BULRUSH. (*S. olneyi* A. Gray)

Perennials with long rhizomes. Stems triangular in cross-section, pithy, to 2 m or more in height. (Figures 2, 11, 12, and 13).

Local distribution: Emergent from shallow water and in wet soil around pozos at La Soda and La Salina. Also at Quitovac, Quitobaquito, along the Río Sonoyta, Laguna Prieta, and along the Río Colorado.

Phytogeography: Widely distributed in wetland habitats in North, Central, and South America.

Remarks: The "roots" have been used for food (see Bean and Saubel, 1972). After studying the type specimens, Schuyler (1974) concluded that the bulrush previously known as *S. olneyi* A. Gray should properly be *S. americanus* Pers., and that the plant which western authors have been calling *S. americanus* Pers. should be *S. pungens* Vahl. *Scirpus pungens* is regarded as a closely related but distinct species from *S. americanus.*

Exsiccatae: Pozos 10 km W of Gustavo Sotelo, *84-4.* La Soda, *86-520.* La Salina [= Pozo Borrascosa], in wet soil, *Ezcurra s.n.* (28 Jun 1982). Laguna Prieta: *Ezcurra s.n.* (20 Ap 1985, MEXU); *85-752; Roth* 6 (7 Jun 1959). Muddy banks of Río Colorado, 20 mi N of El Golfo, *75-56.*

Scirpus maritimus L. var. **paludosus** (A. Nels.) Koyama. SALT-MARSH BULRUSH

Perennials with prominent horizontal rhizomes and triangular, leafy stems arising from a thickened tuberous root; leaves well-developed, often 20–40 cm long.

Local distribution: In northwestern Sonora known only from La Salina where it grows in dense colonies emergent from shallow, alkaline water and wet soil surrounding a few of the local pozos.

Phytogeography: The species is cosmopolitan but this variety is restricted to southwestern North America where it occurs in fresh, saline and alkaline marshes, such as in the Salton Basin and along the Colorado River.

Remarks: The tuberous roots are apparently edible, as are the seeds.

Exsiccatae: La Salina, in wet soil: *84-28, 86-548.*

GRAMINEAE—GRASS FAMILY

Distichlis spicata (L.) Greene. *ZACATE SALADO,* SALTGRASS (*D. spicata* var. *stricta* (Torr.) Scribn.; *D. stricta* (Torr.) Rydb.)

Perennial saltgrass forming dense, matlike colonies; the plants with much-branched and creeping rhizomes and stolons. (Figures 4, 11, and 13).

Local distribution: Locally abundant at most of the pozos and on slightly raised sand hummocks in and around many of the saltflats: often in monotypic stands or with *Nitrophila.* At La Salina it forms 100 percent cover in places along the edge of the playa. Also abundant above the delta along the banks of the lower Río Colorado and sandy soils only a few meters or even adjacent to the margins of tidal mudflats near the shore in inlets of Bahía Adair.

Phytogeography: Baja California Norte and Sur and near the coast of Sonora at least as far south as the Guaymas region; for the most part, not in tidal marshes in Sonora. Coastal regions on both sides of Canada southward through much of Mexico, the West Indies, and the Pacific Coast of South America; also interior basins of North America.

Remarks: It seems to be a pioneer species in the formation of a pozo. The leaves are salt-excreting and copious condensation of dew running off the stems may wash away some of the salts at the soil surface, and begin the successional process of pozo formation. The plants also act as a sand trap, allowing for a buildup of sand soil. It is also the characteristic plant at older and apparently senescent pozos. For example, the relatively high peaty mound surrounding Pozo Muerto seems to have been built up by this grass. Under conditions of high soil moisture, partial shade and low salinity, such as at La Salina and Laguna Prieta, the internodes become greatly elongated, the stems unusually tall and slender, and the leaf blades reach more than 11 cm in length. Under drier, more arid, saline conditions the leaves are much shorter and densely crowded.

Exsiccatae: La Soda, *86-524.* La Salina [= La Borrascosa]: *84-20, 86-536.* Laguna Prieta: *Ezcurra s.n.* (20 Ap 1985, MEXU); *85-742; Roth 3.* Banks of Río Colorado, 5 km S of El Doctor, *85-1054.*

Phragmites australis (Cav.) Trin. *CARRIZO*, REEDGRASS, COMMON REED (*P. communis* Trin.)

Perennial bamboo-like reeds, 2–3 m tall with strong rhizomes and tough roots; the roots often deeply buried in semi-saline or alkaline mud. Leaves large, distichous (two-ranked) and evenly spaced, the blades flat. Panicles large and plume-like. New shoots mostly appearing in spring and rapidly growing to full height. Most of the leaves and stems dying during the winter. (Figures 4 and 13).

Local distribution: In dense stands at some of the pozos at La Salina. Also along the banks of the lower Río Colorado, at Laguna Prieta, and Burro Spring near Quitobaquito. Great stands once grew along the lower Río Colorado (Castetter and Bell, 1951:21) and undoubtedly also at the delta. In the late 1980s reedgrass was still abundant at Laguna Prieta and presumably it was even more abundant there before extensive ground-water pumping in recent decades.

Several widely scattered, highly localized *Phragmites* populations occur at water holes and other wetland habitats in western Sonora and on Tiburón Island (Felger and Moser, 1985).

Phytogeography: This species is cosmopolitan.

Remarks: The spikelets usually break off beneath the long-bearded rachilla, which seems to be an adaptation to wind dispersal. However, in regions such as the Sonoran Desert where the populations are widely disjunct, it seems likely that birds, flying from one water hole to the next, would be major agents of dispersal.

Reedgrass was an important native resource. The stems were used for housing, arrow shafts, musical instruments, cordage, pipes, containers, knives, eating utensils, and many other practical and aesthetic purposes (Bean and Saubel, 1972; Castetter and Bell, 1951; Felger and Moser, 1985; Uphof, 1968).

Although the young shoots are edible (Uphof, 1968), there is no indication that reedgrass was so used in our region. The Cocopa and others collected a sweet manna-like "honeydew," the exudate of scale insects, from the leaves as a highly esteemed food (Heizer, 1945; Jones, 1945). We have not seen honeydew on reedgrass at La Salina, Laguna Prieta, or Burro Springs.

Exsiccatae: La Salina [= La Borrascosa]: *Ezcurra s.n.* (28 Jun 1982, MEXU); *86-544.* Laguna Prieta, *85-738.* BAJA CALIFORNIA NORTE: El Mayor, Río Hardy, *77-6.*

Polypogon monspeliensis (L.) Desf. *ZACATE COLA DE ZORRA*, RABBITFOOT GRASS.

Non-seasonal ephemerals; highly variable in size depending upon soil moisture, mostly 8–100 cm tall. Leaf blades 3.5–22 cm long, 5–20 mm wide. Panicles very dense and furry-looking with tawny-colored awns, suggesting a rabbit's foot. (Figures 2 and 14).

Local distribution: At La Salina in partially saline or alkaline wet places with cattails (*Typha*). Not seen at the other pozo localities. Very common in permanent to temporarily wet and often highly alkaline soils along the riverbed and banks of the Río Sonoyta, as a common agricultural and ruderal weed in sites where the soil is at least temporarily wet.

Phytogeography: Native to Europe, now widespread in western North America.

Remarks: Germinating *en masse* in December in wet soil around several pozos at La Salina where it locally formed 100 percent ground cover of seedlings. Although it has been in North America for some time, it seems to be spreading in northwestern Sonora. Its advance seems largely correlated with human disturbance of the region. During the late 1970s and 1980s it was found at several widely scattered wet places within the Pinacate region, mostly on semi-saline or alkaline soils.

Exsiccatae: Pozos at La Salina [= La Borrascosa]: *Equihua, s.n.* (28 Jun 1982); *86-545.* Quitobaquito, *7677.*

Sporobolus airoides Torr. *ZACATÓN ALCALINO*, ALKALI SACATON.

Very coarse perennials forming large clumps with tough, knotty bases and well-developed roots. Flowering stems frequently 1.2–1.8 m tall. Grain 0.95–1.2 mm long. Flowering during warmer times of the year, mostly from April to November, the plants dormant during the several cooler months of the year.

Local distribution: Occasionally extending into the margins of the pozo communities on higher, sandy hummocks at some of the senescent pozos. Abundant on surrounding dunes, saline-sandy flats, and sandy soils and low stabilized dunes, from the Río Colorado delta region to Puerto Peñasco. Southward along the Sonora coast to about Tastiota (vicinity 28° 22'N).

Phytogeography: Widespread in western United States and northern Mexico, often on alkaline or semi-saline soils.

Remarks: The grain is edible (Heizer and Elsasser, 1980) and it was probably a significant food resource, especially near the coast. The readily separating grain, produced in large quantity, should be very suitable for harvesting with a basket.

Exsiccatae: La Salina, *86-550.* La Soda, *86-519.* Laguna Prieta: *Ezcurra s.n.* (20 Ap 1985, MEXU); *85-746.*

JUNCACEAE—RUSH FAMILY

Juncus acutus L. SPINY RUSH.

Large, cespitose, tussock-forming perennial rush resembling a giant pincushion, commonly (0.5) 1–2.2 m tall. Stems and leaves rigid, terete, and spine-tipped. Inflorescences appearing lateral near the ends of the leaf-like stems. Tepals mostly obtuse, the margins with white-membranous wings. Capsules brown, stiff and almost woody, obovoid to subglobose, about 1.5 times or more longer then tepals. (Figure 2).

Local distribution: Common in moist alkaline or saline soils at La Salina: at the pozos, and playa flats immediately adjacent to the playa saltflats; not in the adjacent desert.

Phytogeography: In the Old World and southwestern North America in western Arizona, Baja California Norte and Sur, southern California, southern Nevada, and in Sonora for certain only from La Salina and the vicinity of Bahía Kino.

Remarks: The New World plants apparently are subsp. *leopoldii* Snogerup, or var. *sphaerocarpa* Engelm.

Juncus acutus closely resembles *J. cooperi* Engelm. except that the latter has narrower tepals and capsules, entire-margined tepals, and shorter capsules. They are obviously closely related and perhaps conspecific. The distributional pattern of the two taxa in our region is perplexing. *Juncus cooperi* occurs in moist alkaline or saline soils at Laguna Prieta, along the Río Colorado, and Quitobaquito; it also occurs in southeastern California, and extreme northeastern Baja California Norte (Felger in prep.). It does not make sense that the Laguna Prieta and Río Colorado populations are actually a different species from the La Salina population. If anything, *J. acutus* at La Salina is out-of-place.

Exsiccatae: La Salina, *86-538.*

LEGUMINOSAE—LEGUME FAMILY

Prosopis pubescens Benth. *TORNILLO*, SCREWBEAN.

Large woody shrubs or small trees sometimes reaching 6 m tall; winter-deciduous, leafing out in spring. Flowering in May and sporadically through summer and fall. Pods produced in substantial quantities during the summer months. (Figures 2, 4, 11, and 13).

Local distribution: Common at La Salina as a large shrub or small tree at the larger pozos and along the edge of the saltflat and base of dunes; occasional scattered trees at a few of the other pozos localities. Also at Laguna Prieta, scattered places along the shore between La Salina and El Golfo—particularly at canyon mouths (*e.g.*, El Tornillo), along the Río Sonyota and the Río Colorado where it was once incredibly abundant. Not known elsewhere in Sonora.

Phytogeography: California and northeastern Baja California Norte to western Texas.

Remarks: The larger trees have been cut for firewood; a few axe-cut stumps at La Salina measured 12–20 cm in diameter. The pods were a major source of carbohydrate for people living along the Río Colorado (Bell and Castetter, 1937). The wood was used for fuel and house construction, while the roots and bark served as medicine (Bean and Saubel, 1972; Bell and Castetter, 1937; Felger 1977).

Exsiccatae: La Salina, [= Pozo Borrascosa] *84-22, 86-535.* Laguna Prieta: *Ezcurra s.n.* (20 Ap 1985, MEXU); *85-749.*

LYTHRACEAE—LOOSESTRIFE FAMILY

Lythrum californicum Torr. & Gray

Erect perennials reaching 1.2–2 m tall. Stems soft-wooded, brittle, slender, and with peeling tan-colored bark. Flowering with new growth in late spring; winter-dormant and winter-deciduous.

Local distribution: Well-established in moist or wet soil at the edge of fresh water pools of several of the larger pozos at La Salina.

Phytogeography: Southwestern North America, mostly in non-desert habitats. Wiggins (1964) states that it is rare in the Sonoran Desert, where it is known from the western edge of the desert in southern California and the eastern edge of the desert in Pima County, Arizona. Also along the Gila River in Arizona and in Guadalupe Canyon in northern Baja California Norte.

Remarks: It seems more than likely that there was an extensive population of this species at the delta of the Río Colorado.

Exsiccatae: La Salina, moist soil at pozos, *84-33, 86-556.* Baja California Norte, Guadalupe Canyon, *Starr 1.*

RUPPIACEAE—DITCH-GRASS FAMILY

Ruppia maritima L. DITCH-GRASS.

Submerged aquatics, delicate and grass-like, probably facultatively annual and perennial in our region. Fruit hard, brown, nut-like, about 2×1 mm, the single seed about 1 mm in diameter.

Local distribution. One large colony found in warm, shallow water at one of the La Saline pozos (Figure 12). In the late 19th century it was collected at Colonia Lerdo near the delta of the Río Colorado.

Phytogeography: This species occurs in fresh, brackish and sea water in many parts of the world.

Remarks: Perhaps it becomes more common at some of the La Salina pozos during the summer. Known from many parts of the Gulf of California, especially the Infiernillo Channel on the east side of Tiburon Island, where it grows during hot weather rooted in shallow subtidal seawater in protected bays and esteros (Felger and Lowe 1976; Felger and Moser 1985). In these regions fragments of the plants are common in the beach drift during the warmer months of the year, but it is not known from the beach drift at the head of the Gulf. Undoubtedly it was abundant in the delta region of the Río Colorado.

Exsiccatae: La Salina, in clear water ca. 20–50 cm deep at edge of water hole, roots and rhizomes in soft mud, *86-542.*

SALICACAE—WILLOW FAMILY

Salix exigua Nutt. SANDBAR WILLOW, COYOTE WILLOW.

Slender spindly shrubs in our region, 1.8–3 m tall, the leaves linear, mostly 3.5–12 cm long, 0.8–2.8 mm wide. Flowering in spring and sporadically on few branches in fall.

Local distribution: Dense colonies grow in wet soil at some of the La Salina pozos. It is an agricultural weed south of San Luis and undoubtedly was once abundant along the lower Río Colorado and in the delta region.

Phytogeography: There are several broadly intergrading geographic forms with several infraspecific taxa often recognized, and the specific boundaries are likewise blurred. Ours fall into subsp. *exigua*, the Coyote Willow, which extends from Alberta southward in western United States to northwestern Mexico. Whatever system is followed, the species has a large geographic range, extending from Alaska across much of Canada and most of United States southward to Baja California Norte, northwestern Sinaloa, and Chihuahua.

Remarks: Coyote Willow at La Salina locally grows in extremely dense stands intermixed with *Lythrum, Phragmites, Scirpus,* and *Tamarix.* The individual plants are unusually small, wispy, slender, and often few-branched growing up through dense cover and extreme crowding, the leaves relatively narrow even for this narrow-leaved willow. Elsewhere, this widespread species is often characterized as a willow of riverine habitats with running water and flooding such as along sand bars and floodplains.

Exsiccatae: La Salina ["Pozo Borrascosa"], *84-19, 86-547.* Weed at edge of agricultural fields, 18 km S of San Luis on road to El Golfo, *86-1036.* ARIZONA: Yuma, floodplain of Colorado River, *Swingle 240, 241* (1916).

SAURURACEAE—LIZARD-TAIL FAMILY

Anemopsis californica (Nutt.) Hook. & Arn. *HIERBA DE MANSO.*

Herbaceous perennial herbs with thick, creeping and aromatic root stocks, and long, above ground stolons. Leaves simple, petioles 3–80 cm long, the blade ovate, 5–15 (−30) cm long, 3–7.5 (−14) cm wide (drought-stressed plants are often smaller). Inflorescence an anemone-like cone-shaped many-flowered head (a compact spike) with petal-like subtending bracts (*Anemopsis* is Greek for "anemone-like," referring to the flower head). Massive flowering in late spring and summer, the plants facultatively winter dormant, the leaves usually freeze-killed. (Figures 4, 11, and 15).

Local distribution: Extensive colonies at the larger pozos at La Salina, at Laguna Prieta, swampy places at the edge of the Río Colorado, and at Quitobaquito. At La Salina it frequently grows intermixed with *Distichlis spicata,* or *Eleocharis rostellata,* and also often beneath *Prosopis pubescens;* but the local distribution of *Anemopsis* is more limited than these often associated species.

Phytogeography: Wide ranging in semi-saline and alkaline wetland soils in southwestern United States and northwestern Mexico.

Remarks: Hierba de Manso has long been highly esteemed for medicinal purposes in western North America (*e.g.*, Bean and Saubel, 1972:38–39; Curtin, 1949:78–79, 1965:215–216; Ford, 1975:341–343; Felger and Moser, 1985:363), and continues to be widely used in Sonora. The Saururaceae are characterized by having etherial oil cells (in the parenchyma tissue) and tannin, which may account for the long and varied medicinal use of *Hierba de Manso.* At least one of the active ingredients seems to 4-allylveratrole, a mild antispasmodic principle (Childs and Cole, 1965). The term *manso* may be translated as gentle, lamblike, meek, mild, quiet, soft, or tame. Various Sonorans, such as people in Sonoyta, Guaymas, and the Seri, have transplanted, protected, cultivated, and wild-harvested this plant because of its medicinal value. Lumholtz (1912:264–265) gives

Figure 11. *La Salina. Near pozo: Screwbean, Saltgrass, and Hierba de Manso. Distant pozo with Salt Cedar, Bulrush, and Saltgrass. Photo by R. S. Felger, December 1986.*

Figure 12. *La Salina. Habitat of Ditch-grass (Ruppia maritima) at a medium-sized pozo. Bulrush and Saltgrass. Photo by R. S. Felger, December 1986.*

Figure 13. *La Salina. Exterior of one of the larger pozos. Screwbean, Reedgrass, Bulrush, and Saltgrass. Photo by R. S. Felger, December 1986.*

Figure 14. *La Salina. Exterior of one of the larger pozos. Salt Cedar and Rabbitfoot Grass seedlings and dead plants from last season. R. S. Felger, December 1986.*

Figure 15. *Hierba de Manso, Anemopsis californica. La Salina, June 1982. Photo by Miguel Equihua.*

the following account of his experience with *Hierba de Manso* at La Salina:

> *A plant (*anemonopsis [*sic*] californica *called by the Mexicans* herba del manso *was a singular growth in these pozos. Its large root, which has a strong medicinal scent, like that which characterizes an apothecary shop, is perhaps the most popular of the many favorite remedies of northern Mexico. It is used internally to cure colds, coughs, or indigestion, as well as externally for wounds or swellings, and is employed in a similar way the the Indians. Of the latter, those who lived in the dune country are said to have been in the habit of chewing bits of this root, as elsewhere tobacco is chewed. These plants grew here in great numbers and to enormous proportions; some of their roots were as much as three feet long and very heavy. The root finds a ready sale everywhere and my Mexicans were not long in gathering as many of the plants as they could carry on their animals. One of the men, whose horse was well-nigh exhausted, walked himself in order to put a load of fifty pounds on his horse.*

In the late 1980s it was cultivated in some of the older homes in Sonoyta, primarily as a medicinal plant. Although there is the possibility that earlier people planted it at the La Salina pozos and other waterplaces in the region, these habitats seem "typical" for the species. *Hierba de Manso* has also been used as a source of tannin and there have been experimental and some commercial plantings of it for tannin production.

Exsiccatae: La Salina [= Pozo Borrascosa]: *Ezcurra s.n.* (28 June 1982, MEXU); *84-30, 86-540.* Laguna Prieta: *Ezcurra s.n.* (20 Ap 1985, ARIZ, MEXU); *85-739; Roth 8* (7 Jun 1959). Muddy banks of Río Colorado, 20 mi N of El Golfo, *75-54.*

TAMARICACEAE—TAMARIX FAMILY

Tamarix ramosissima Ladeb. SALT CEDAR.

Shrub, frequently 2.5 m tall. Leaves small and scale-like, the branchlets winter-deciduous. Flowers pinkish-white to pink.

Local distribution: Common and well-established at many of the La Salina pozos, Laguna Prieta, and at many other wetland habitats in northwestern Sonora. Abundant along the Río Sonoyta, Río Colorado, and as an agricultural weed. (Figures 2, 4, 11, and 14).

Phytogeography: Native to the Old World and established in many other arid and semiarid regions, especially in western North America.

Remarks: The La Salina population is probably increasing at the expense of certain native wetland species, although perhaps a population equilibrium of sorts has been attained. Seedlings and young plants are numerous. Shrubby salt cedars have been established along the Río Colorado and the delta region for at least half a century. In many places shrubby salt cedars have invaded riverine habitats following the demise of the native riparian communities; but cause and effect are difficult to assess since the events have co-occurred chronologically. However, shrubby tamarisk has invaded two primordial, virgin wetland habitats in the Sonoran Desert, places free from human influence until about the present decade: the Sauzal water holes on the south-central side of Tiburon Island (Felger and Lowe, 1976; Felger and Moser, 1985) and the La Salina pozos. The willows at both places seem to be loosing ground to tamarisk. The Sauzal willow is *S. gooddingii* Ball. Shrubby tamarisk was well-established and common at Sauzal in the early 1960s.

Exsiccatae: Pozos at La Salina [= La Borrascosa]: *Ezcurra s.n.* (28 Jun 1982); *84-27, 86-537.* Laguna Prieta: Abundant, *Ezcurra s.n.* (25 Ap 1981, MEXU). 5 km S of El Doctor, edge of Río Colorado riverbed, *85-1057.* Delta of Colorado River, California, *Godfrey Sykes s.n.* (9 Ap 1935).

TYPHACEAE—CATTAIL FAMILY

Typha domingensis Pers. *TULE*, CATTAIL.

Winter-dormant perennials emergent from shallow water and adjacent wet soil. Leaves erect, 2–3 m tall. Flowers densely packed on a tall spike; the staminate part of the inflorescence above the pistillate portion and separated by a barren gap or interval without flowers. (See cover photo, this issue of *Desert Plants.*)

Local distribution: Well-established colonies occur at some of the La Salina pozos, Laguna Prieta, along the Río Sonoyta, the Sonora banks of the Río Colorado, and along irrigation ditches and farmland south of San Luis. It was once extremely abundant along the lower Río Colorado and its delta.

Localized colonies occur in natural as well as disturbed habitats at widely scattered water holes and wetland places in northwestern Sonora. Some of these populations come and go with the water supply (Felger, in prep.); these repeated introductions are probably the results of bird-introduced seeds.

Phytogeography. As with most cattail species, *T. domingensis* is wide ranging; it grows in brackish and fresh water across the southern two-thirds of the United States and southward through most of tropical America.

Remarks: Typha domingensis occurs at many water places within the Sonora Desert, while the closely related *T. angustifolia* is more abundant in non-desert regions.

The Tohono O'odham (Papago) at Quitovac used cattails for basketmaking and the rootstock for food (Nabhan *et al.* 1982). The Seri and others made use of the pollen for face paint (Felger and Moser 1985:373) and many people used the starchy rootstocks and new shoots for food (Ebeling 1986).

Specimens from our region have obovoid sterile ovaries characteristic of *T. domingensis,* but the leaves are often only 6–8 mm wide, which is rather narrow for this species.

Exsiccatae: Laguna Prieta, *85-751.*

Observation: La Salina, Felger, 12 Dec 1986.

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Photograph of Sesbania rostrata plants grown with and without inoculation and with and without fertilization with urea.

Closeup view of inoculated plants to show vigor.

Nitrogen Fixation by Desert Legumes. This issue of *Desert Plants* includes a provocative article on the legume genus *Sesbania* by H. M. Abdel Magid in the Department of Soil and Water of King Saud University. The article speaks of the "drought stricken fragile ecosystems of arid and semi-arid regions" and the potential suitability of *Sesbania* for improving the fertility and utilization of poor desert soils. *Sesbania* species are capable of providing forage, green manure, firewood, gum, pulp and paper, edible leaves and flowers.

The legume plants with which temperate agriculturists are most familiar are the annual species of beans, peas, vetches, clovers, lespedeza, alfalfa, soybeans and similar crops which are grown for a season and which restore soil fertility for other crops.

Many *Sesbania* species grow to great size in the tropics and subtropics, even within a few months. Professor Abdel Magid reminds us of the "awesome imminent crisis and challenge in finding fuelwood that might face the world by the year 2000 A.D." In the report on *Firewood Crops* by our National Academy of Sciences, *Sesbania bispinosa* is characterized as producing high yields of firewood in six months. A yield of 15 dry tons per hectare has been reported for a field in Italy. Production could be even higher in the tropics where more than one crop might be harvested per year.

Legumes make good crops because they can gain a "captive" nitrogen supply from root nodule bacteria. Students of desert plants naturally see a parallel with succulent plants which are able to gain a "captive" water supply and the usually associated CAM-plant condition whereby there is also a "captive" carbon dioxide supply. A captive nitrogen supply is important not only in heavily cropped fields where available nitrogen is transitorily low due to organic material having repeatedly been removed from the system (making it something of an artificial desert), but also in natural deserts where available nitrogen is low simply because of aridity. Nitrogen available in soil derives both from decay of organic material within soil and from rain-borne nitrogenous compounds produced by lightning. Arid soils are naturally nitrogen deficient because of their low organic content and their source of water being from irrigation rather than rain.

Desert legumes promise to provide a fruitful area for scientific investigation. Since repeated annual cropping of organic material from traditional temperate farming soils tends to desertify such soils temporarily with respect to nitrogen, legume crops have been adapted by man to fill a very important niche—that of restoring the fertiility in a rotation of crops. Whereas legume crops have been molded to this desertified niche only for the few thousand years that man has been involved, the natural desert legumes obviously have become adapted to natural deserts literally over eons of time. We suspect that they may have developed some physiological pathways and adaptational mechanisms of potential interest in helping us further mold plants both to the transitory agricultural desertification of cropland (which is cured by suitable rotational schedules) and to the more insidious desertification that involves loss of organic material from land for which there is as yet no solution.

Bogs represent extremely wet situations which are deficient in nitrogen simply because of pH relationships of excessive organic material and excessive water. Necessity is the mother of invention. Carnivorous plants are generally unique to such boggy situations and represent adaptations for obtaining nitrogen. They merely digest protein of insects and small animals, breaking the proteins into amino acids and available nitrogen. The opposite extremes of low nitrogen because of deficient organic material and deficient rainfall have molded the arid counterpart of the carnivorous plant: the legume. We have already learned to use legumes in countering low nitrogen in soil due to repeated agricultural removal of organic material. This involved many generations of temperate zone agriculturists. Now we look ahead to the prospect of learning about legumes for their value in deserts and desertified situations where organic material is deficient because rainfall is low. Has nature molded something which, although now obscure, will prove to be a seed of some great good? We think so. The Boyce Thompson Southwestern Arboretum is planning a program of desert legume research to be led by Dr. R. P. Upchurch.—F. S. Crosswhite and C. D. Crosswhite