Desert Plants

Volume 3. Number 2. *Summer 1981*

Published by The University of Arizona for the
Boyce Thompson Southwestern Arboretum

Soaptree Yucca (**Yucca elata**) *growing at the Boyce Thompson Southwestern Arboretum. The O'odham people of the Sonoran Desert know this species as* **takui** *and use the durable fibrous leaves for making baskets.*
See article on page 47.

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

Volume 3, Number 2, *Summer 1981*
Published by The University of Arizona
for the Boyce Thompson Southwestern Arboretum
P.O. Box AB, Superior, Arizona 85273.

The Boyce Thompson Southwestern Arboretum at Superior, Arizona, is cooperatively managed by The Arizona State Parks Board, The Boyce Thompson Southwestern Arboretum, Inc., and The University of Arizona.

Editorial

Ethnobotany. How many times have we heard it said that we *are* what we *eat*? When Frank Cushing was adopted into the pueblo village of Zuñi in the nineteenth century, one prerequisite was that he eat Zuñi food long enough to have starved four times without it, at which point his flesh was considered "of the soil of Zuñi." The study of plants used by ethnic groups is called ethnobotany. Since ethnobotany inquires into **uses of plants** it is included in the broader field designated **economic botany.**

A traditional ethnobotanical study of a group of people includes an analysis of their agriculture as well as an inventory of the wild plants they utilize. What are the major crops? Are different varieties of a single crop intentionally kept separate? Before Columbus discovered America the Indians of southern Arizona had red corn, white corn, yellow corn, blue corn, crazy corn and laughing corn. They had flour corn that was soft enough when dry to be ground to cornmeal with stone mano and metate. They had flint corn that stored well because it was resistant to insects.

Aside from surveying crops, ethnobotany seeks to discover what other plants are used as food by ethnic groups. Are any of these on their way to becoming domesticated? Were any of the "wild" plants introduced intentionally or unintentionally by man? What plants are used for medicine? for clothing? for housing? for making baskets? for shade? for soil retention?

Man searches for better ways to utilize his environment and improve the quality of his life. Just as the plant kingdom is divided into species each with limited natural distribution around the world, so too is man divided into numerous ethnic groups. History shows us that a new discovery of a plant use, or new plant technology, or new plant domestication, spreads within the ethnic group concerned because the people of the group are in communication and harmony one with the other. But the same factors which keep ethnic groups apart also tend to keep plant knowledge bottled up.

Today we find it hard to envision how Europeans lived without the common bean, the lima bean, corn, potatoes, tomatoes, bell peppers, chili peppers, pumpkins, squashes and other plants which had been domesticated by the American Indians. The taking of these plants to Europe by man and from there around the world was only the end of a very slow process of discovery, domestication and then spread from one ethnic group to another in the Americas. Although these were all New World crops of some antiquity, not all had yet spread to all of the indigenous ethnic groups of the Americas at the time Columbus discovered the New World. The cultivation of corn had not even spread from the Indians of Arizona to the nearby Paiute of Owens Valley, California even though these latter people had irrigation technology. Apparently it had already taken several millenia for the cultivation of corn to spread from Tehuacan, Mexico to Arizona.

Today in the world there are many plant uses known to various ethnic groups which if only known to other such groups could significantly enrich their lives. All people on earth belong to one ethnic group or another. Ethnobotany is of hybrid origin between plant science and anthropology. It seeks to communicate plant knowledge from each ethnic group to the outside world in an unbiased manner which contributes not only to plant science but which promotes a better understanding of the people themselves and thereby diminishes unwarranted prejudices and misconceptions.

Desert Plants, Habitat and Agriculture in Relation to the Major Pattern of Cultural Differentiation in the O'odham People of the Sonoran Desert

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Preface—Genesis and Ethnogenesis

The O'odham have a creation story somewhat analogous to that in Genesis of the Bible but taking place in their own world,—the Sonoran Desert. Is it any wonder, considering that life and subsistence of the O'odham were so clearly linked to the plant resources of the desert, that genesis of the earth should start with creation of **shegoi**, the Creosotebush?—*"Then he thought within himself, "Come forth, some kind of plant," and there appeared the Creosotebush ... Next Earth Doctor created some black insects,* **tcotcik tâtâny,** *which made black gum on the Creosotebush ...* "

Here is detailed not only the creation of the most common plant of the Sonoran Desert, *Larrea tridentata*, but also creation of the lac insect *Tachardiella larrea* which caused the Creosotebush to yield an item of economic importance (lac) to the O'odham. In long-overdue justice to the pantheon of the O'odham, the present paper will attempt to show how a people with an innate sense of ecology, and whose world began with the creation of the plants of the desert, quite fittingly underwent an ethnic genesis controlled in large part by those very plants and the habitats in which those species grew.

Introduction

Castetter and Underhill (1935: p. 3) believed that most statements that could be made about one branch of the O'odham "have been true for the other, and it is only within comparatively recent times that a noticeable difference has grown up." On the other hand, ritual speeches of the **nawait** (Saguaro wine) ceremony of these people, which seems to be ancient, appear to document the differentiation of an agricultural O'odham from a western non-agricultural facies of the people. In one phase of the nawait oratory, the O'odham referred to in one of the ancient speeches are obviously at a hunting and gathering level of subsistence and eat wild food plants which grew after the rains had fallen (Crosswhite, 1980: pp. 44, 59). At a later stage in the oratory, growing of corn given by a deity occurs in the eastern, northern and southern sections of the O'odham homeland, coming up after heavy rainfall, but there are only drizzles to the west and the people in that quarter have only wild plants to eat (Crosswhite, 1980: pp. 48, 59). Students of the O'odham culture know the people of this less favorable quarter as a distinctive non-agricultural facies, the Hiach-eD O'odham.

Actually, the historic patterns of distribution of *three* facies of the O'odham in the northern part of the Sonoran Desert can be explained by reference to the pattern of increasing rainfall from west to east and by the nature of the desert rivers arising in the mountains of the east and flowing west. Discussion of these three facies of O'odham culture in relation to their respective environments sheds some light on the topic of ecotypic cultural genesis and will be the substance of the present article.

In preparing this paper it was necessary to consider length of time which might be necessary under arid conditions for three types of cultural changes, 1) those due to the independent discovery of a unique means to exploit a plant species or to deal with an environmental factor, 2) those due to diffusion of culture from one people to another, and 3) those occurring as modifications in transmission along ethnic or genealogic lines. It was concluded that the first type of change would be slow indeed. The discovery of how to exploit one plant species would take time, two species more time, three species even more, four species more yet, etc. Since the plants of the Sonoran Desert are rather different from those of surrounding regions, the first people to encounter this desert would have been ill-prepared. Therefore an indigenous desert culture which had discovered most of the plant uses would necessarily be of some antiquity. To gain perspective on the second type of change, the documented rate of diffusion of plant usages from Pueblo people to the Navajo was investigated. It was concluded that this could occur very quickly with the recipient culture remaining ethnically quite independent. For the third type, the rate at which the village of San Xavier has diverged from the culture of the people to the west was instructive.

Linguistic Considerations

All eight groups of people most closely related to the Sonoran Desert O'odham by language—Pima Bajo, Northern Tepehuan, Southern Tepehuan, Yaqui, Mayo, Cora, Huichol and Tarahumara (cf. Saxton and Saxton, 1969: p. 188) have a geographic distribution to the southeast in Mexico. Although this could indicate that the northern

Illustration of **Hiach-eD O'odham** *("Areneños") with fish and wild Carrizo Cane* **(Phragmites communis)** *near the Gulf of California at the time of the boundary survey following the Gadsden Purchase of December, 1853. Drawn by botanist Arthur Schott for a report to Congress. Reproduced from U. S. Senate Exec. Doc. 108 dated 1857.*

Illustration of **Tohono O'odham** *("Papagos") harvesting fruit of chuchuis, the Organ Pipe Cactus* **(Lemaireocereus thurberi)** *at the time of the boundary survey following the Gadsden Purchase of December, 1853. Drawn by botanist Arthur Schott for a report to Congress. Reproduced from U. S. Senate Exec. Doc. 108 dated 1857.*

O'odham might be descended from an indigenous group which had members who migrated to the southeast (cf. Hayden, 1970), it also suggests the possibility of migration into the Sonoran Desert from the southeast.

Indeed, even in historic time there is evidence of movement of O'odham from the southeast into the Sonoran Desert. The Akimel (river) facies of the O'odham, now limited to a small region of the desert, was spread over a broad region of ecological transition to the southeast above and below the Sonoran Desert boundary when the Spanish padres discovered these people (cf. Spicer, 1962). In historic time the Sobaipuri branch of the O'odham moved into the Sonoran Desert from outside the desert on the San Pedro River to the southeast (cf. Spicer, 1962: p. 127). Whether this relatively minor migration was a part of a larger and similar picture of migration before Spanish contact is not known. Hayden (1970), did, however, theorize that Sobaipuris had invaded the Hohokam domain along the Gila River at the time that the ancient prehistoric culture of the Gila River became extinct [about A.D. 1450].

Today the northern O'odham are homogeneous to the extent that they speak a common language (O'odham), although they do display differentiation in that the language has nine major dialects, eight of which (**S-ohbmakan, Totoguani, Ge Aji, Ahngam, Ko-lohdi, Huhuwosh, Gigimai, and Huhu'ula**) are referred to by Americans as "Papago" with the ninth dialect ("Pima") being spoken by both Kohadk Papago and the river Pima (Saxton and Saxton, 1969).

Although the present paper attempts primarily to discuss the northern O'odham, i.e. those of southern Arizona and northern Sonora, a brief discussion of the concept of the Piman tribes, the generic group which includes these people, is given below. It is possible to treat the northern O'odham more thoroughly than their southern counterparts since, as pointed out by Castetter and Underhill (1935: p. 3), "because of the inhospitality of their desert land they did not suffer the thorough conquest which befell the other Mexican tribes and have thus kept many of their ancient customs intact."

The Piman Concept

The names Pima and Piman are applied to certain Uto-Aztecan Indians in different senses. The term Piman is used as a generic term for both the O'odham of southern Arizona and northern Sonora as well as the Pima Bajo of eastern Sonora and adjacent Chihuahua. In addition, the Tepehuan people of Durango and Chihuahua spoke an O'odham language and are considered "Piman." In the United States the term Pima is used only for the O'odham of the Gila and Salt Rivers and the term Papago for the O'odham of the other settlements. Actually, none of the Pimans called themselves either Pima or Papago. The people in the north referred to themselves as O'odham and to the Pima Bajo as **Chuhwi Ko'adam** (= "Jackrabbit Eating People") according to Saxton and Saxton (1969). On the other hand, the Pima Bajo referred to themselves as O'odham and to northern compatriots as **Papawi Ko'adam** ("Tepary Bean Eating People").

When the Spaniards first encountered O'odham people they asked them who they were and erroneously believed the response "pimatc" (= "I don't know") to be their name (Russell, 1908: p. 19). Today the Pima Indians of Mexico live above the Sonoran Desert in the region of the Sonoran-Chihuahuan boundary near the Sonoran Foothills division of the desert. When compared ecologically with the Pima of the Gila and Salt Rivers of Arizona, these "Pima Bajo" seem so different that if the strong linguistic and ethnic tie were not known they would probably be dismissed as not closely related.

The Lower Pima are clearly the closest relatives of the O'odham of the Sonoran Desert and their geographic separation from these latter Indians by the intervening Opata deserves comment. Spicer (1962) thought that the Opata may have pushed into Sonora prior to 1600 from the northeast. If so, they may have eventually severed the northern Pima from the southern Pima by taking over the region from Cucurpe to Opodepe on the Rio San Miguel and Rio Sonora. It is instructive to note here that the O'odham word for enemy (**Ohb**) relates to their name for an Opata tribesman (**Ohbadi**) and that when O'odham came into contact with the more northerly Apache, a people who proved to be unfriendly, they essentially transferred the same designation to them (Ohb, cf.: **Opata, Ohbadi, Apache**).

Within historic time the Upper Pima had a non-desert contingent and the Lower Pima had a Sonoran Desert contingent. Spicer (1962) traced the geographic distribution in 1750 of both lower (desert) and upper (mountain) groups of the Lower Pima in Sonora and adjacent Chihuahua. Spanish padres encountered the Pima Bajo in a wide swath stretching on either side of the Sonoran Desert from near present-day Hermosillo east past Maicoba into present-day Chihuahua (Spicer, 1962).

Since they were clearly related in the eighteenth century by language and customs to the southern Pima, one facies of the northern O'odham, the Akimel O'odham, were called Pima Alto or Upper Pima, the originally encountered Pima being then differentiated as the Pima Bajo or Lower Pima on latitudinal grounds (cf. Fontana, 1974). It should be kept in mind that the Upper Pima (now simply "Pima" to United States residents) are now confined to lower elevations than the Lower Pima of today and that the Lower Pima who have retained an ethnic identity now live at the upper elevations. To avoid confusion, the Upper Pima are now sometimes referred to as the **River Pima** and the Lower Pima as the **Mountain Pima**, for their habitat in the Sierra Madre. For the present paper, rather than using recent political tribal designations such as Pima or Papago, it was decided to use the names relating to habitat by which the O'odham have traditionally differentiated their major cultural divisions.

Correlation of the Spatial Pattern of Cultural Differentiation With Environmental Severity, Water Availability and Agricultural Potential of the Habitat

Within the Sonoran Desert in historic time three major cultural groups of O'odham have been distinguished by anthropologists (Fontana, 1974). These same divisions have been recognized by the O'odham people themselves. The three groups are distinguished one from the other by differences in material culture as well as in behavior. There are major differences in subsistence patterns.

Quite remarkably, each of the three facies has occupied a separate segment of the dry-to-wet climatogeographic continuum in the desert region of southern Arizona and northern Sonora. **The Akimel O'odham** (= "River People"), known in English and to the United States government as the Pima Indians, are the O'odham who are adapted to living in the habitat where water is most readily available. Their well-developed irrigation agriculture has supported them with ease while providing excess agricultural products for trade. Their exploitation of riparian plants and floodplain resources is evident in the construction of their traditional houses and in many recipes using pods of **kui** or **chui**, Mesquite (*Prosopis velutina*). The **Tohono O'odham** (= "Desert People"), known today in the United States as the Papago Indians, are the O'odham who are adapted to living in the middle segment of the spectrum, that ecological situation where, without modern deep well technology, agriculture could be achieved only by precise timing in relation to the annual Sonoran Monsoon. Their survival on the desert required them to master techniques of food-plant gathering, processing and storing in addition to their practicing a difficult type of "de temporal" agriculture. A great deal of planning and hard work was required to exploit a combination of desert plants and environmental resources which were available for only short times during the changing seasons of the year. The **Hiach-eD O'odham** (= "Sand People"), now extinct as a recognizable cultural group, were the O'odham who were adapted to living in the harshest environment, the most xeric segment of the continuum. Although they had ready access to the Gulf of California, the salty water there was not "available" for drinking or farming. Agriculture was impossible in their habitat and life depended upon knowledge of small desert waterholes or "tinajas" for drinking purposes and upon gathering certain desert plants for food.

It is evident that the three climatogeographic segments of the O'odham have not only been strongly linked to separate environmental situations along a wet-to-dry continuum, but that they seem to recapitulate important developmental grades in subsistence from that of the hunter-gatherer (Hiach-eD O'odham) through the semi-agricultural (Tohono O'odham) to the more fully agricultural (Akimel O'odham). In theory, the cultural subsistence level of the hunter-gatherer should be more primitive than that of the agriculturist who uses river water irrigation.

Certainly the most desirable habitat with regard to human comfort and convenience would be that of the Akimel O'odham even if agriculture and irrigation were totally unknown. The resources of the river, the floodplain and the surrounding desert would all be available, and there would be more shade and water. The greater abundance of water would promote growth of edible wild plants and would attract wild animals which could be used as food. Even without fields and irrigation, something resembling the "second garden" of the Akimel O'odham probably occurred along the lower river terrace. Since the Akimel habitat should in theory be the most desirable and the most productive, it should be expected that intrusions of foreign people might occur and that those residing there would be periodically challenged by other groups for possession of the habitat. A corollary to this might be that the population within this most favorable habitat might exhibit a high degree of change in ethnic composition from one period to another and that the strongest and most able invaders would prevail. Nevertheless, the ease with which people could live in this habitat would tend (with enough time) to produce relatively sedentary people who might become less aggressive and less war-like as food surpluses increased.

The least desirable habitat from a subsistence viewpoint would be the harsh and xeric environment of the Hiach-eD O'odham. It would be hard for people living in such a region to amass products of enough value to tempt other groups to take them by planned warfare and it seems improbable that any outside group would covet the habitat in the least. Nevertheless there is evidence that occupants of this unfavorable habitat were fierce and war-like. The most readily given explanation is that the nomadic hunting and gathering people, being of a supposedly primitive cultural level, might have been inherently more aggressive than sedentary folk. Theoretically, a people well-adapted to a habitat which no one else wanted, if very capable of self-defense or ambush, could stay in possession of their land for a great period of time.

The reason behind unfriendly, aggressive or "wild" behavior of such people might lie in the fragile nature of subsistence in such a habitat, with any intrusion from the outside being a real act of trespass that had to be stopped immediately. For example, if there was often only enough water in a tinaja for the local population to have a three-day supply to get them to another known tinaja, then any uninvited visitor with water-guzzling horses or mules may have posed a real threat to the life of the inhabitants. This less favorable habitat happened to lie on the salt and shell trade route between the Gulf of California and the interior desert of southern Arizona. It would not be illogical for inhabitants of the Hiach-eD habitat to expect travellers to defray their trespass by means of gifts. In the absence of gifts, then tolls might be demanded. In the absence of tolls, violence might be predicted.

The intermediate habitat, that of the Tohono O'odham, bears one constant difference from the Hiach-eD habitat,—rainfall from summer thunderstorms is sufficient to permit seasonal crop growth in alluvial areas where run-off accumulates. Exploitation of this habitat would theoretically be most efficiently accomplished by a scattered rancheria-dwelling people practicing transhumance, a pattern of annual movement to exploit seasonal resources. Food production or gathering would not be as easy as in the habitat of the Akimel O'odham, but certainly would be much more readily accomplished than in the Hiach-eD habitat.

The three O'odham groups are intimately adapted to their specific habitats. As a generality, the Tohono O'odham possess much of the basic cultural inventory of the Hiach-eD facies in addition to their own, just as the Akimel O'odham possess much of the basic culture of the Tohono facies in addition to their own. Nevertheless, the Akimel people might find it difficult to survive in the harsher Tohono or Hiach-eD habitats without considerable hardship. Likewise, the Tohono people probably would find it difficult to survive within the harsher Hiach-eD habitat without significant changes in behavior. However, the reverse is not necessarily true. Most of the resources of the Hiach-eD habitat are found again as components of the Tohono and Akimel habitats, as are most of

Illustration of **Akimel O'odham** *("Pimo women") with traditional baskets, undoubtedly of Willow* **(Salix gooddingii)** *woven on a foundation of Cattail* **(Typha angustifolia),** *and carrying Cotton* **(Gossypium hopii)** *as well as a jar by means of a cotton headring. Drawn by botanist Arthur Schott at the time of the boundary survey following the Gadsden Purchase, for a report to Congress. Reprinted from U. S. Senate Exec. Doc. 108 dated 1857.*

the Tohono resources found again as components of the Akimel habitat. Undoubtedly if the Akimel habitat were left unpopulated, it would be rapidly exploited by people from the Tohono habitat. Likewise, if the Tohono habitat were vacated, it probably soon would be exploited by people from the Hiach-eD habitat. Indeed, apparently the descendents of the Hiach-eD people now occupy Tohono habitat. The Hiach-eD habitat has probably become considerably hotter and drier during the last 100 years (cf. Hastings and Turner, 1965). If ecotypic cultural genesis were operable, then one would predict that Tohono people moving in to fill the Akimel habitat would eventually develop the culture of the historic Akimel O'odham.

The Hiach-eD O'odham

Our knowledge of subsistence by the Hiach-eD people is less than perfect. Most individuals of this cultural group were either killed by a posse of Mexicans (Childs, 1954) or were rounded up and taken to Caborca, Sonora. Some escaped to Arizona. Their culture is nearly extinct as an identifiable unit and their dialect (S-ohbmakam) is scattered from Ajo, Arizona south and west (Saxton and Saxton, 1969: p. 183).

Two Jesuit priests, Father Kino and Father Kappus, travelling with a military escort under Juan Manje, encountered the Hiach-eD people in 1694. The first seen were described as nearly naked people who covered parts of their body with hare (i.e. jackrabbit) fur and were poor and hungry, living on roots, locusts and shell fish. The next group were similar and "lived by eating roots of wild sweet potatoes, honey, mesquite beans and other fruits. They travelled about naked; only the women had their bodies half covered with hare fur ... " (Manje, 1954). In 1701 the Spaniards encountered a band of these Hiach-eD O'odham in the Sierra del Pinacate, counting 50 persons described as poor and naked, subsisting on roots, locusts, lizards and some fish.

The Hiach-eD O'odham were nomadic hunters and gatherers, their population in any one place being ephemeral. They roamed widely through the Sierra Pinacate and sand dunes at the head of the Gulf of California east of the Colorado River in a manner not dissimilar to that of unrelated coastal Seri to the south. They traded with the Cocopa (Fontana, 1974) or Yuma (Childs, 1954) but mainly moved about looking for wild food plants and food animals.

Lumholtz (1912) described the Hiach-eD O'odham as intelligent, healthy and able-bodied. He was told that a large number had died about 1850 from a disease which included vomiting blood. This may have been an epidemic of yellow fever which affected other cultural facies of the O'odham at about this time. Lumholtz concluded that the existence of these people depended on knowing the few places along the coast where potable water could be obtained by digging and the few places in the mountains where rain filled tinajas. Often stones were piled up to show the way to tinajas in the mountains surrounding the sand. Sometimes as many as eight stone tanks naturally occurred one above the other and access to the upper ones could be precipitous (Lumholtz, 1912). The Hiach-eD people jealously guarded their water from guzzling horses, mules and burros of strangers. Lumholtz (1912) believed that they were merciless to strangers, making travel on the roads dangerous and "nobody could follow them into the sand dunes to their principal retreat at Pinacate."

The Hiach-eD O'odham were already nearly extinct when Thomas Childs (born 1870) married a woman whose father belonged to that band. His sketch of the "Sand Indians" (Childs, 1954) reveals information that might otherwise have been lost to history. The publication by Lumholtz (1971) of ethnographic material on these people is also valuable. He travelled through the homeland of the Hiach-eD people in 1910 with two of them as guides, one an old medicine man.

At the time of Lumholtz's 1910 expedition the Hiach-eD people had not lived in their sand dune country for forty or fifty years and they existed only as a few families who had taken up residence elsewhere. Lumholtz described one Hiach-eD guide as being "not very good in following tracks, but knew how to trap wild animals, and the rapid and dexterious manner in which he prepared them for eating reminded me of the Australian savages. His ideas about property were not highly developed ... "

Childs (1954) "lived with and around them" all his life and described a period in history when older Hiach-eD O'odham remembered when the people had spent their entire existence as a nomadic people. Childs' own experiences with them were during a period when they seasonally visited the dunes, Pinacate and ocean to re-live pages from their past.

Recently Felger (1980: pp. 87–114) has described the vegetation and flora of much of the habitat of the Hiach-eD people, the Gran Desierto of Sonora. He pieced together a list of the edible plants in approximate order in which he thought they may have been utilized by the Hiach-eD O'odham. He thought the Sand Root, **hia tatk** *(Ammobroma sonorae)* to have been most important, followed by seeds of Desert Bugseed *(Dicoria canescens)* and pods of Mesquite *(Prosopis glandulosa)*. Other seeds listed were those of Ironwood *(Olneya tesota)*, Blue Palo Verde *(Cercidium floridum)*, Mormon Tea *(Ephedra trifurca)*, Gran Desierto Sunflower *(Helianthus niveus)*, Tansy Mustard *(Descurainea pinnata)*, Amaranth *(Amaranthus palmeri, A. fimbriatus)*, Blazing Star *(Mentzelia* spp.), *Oligomeris linifolia*, Sand Locoweed *(Astragalus insularis)*, and Peppergrass *(Lepidium lasiocarpum)*.

Greens and potherbs listed by Felger were herbage of Evening Primrose *(Camissonia claviformis)*, inflorescence of Beargrass *(Nolina bigelovii)*, herbage of Amaranth *(Amaranthus palmeri, A. fimbriatus)*, and the young inflorescences of Wild Buckwheat *(Eriogonum* spp.). Bulbs were those of Desert Lily *(Hesperocallis undulata)* and Blue Sand Lily *(Triteliopsis palmeri)*. Fruits were those of Desert Wolfberry (*Lycium andersonii*) and Desert Mistletoe *(Phoradendron californicum)*. Probably of least importance were the flowers or nectar in the flowers of Ocotillo *(Fouquieria splendens)* and Chuparosa *(Justicia californica)*.

The Sand Root (*Ammobroma sonorae*) was recently discussed by Nabhan (1980: pp. 188–196). This large fleshy parasite of *Franseria, Dalea, Coldenia, Eriogonum* and *Pluchea* is found only in the sand dunes at the head of the Gulf of California. The plant is subterranean and about three feet long, without leaves and "looks like a root covered with scales which grow thicker toward the top" (Lumholtz, 1912). The plant is more tender and succulent than a radish when eaten raw. It satisfies both hunger and thirst. When cooked at a campfire it tastes like sweet potatoes. Unfortunately the Sand Root is easy to find only in March and April when it protrudes from the sand and produces flowers. Some of the Hiach-eD O'odham who were proficient at gathering the plant apparently could find it during any time of the year. Some were said to live chiefly by eating this plant.

Lumholtz (1912), Childs (1954) and Fontana (1974) have also discussed the food habits of the Hiach-eD people, recording various plants in their ethnobotanical inventory. Pink or yellow flower buds of certain species of Cholla Cactus (*Opuntia* sp.) were gathered, allowed to dry slightly, hit with a stick to remove the spines, and roasted. This food, **chi'odima,** had a pleasing somewhat sour taste but residual spines could be a problem if not properly prepared (Childs, 1954). Lumholtz (1912) stated that the Hiach-eD people roamed as far east as Quitobaquito and Santo Domingo to gather beans of Mesquite (*Prosopis*), fruit of Saguaro (*Carnegiea gigantea*), and fruit of **chuchuis,** the Organ Pipe Cactus (*Lemaireocereus thurberi*). He observed that bedrock mortars from six to ten inches deep used for pounding Mesquite beans were to be seen near each of the tinajas and that the pestles were frequently found nearby. Childs (1954) stated that when mortars in large boulders had been well used, the huge boulders were turned over and new pounding holes for Mesquite preparation were made.

The Hiach-eD people toasted, ground and mixed with water the beans of **ho'idkam,** Ironwood (*Olneya tesota*), to make pinole, a nutritious beverage (cf. Lumholtz, 1912). The seeds of Indian Wheat (*Plantago* sp.) were eaten, either uncooked or toasted and ground into pinole. **Wipih si'idam** (Evening Primrose) growing on sand dunes was abundant after scant winter rains, some of the clumps being over five feet in diameter and having more than 100 flowers (Lumholtz, 1912). These juicy plants were boiled and eaten. Other plant foods utilized by the Hiach-eD people and recorded by Fontana (1974) were wild Century Plant (*Agave*), the bulb of Covena (*Brodiaea capitata*), the tender new growth of Lambsquarters (*Chenopodium murale*) and Patota (*Monolepis nuttaliana*). Childs (1954) reported that the Hiach-eD O'odham smoked tobacco "from time immemorial."

The Hiach-eD people are said to have killed only to eat and that if one had meat they all had meat. Hiach-eD hunters could get close enough to antelope and mule deer to kill them with bow and arrow (Lumholtz, 1912). When antelope were among Creosotebush they were easily spotted from the color which, though light reddish-brown above, presented a white aspect from the legs and underside. They were chased until the animals stopped a distance away. The hunter would then lie down and wait for an animal to move, then chase again, lie down again and continue the cycle until the animal itself lay down and could be killed (Childs, 1954).

Hiach-eD O'odham killed mountain sheep with bows and arrows, especially in the large craters of the Pinacates (Lumholtz, 1912). They refrained from killing these animals unless needed for food and then only in the quantity required (Childs, 1954). When all other foods failed, the Hiach-eD people would ask **I'itoi,** the legendary "Elder Brother," to send an old mountain sheep ram that he had no further use for. The people would send a man to sit and wait with bow and arrow at a large rock on the east side of the Pinacate. An old ram would appear when needed as if having been sent by I'itoi. Whenever mountain sheep were killed, the horns would be added to shrine-like piles scattered over the desert (Fontana, 1974).

Hunters flushed packrats from their nests by setting fire to cactus spines which lined their burrows. When the rodents appeared they were shot with bow and arrow. Jackrabbits (*Lepus* sp.) were run down by foot in the sand during summer (Lumholtz, 1912). Cocopa could outrun the Hiach-eD people in the sand according to Childs (1954). Lumholtz (1912) described the preparation of a jackrabbit for eating by an old Hiach-eD man. The rabbit's legs were broken with a stick in a few seconds and the hair was singed away by holding the body over the fire.

Large game and small game yielded meat which was dried for future use (Lumholtz, 1912). Generally the meat was cut up and strung on ropes (Childs, 1954). Quails and probably doves were eaten but there was a taboo against using buzzards, hawks and eagles as food (Fontana, 1974). Quail were trapped in a Saguaro rib box propped up by a stick. A string attached to the stick usually led to a boy hiding behind a bush. The lizards used as food belonged to the family Iguanidae (Fontana, 1974). Locusts referred to by Spanish explorers were probably the **ma-kum** mentioned by Greene (1936) and Russell (1908) that were processed by various O'odham into snacks like corn curls and eaten while drinking Saguaro wine. These sphinx moth larvae (*Celerio lineata*) were processed by the Hiach-eD people by removing the heads and inner organs and placing the remainder between two ollas to roast over hot coals (Childs, 1954).

Surveyors for the railroad observed the Hiach-eD people in 1854 (Gray, 1856). The Indians had very short front teeth, but the cause could not be determined. Childs (1954) solved the mystery by reporting that the Hiach-eD "ate their Missmire Clams raw and opened them with their teeth." Apparently the teeth had been worn down by abrasion in opening the clam shells. The clams lived in the sand and were very easy to gather. Since the Hiach-eD people had no boats, oysters living out on coral reefs were difficult to obtain and then only at low tide. Fontana (1974) reported that the Hiach-eD O'odham ate sea turtle, fish, shrimp, clams and oysters both fresh and dried.

We have a first-hand account from Childs (1954) of how two Hiach-eD O'odham men caught fish at the Gulf in the traditional way. These fish were Totoaba, some over 250 pounds in weight. Fishing was done when the moon changed from full to new and the tides were high. As the tide came in the large fish came in to eat the small fish. As the tide went out the fish were often left stranded where they could easily be speared and then strung on a rope. The fish spear consisted of the retrorsely barbed underside of the tail of the Sting Ray (*Dasyatis*) lashed to a willow branch. A fisheries management system is suggested by Fontana's (1974) mention that Hiach-eD O'odham were known to build low stone enclosures for the fish to become stranded in.

According to Fontana (1974) the Hiach-eD people did not have houses. They piled up boulders one or two courses high and slept within the enclosure as a windbreak. Clumps of grass were placed against the roofless shelters to further deaden the force of the wind and penetration of the cold. Lumholtz (1912) thought that in winter they erected grass huts but he apparently never saw one.

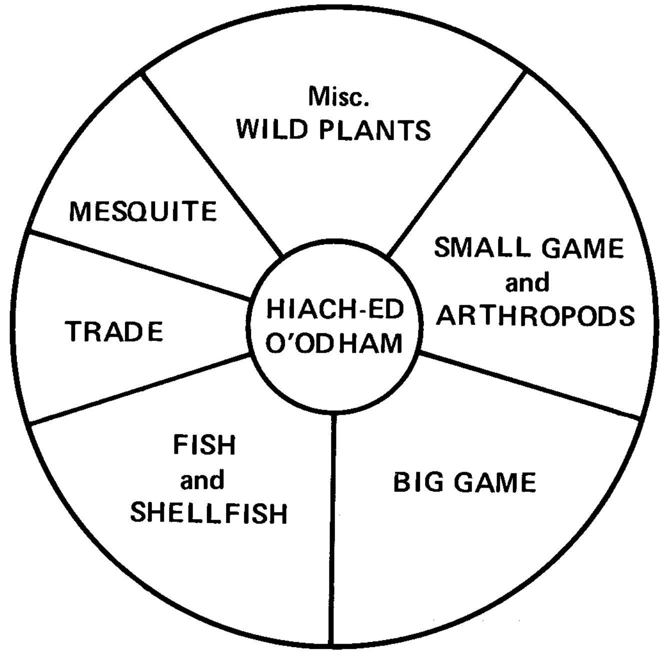
Lumholtz (1912) recorded that Hiach-eD O'odham apparel came from the skin of mountain sheep, antelope and mule-deer. Childs (1954) mentioned a preference for antelope skin because it was easier tanned than deer skin. Early explorers mentioned hare (i.e. rabbit) fur. The clothing probably depended on whichever kind of animals the people had been eating. In preparing animal skins, "The hair was removed with a bone taken from the lower foreleg of the animal" (Lumholtz, 1912) or with a whale rib bone found lying on the coast (Childs, 1954). The skin was rubbed with brains of the animal killed to soften it and smoothed with a rock for the same purpose. *Jatropha* roots were crushed and soaked to make a solution for tanning leather.

Hiach-eD men wore a breech cloth held up by cord made from badger hair. Occasionally they wore a skin shirt. Women apparently wore a short skirt but were naked above (Lumholtz, 1912). This skirt had fringes hanging down (Childs, 1954) and apparently consisted of nothing more than these fringes (Fontana, 1974) hanging from buckskin strings (Lumholtz, 1912). Mineral or plant dyes colored the clothing red or yellow (Childs, 1954). Sandals and straps were made from sea lion skin. The sea lions were killed where they rested on shoreline rocks along the Gulf (Fontana, 1974) by striking them on the nose with rocks (Lumholtz, 1912). The Hiach-eD O'odham wore long hair and periodically plastered it with mud to kill lice (Childs, 1954). Men kept their long hair out of their eyes by tying it with badger hair plaited into a cord or ribbon (Lumholtz, 1912).

The Hiach-eD people constructed baskets from Torote Prieto (*Jatropha*), Willow (*Salix*) and Bulrush (*Scirpus*). They apparently made carrying nets but not burden baskets. They went to the Colorado River to obtain Willow (*Salix*) for making bows (Lumholtz, 1912) or made them from Desert Willow [*Chilopsis*?] according to Fontana (1974). Arrows made from Arrowbush (*Pluchea sericea*) were plumed with hawk feathers (Childs, 1954). The Hiach-eD people made an annual journey to Yuma to trade baskets and sea shells for maize, tepary beans and squash (Lumholtz, 1912).

Ezell (1954) concluded on archaeological evidence that the plainware pottery of these people was Yuman but the decorated types Piman. Fontana (1974) thought that the plainware was obtained by trade with the Cocopa. Childs (1954) said that the Hiach-eD made their own pottery, while Ezell (1954) suggested that they made their own utilitarian pottery in a [borrowed?] Yuman tradition while obtaining decorated pottery in trade with O'odham in Sonora. If the Hiach-eD O'odham are defined as a non-pottery-making, non-agricultural people who built no permanent houses, then ones who did any of these things are considered transitional Areneños (Hiach-eD-like Tohono O'odham) by Fontana (1974).

Hayden (1967) has presented evidence that the [Hiach-eD people] may have occupied at least some of their habitat continuously from early post-Altithermal times to the 20th century. He identified the [proto Hiach-eD] people with the Amargosa complex of Rogers (1966) and deduces that the Amargosa people spoke a proto-Uto-Aztecan language (Hayden, 1970). If this is true, then the Hiach-eD people would be the descendents of those who stayed behind when the proto-Uto-Aztecans pressed on south into the heart of Mexico. By such a theory, those who remained behind in what is now northern Sonora and southern Arizona, would have diverged into two groups, 1) the proto-O'odham in the Lower Sonoran Life Zone, and 2) the proto-Mogollon in the Upper Sonoran Life Zone. Such a split would have restricted the proto-O'odham group to the range of the Saguaro cactus and the proto-Mogollon to cooler intermediate elevations from which resources of higher elevations could be exploited but where winter temperatures were not too severe. If this is true, then the people occupying the better habitats progressed culturally, but in the case of the Hiach-eD habitat, the environment offered nothing more than the Hiach-eD level of subsistence. The limited potential of the habitat to the south suggests that the Seri may have paralleled the Hiach-eD culture, although of a different ethnic and language group.



Estimated subsistence ratios for the **Hiach-eD O'odham,** *general hunters, fishermen and gatherers, about 1750 A.D.*

The Tohono O'odham

The Sonoran Desert O'odham who became adapted to the intermediate segment of the dry-to-wet continuum in the Lower Sonoran Life Zone were the Tohono people. They are thought to have adjusted their homeland with various fluctuations in climatic cycles. An old calendar stick kept by these people reveals that there was snow three feet deep in the decade of the 1840s and that many Tohono people went "down into the low lands or coast country of Mexico" but eventually returned north because of a "miasma of death [probably yellow fever] hanging over the low lands." The article on the Cenozoic history of the Saguaro by Lowe and Steenbergh (Desert Plants, this issue) makes it clear that catastrophically cold weather has probably been intermittent in the Saguaro habitat for several thousand years. Did temporary displacement of the Tohono people to the south occur in other centuries as well? A number of prehistoric artifacts in the homeland of these people, including a finely polished redware pottery (cf. Haury et al., 1950) suggest contact with Sinaloa.

The Tohono O'odham have depended on channelled run-off water from short intense summer thunderstorms for a type of farming distinct in methodology from ordinary dry-land agriculture and equally different from normal irrigation agriculture. The Tohono people were discussed by Fontana (1974) under the heading "Two-Village People." Traditionally these families had a winter home, a summer home and a cactus camp. Most of their homeland consisted of broad valleys with alluvial soil bordered by steep mountains (Bryan, 1925). Water was found in winter only in such hills and the winter home or "the well" was located there (Castetter and Underhill, 1935). Thunderstorms in summer brought rainfall and run-off to the valleys so they could be lived in and farmed. The summer home was known as "the fields." As part of the annual pattern of "transhumance," moving from winter well-site to summer fields, the Tohono O'odham camped in large stands of **hahshani**, the Saguaro Cactus (*Carnegiea gigantea*), for about three weeks to harvest and prepare the fruit.

They depended on a summer harvest of Saguaro fruit and on an autumn harvest of beans, corn and squash. Mesquite (*Prosopis velutina*) beans and other wild foods were also gathered. Today the Tohono O'odham are known as the Papago. Many have adapted to Anglo industrial culture with only few continuing to farm by flash-flood methods or to harvest Saguaro fruit by traditional means.

Fontana (1974) reported the two village "transhumance" system of the Tohono O'odham to be "at the core of the way of life of more than 4,000 O'odham at the time of Spanish contact." Thackery and Leding (1929) estimated the number of Tohono families in the 1920s to be 1200. Today there are probably twelve to fifteen thousand of these people, five to six thousand of whom live in their traditional homeland.

The Annual Saguaro Harvest and Crop Cycle. Harsh areas of Sonoran Desert were made more habitable to the Tohono people by their techniques of Saguaro fruit harvest, fruit processing technology, "hermetic sealing," food storage technology, and by their growing desert-adapted races of beans, corn and squash with rapid life-cycles, using water harvested from the brief summer thunderstorms. If it weren't for the fruit harvest in June and July, the Tohono people would not have had adequate food reserves for proper nutrition during the period when crops were planted in July and before they were finally harvested in September and October (Crosswhite, 1980). Of course, other wild food plants, particularly Mesquite, were also important. Since the Tohono people consistently produced excess Saguaro products to trade to the Akimel O'odham and the Akimel people are documented as trading Mesquite beans to the Tohono, there obviously was an abundance of Saguaro and scarcity of Mesquite among the Tohono. This logically follows from habitat considerations.

The Tohono O'odham combined a knowledge of ecology with a goodly amount of symbolism to develop an annual Saguaro harvest and crop cycle notable for its ritualism and its effectiveness in keeping the people on schedule with gathering and planting while providing a sense of fulfillment in a difficult subsistence economy (Crosswhite, 1980). The promise of wine from Saguaro fruit may have made easier the hard work of fruit harvesting, processing and storing which resulted in eleven other food products aside from the wine: syrup, jam, dehydrated pulp, animal food seed mix, seed flour, seed oil, pinole, atole, snack foods, soft drinks and vinegar.

The Tohono O'odham may have believed according to the ritual "Running Speech" of the nawait ritual that the Saguaro had a supernatural anthropomorphic dimension coming from its contact with the man who resided at the rainhouse where winds, clouds and seeds were located (Crosswhite, 1980). Contact with wine from the Saguaro was used in calling for rain by the Tohono people, but whether they thought that its use also conferred on them some of the qualities of the Saguaro is not known.

Was the ability to learn from and emulate the Saguaro enhanced by drinking its wine? The over-all significance of the Saguaro to the Tohono O'odham can be seen from their annual calendar which began the new year with ripening of Saguaro fruit and was kept on schedule by reference to phenology of the Saguaro, crops and wild plants,—the progression of the seasons in the environment.

The Tohono people demonstrated profound respect for the Saguaro, successfully emulating its qualities to survive on the desert as it did. These people did not live to any extent beyond the distributional limits of the Saguaro to the north, east, south or west. They harvested water which was conducted to their fields from a great expanse of desert just as the extensive water-harvesting roots of the Saguaro channelled water to the plant from a great expanse of land in contrast to normal roots. Just as the Saguaro stored water from time of plenty to time of scarcity, the Tohono people learned to store food from time of plenty to time of scarcity. Underhill (1979) recorded that the Tohono likened the seedling of a Saguaro under a nurse plant such as Palo Verde (*Cercidium*) to a fat child cared for by a mother. Both Tohono O'odham and Saguaro were adapted to the winter-warm south-facing sites in the desert which have existed in southern Arizona and northern Sonora during the last 10,000 years. The Tohono people began annual preparations for planting crops by waiting until the seeds of the Saguaro were about to fall to the ground and subtropical germination pre-requisites of heat and moisture were about to coincide.

After the Saguaro harvest had provided food that could be eaten or stored and after the nawait ritual had brought rain, it was time to plant seeds of tepary beans, corn and cucurbits. According to Underhill (1946), tradition required that crops not be planted until after the Saguaro wine ceremony. The Tohono people have been classified as semi-agricultural. This was not because they were unable to master the full concept of agriculture, but rather because their homeland would only support crops during the period of summer rain. To master agricultural technology relating to water harvesting and also to master the details of Saguaro fruit technology would seem to place these people at a technical level somewhat higher than has been generally appreciated.

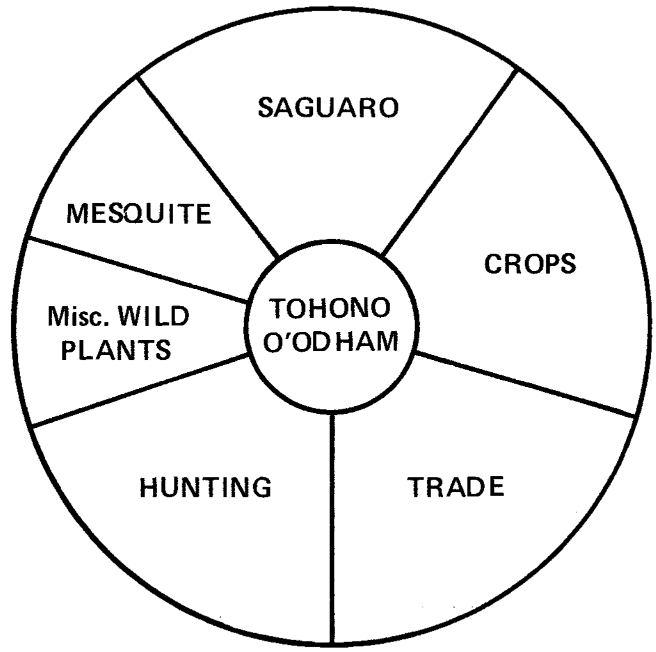
When the summer villages were occupied, the women collected wild food plants and did the cooking, boys hunted small game, "while the men attended to what agriculture was possible" (Castetter and Underhill, 1935). Men kept water channels clean and functional through the growing season, kept terraces intact, and used a sharp-edged piece of Mesquite wood in the field to hoe weeds.

The Importance of Beans. Tepary Beans, **papawi** (*Phaseolus acutifolius*), have been such an important item of diet for the Tohono people that they were sometimes referred to as Papawi Ko'adam (Tepary Bean Eating People), from which the name Papago is said to have been derived. Common beans, **muhni** (*Phaseolus vulgaris*), were also cultivated. A study of the dietary habits of the Tohono people in the 1940s (Ross, 1944) revealed that beans were more frequently used in meals than any other food. Surprisingly, this survey showed that corn was used in only 3% of all meals. In this regard, the Kohadk people behaved differently, eating corn every bit as frequently as beans. When all Tohono children filled out a questionnaire on their food likes and dislikes at school, beans were the least disliked of 28 plant foods surveyed and the second most liked. Only oranges were liked by slightly more children. Beans were even slightly more liked than apples, bananas, watermelon and candy! If indeed there is a real ethnic preference among the Tohono people for beans, it might be suggested that this developed from long years of usage brought about by the fact that the rapid life cycle of *Phaseolus acutifolius* rendered it much better adapted to de temporal agriculture than corn and other crops.

Traditional Growing of Beans, Corn and Cucurbits. The traditional crops, aside from beans, were **huhni** (corn) and **hahl** (squash and pumpkin). The fields of the Tohono O'odham were characteristically located at mouths of washes in the flatlands where relatively fertile silty soil had been deposited by run-off floodwaters. Such desert washes were ordinarily dry but flowed briefly from violent summer thunderstorms. Castetter and Underhill (1935) described agronomy of the Tohono people, observing that ditches "are dug from the wash to the fields situated alongside, the ditch ending in the middle of the field so that the water will flow over it." New fields generally were prepared by levelling, removing stones, terracing and then channelling the run-off.

A prepared field was not seeded until it had been soaked and was starting to dry on the surface. Underhill (1951) described planting preparations for corn: "Grandfather stands at the end of the field with the corn in a little bag of deerskin and sings the corn song. Then he speaks to the corn ... then he gives the bag to Mother." Seed holes were made using planting sticks of Ironwood (*Olneya tesota*) having sharp fire-hardened points. Such holes were generally three feet apart and six inches deep. As a rule the man laid out the fields and made the holes. The woman followed behind, "carrying the seeds in a small basket; she pushed a little loose earth into the hole with her bare toes, dropping in four seeds," and covered them with a single foot movement (Castetter and Underhill, 1935).

A little tobacco might be secretly grown away from the food plants to preserve its mystical nature. Although



Estimated subsistence ratios for the **Tohono O'odham,** *de temporal agriculturists, about 1750 A. D.*

tokih, Cotton (*Gossypium hopii*), was known, it is not likely that the small fields of the Tohono people and the shortage of water permitted growing this crop. Indeed, early explorers differentiated the Tohono people from the Akimel O'odham by the fact that the former wore animal skin clothing while the latter wore cotton clothing.

The crops were harvested in October after a growing season of 100 days or less. "After being flailed and winnowed, then thoroughly dehydrated on the roof of the house, they were stored in jars or baskets. The Papago usually hid their food for safekeeping ... " (Castetter and Underhill, 1935). It was not uncommon for Apache raiders to take food from the Tohono people after harvest.

Subsistence Ratios From the Saguaro and Crop Cycle. Fontana (1974) estimated that about one-fifth of the food supply of the Tohono O'odham came from cultivating 0.1 - 1.0 hectare family-sized garden plots. Tohono people during the first half of the 20th century probably harvested and stored 600,000 pounds of Saguaro fruit per year in addition to that fruit which was eaten raw during the three-week Saguaro harvest (Crosswhite, 1980). This quantity would easily account for one-fifth of their food supply and helped provide trade products that were significant in their obtaining another one-fifth of their food from the Akimel O'odham or others.

Trade. Saguaro syrup, Saguaro jam, Saguaro seeds and Saguaro seed-meal prepared by the Tohono people were common items of commerce in the Sonoran Desert for as far back as history has been recorded. When W. H. Emory collected the first botanical specimen of Saguaro [*the specimen from which the species was scientifically described*], he encountered Saguaro fruit products in local

O'odham commerce. Crosswhite (1980) compared changing dollar values for Saguaro syrup from the time American money began to be used in the Sonoran Desert up to the present. The importance of Saguaro product commerce is emphasized by the fact that many of the clay pots used by the Akimel people were believed by Russell (1908) to have accumulated from the Tohono people having brought them "filled with cactus sirup to exchange for grain."

That one-fifth of Tohono O'odham food came from trade might at first seem high. It should be kept in mind, however, that the value of the Saguaro fruit products that the Tohono people offered was increased by their being packaged in re-usable clay pottery containers. The containers themselves were enhanced in value by being decorated with painted designs. This marketing technique is similar to the modern flour mill packaging flour in printed muslin bags for sale to rural people who sew their own clothes, or to makers of detergent and oatmeal including a free cup or wash-cloth in the boxed product.

The value of Saguaro fruit products was even further increased by offering them in conjunction with ritualistic group singing. It is tempting to think of the Akimel people as having been "haves" and the Tohono people as the "have nots" with trade between the two allowing the Tohono to benefit from the largesse of the river people. But Russell (1908: p. 93) was quick to point out that the Tohono people had so thoroughly mastered their "all but hopeless environment that the trade which they carried on with the Pimas was by no means one-sided ... "

Aside from syrup jars, often more clay pots of other types were made by the Tohono people than needed for family use with an intent to trade or, with the advent of money, to sell the excess. Trading trips were made to the Akimel O'odham of the Gila River, to Mexico and to the Yuma Indians of the Colorado River (Underhill, 1939). The latter author noted that a water olla was worth enough beans or corn to fill two basket bowls. In early days of Tucson, Tohono O'odham women walked the streets with burden baskets filled with clay pots for sale to the townspeople.

Foot caravans to collect salt at the Gulf of California in the vicinity of the present-day Puerto Peñasco, Sonora, were traditional events of the Tohono people. The journey is thought to extend back into antiquity and had a religious significance discussed by Underhill et al. (1979). Some of the salt was used for cooking and for domestic purposes but much of it was traded to the Akimel O'odham and others. One suspects that prehistorically the Tohono O'odham must have kept inland Indians well supplied with this commodity. Records going back to 1860 show that the Tohono people were selling unbelievable quantities of salt to the residents of Tubac and Tucson, the superintendent of a mining company at this time stating that he alone was buying 20,000 pounds of salt annually from them (Russell, 1908).

Items traded by the Akimel O'odham to the Tohono O'odham were **pilkani** (wheat), corn, beans, mesquite beans, cotton blankets, cotton fiber with seed, dried squash, dried pumpkin, dried melon, rings of willow splints, and rings of devil's claw splints (Russell, 1908).

Other Subsistence Sources. We have accounted for three-fifths of the food supply of the Tohono O'odham as having come from the annual Saguaro harvest and crop cycle and by trade which partly resulted from this cycle. The remaining two-fifths would have come from general hunting and gathering that was similar to that which characterized non-agricultural Hiach-eD people. Plant and animal food was probably equally represented in this portion of their subsistence. Mesquite alone may have accounted for as much as half of the plant material in this category. Extensive lists of the plants and animals utilized are given by Castetter and Underhill (1935) at a time when older informants were alive and could remember traditional details.

Utilization of Mesquite and Other Legumes. Valleys used for summer farming also yielded wild foods, particularly beans of Mesquite (*Prosopis velutina*) which were not as common in the vicinity of the winter quarters or cactus camp. Fortunately these ripened just as the Tohono people had finished the annual Saguaro harvest and had settled into the valleys for the seasonal farming. Plants growing in remote valleys or in ones not suitable for semi-permanent summer farming were harvested by setting up a Mesquite camp of brief duration. This was not at all the elaborate affair of the cactus camp. Although Saguaro harvest camps were occupied by the entire family for several weeks of the year, Mesquite harvesting and processing sites were probably used only by women who walked to and from the summer village. A Mesquite drink that was mild and nutritious made this hard work more sociable and was aptly named "women's wine."

Aside from using Mesquite pods for food, the Tohono people also parched the seeds themselves to render them edible. This was also done with seeds of Mexican Palo Verde (*Parkinsonia aculeata*), Little-Leaf Palo Verde (**kuk chehedagi**—*Cercidium microphyllum*) and Ironwood (*Olneya tesota*). The seeds of Ironwood could be eaten fresh from the pods when still green, at which time they tasted like green peas. They had to be used in moderation or they would make a person sick.

Utilization of Agave. Certain species of **a'ut** (Agave) were used by the Tohono people for making the foodstuff known as mescal. Rosettes were chosen when the flowering stalk had just begun to shoot upward. At this time enzymes were present which had begun to mobilize the energy reserves of the plant and convert them to sugar. Each plant lived a number of years, flowered once, and then died. By harvesting a plant at the proper time it was possible to convert the many years of energy (which had been stored to allow production of the terminal flower stalk) into human food.

The technology to do this required much more than simply cooking the plants on an open fire. First, the leaves were cut off with special stone mescal knives, leaving only the heart of the plant. Next, a pit in the ground was lined with stones and pre-heated by building a fire in it. After the fire had died down the coals were removed and the *Agave* heads were placed in the pit, covered with moist leaves and branches, and the pit covered with earth. After several hours of extremely slow cooking in the oxygen-starved environment, the proper chemical reactions and "cooking" had taken place to transform the bitter and unpalatable plant into sweet and nutritious food.

There is excellent evidence that *Agave murpheyi,* due to its tendency to form bulbils, was an ancient Indian cultivar in southern Arizona. Although it has been found near prehistoric Indian ruins, it is rare in nature as a convincing component of a natural plant community. Young plants (bulbils) form on the flowering stalk. The most efficient manner of propagation involves stripping a plant of its 200 or so bulbils and putting these aside in the shady environment of a sack or small basket for a week or two until the cut surfaces have healed over, then planting the bulbils in loose soil and watering them occasionally until they become established. The ease of transport and propagation makes this an easy plant to grow.

This remarkable plant was originally made known to science when it was discovered growing near the Boyce Thompson Southwestern Arboretum (Gibson, 1935), the site of a prehistoric Salado settlement. When Gentry (1972: pp. 99-101) finally published the definitive taxonomic treatment of this species, it had been reported from near Roosevelt Lake, in the Tonto Basin, in Paradise Valley, and at the base of the Superstition Mountains. In addition, Gentry reported that he "saw it cultivated at Sells, Ariz., and a Papago Indian reported the same had been brought in from the neighboring mountains in view to the south of Sells." Gentry also found the species in Sonora at San Luisito, along the road to Quitovac from Caborca, "cultivated in a yard, whose owner states that his plants had been brought from the nearby hills" but that "all the larger plants had been cut for eating or for making mescal."

Utilization of Cacti Other Than Saguaro. According to Castetter and Underhill (1935: p. 15), the buds and joints of four species of Cholla Cactus and one of Prickly Pear constituted a staple crop among the Tohono people. "Whole cholla joints, as well as the buds, are pit-baked and dried ... The women carry home the roasted cholla and continue to go out for other batches until a large area surrounding the village has been picked over. The roasted buds are used with greens of the annual salt bush (*Atriplex wrightii*) or lambsquarter (*Chenopodium alba*) as a sort of vegetable stew."

The Prickly Pear, **nohwi** (*Opuntia phaeacantha*), yielded fruit and its tender young stems were scraped of spines, cut in strips, and cooked like "nopalitos" are prepared today. The large waxy flowers of Prickly Pear were washed and then fried in deer tallow (Castetter and Underhill, 1935: p. 16). Cactus fruits eaten by the Tohono O'odham either fresh or cooked, in order of importance, were those of Saguaro (*Carnegiea gigantea*), Organ Pipe (*Lemaireocereus thurberi*), Prickly Pear (*Opuntia* spp.), Hedgehog (**ihswig**—*Echinocereus* spp.) and Fish-hook Pincushion (*Mammillaria*).

Wild Greens and Edible Weeds. The Meals For Millions Foundation (1980) and others have documented many of the edible wild greens used by the Tohono people. **Ku'ukpalk,** Verdolaga (*Portulaca oleracea* and *Trianthema portulacastrum*) was collected in summer and autumn. The plants grew prostrate on the ground. The leaves and young stems were used as greens. **Ihwagi,** Lambsquarters (*Chenopodium* spp.) was collected in spring, washed and cooked. Only young plants were used. **Onk ihhwagi,** Annual Saltbush (*Atriplex wrightii*) was collected in spring for cooking. Only the young leaves and upper stems were usually used. Sometimes onk ihwagi was dried and stored before eating. **Opon,** Patota (*Monolepis nuttaliana*) forms a small rosette on the ground in winter. The whole plant is cooked.

Young pods of **ihug,** Devil's Claw (*Proboscidea*), were eaten as a vegetable. If allowed to mature the pods became inedible but the fiber was used in basketry. The seeds from mature pods were boiled by the Tohono people, however, as a by-product of the basket industry, and eaten (cf. Castetter and Underhill, 1935: p. 25).

Chuhugia, Amaranth (*Amaranthus palmeri*) was collected for greens in summer and autumn. Only small plants or the young leaves of old plants were used. The seeds of Amaranth were an important article of diet to the Tohono people. Plants of this wild species which came up as weeds in the fields were allowed to grow and even encouraged. Most of the edible plants of the "second garden" of the Akimel people also grew as weeds in the primary fields of the Tohono people. The principal difference was that the Tohono people did not have the abundance of water nor enough good land next to their primary field to have the luxury of a real second garden. For this reason the small Tohono fields were probably more weedy than their Akimel counterparts.

Other Plant Foods. Fruits which Castetter and Underhill (1935: p. 19) documented as eaten either fresh or dried by the Tohono people were from Banana Yucca, **hoi** (*Yucca baccata*), Squawbush (*Condalia spathulata*), Netleaf Hackberry (*Celtis reticulata*), Little-leaf Mulberry, **kohi** (*Morus microphylla*), Desert Mistletoe, **hakowa't** (*Phoradendron californicum*), and Tomatillo Bush, **kuawur** (*Lycium* sp.). To these should be added the delicious sweet succulent orange fruits of the Desert hackberry, **kohm** (*Celtis pallida*), which are often quite abundant. The berries of Graythorn (*Zizyphus obtusifolius*) rather than being eaten raw were cooked and the syrup used.

The native Arizona form of the Chillipiquin or Wild Pepper (*Capsicum baccatum*) grows wild only on the west slope of the Baboquivari Mountains, although it is also cultivated. Like *Agave murpheyi,* it is suspected of being an ancient Indian crop plant that has gone wild. The pungent chillies of this plant are widely used by the Tohono people for seasoning food and they have usually been abundant enough to trade or sell.

The bulb of *Dichelostemma pulchella,* which was of primary important to the Paiute of Owens Valley in California (Lawton et al., 1976), was used under the name **hahd** as food by the Tohono O'odham, Castetter and Underhill (1935: pp. 17–18) going so far as to use the common name "Papago Blue Bells" for it. Although these authors state that it was bad tasting, the present author (F.S.C.) relishes these bulbs and seeks them out in the spring. Another bulb plant, know as "Ajo" in Spanish or "Desert Lily" in

English, *Hesperocallis undulata,* although seemingly overlooked by Castetter and Underhill, was quite a famous plant, being not only eaten by the Indians (Kearney and Peebles, 1951: p. 177), but giving its name to the town of Ajo, Arizona. This may have been the **rsat** which grew near Santa Rosa and was important enough to be traded to the Akimel people, but which Russell (1908: p. 93) could not identify.

Wild potatoes, known as **shahD** (*Hoffmanseggia* and perhaps a wild *Solanum*), were also eaten, as were wild onions, **sipuia** (*Allium* sp.) and the tuber of **ho'ok wah'o,** the Night-Blooming Cereus (*Peniocereus greggii*). Although Apaches used this Cereus as one ingredient in a stupefying drink, Castetter and Underhill (1935: p. 18) have reported use by the Tohono only to quench thirst when raw or as a food when baked and peeled.

Hunting and Animal Husbandry. Tohono men and boys had much the same hunting skills as the Hiach-eD people. Aside from the traditional subsistence patterns of the Tohono O'odham, these people adopted the raising of livestock which had been introduced by Father Kino and succeeding Europeans. Raising cattle and chickens became important. A blending of traditional and new culture resulted in the discovery that Saguaro seeds could be fed to chickens as a nutritious supplement. This practice proved quite effective and won at least one 4-H ribbon for a Tohono O'odham youngster. For a number of years Tohono people kept Tucson stores well-stocked with Saguaro seeds and Anglos bought them for use as chicken feed.

Use of Plant Materials For Housing. The traditional house or **kih** of the Tohono people was a dome-shaped brush structure although wattle and daub on a Saguaro rib frame was also used. Crosswhite (1980) theorized that houses utilizing large quantities of Saguaro ribs might have been characteristic of cold eras when large numbers of Saguaros died from freezing and the ribs were available. Saguaros seem not to have been killed or mutilated by the Tohono, even for housing. Lumholtz (1912) described a kih with framework of Mesquite posts with two to four uprights in the middle supporting the roof "made of sahuaro ribs, surmounted with greasewood twigs and some large coarse grass called sacate colorado." Generally this covering of Sacaton Grass (*Sporobolus* sp.) and "greasewood" (i.e. Creosotebush, *Larrea tridentata*) was kept in place "by hoops of ocotillo inside and outside, placed at intervals of eight or ten inches." The top of the house was covered with earth. A small huhulga kih was provided as a temporary residence for a menstruating woman and was the site where she usually accomplished time-consuming tasks such as weaving baskets.

Cooking was not ordinarily done in the house used for sleeping but rather a respectable distance away in a "brush-kitchen." This structure was round and surrounded on all sides, except for the doorway, by walls of dried plant material,—often Saguaro ribs or branches of Ocotillo (*Fouquieria splendens*) supporting a wind-break of corn stalks or grass stems. Since this kitchen had no roof it was suited for use on sunny winter days and through much of the remaining time of the year except summer.

During the heat of summer, cooking and daytime chores were pursued under the **watto,** a ramada with upright Mesquite posts and a roof but no sides. Thus, the domestic housing of the Tohono people, aside from the huhulga kih, usually consisted of a cluster of three similar structures, a complete sleeping kih, a roof-less kih for kitchen work, and a side-less kih for household activities and summer shade. When cattle began to be raised, a stockade-like fence of Ocotillo stems or Saguaro ribs had to be built around the house to keep the livestock from eating the grass of the structure. It also provided something of an enclosed space for domestic work.

Although stems of **melhog** (Ocotillo) were cut from living plants by the Tohono people, Saguaros were not mutilated or killed, probably for religious reasons or out of respect. The skeletal ribs from dead Saguaros were readily used however. Tohono people depended on bacterial necrosis of Saguaro (resulting from *Erwinia carnegieana*) for a natural process of rotting which allowed the wooden skeletal ribs to fall away so they could be used as construction materials and for household purposes. This bacterial rot also allowed the callous "boots" from dead Saguaros to be separated out and used as containers or household implements.

Plants Used in Basketry. The Tohono O'odham relied on basketry for a variety of purposes (Shreve, 1943; Kissell, 1916; DeWald, 1979). A plaited basket with a twill weave was made from split leaves of **uhmug,** Sotol (*Dasylirion wheeleri*), often incorrectly referred to in the literature as *Agave.* Leaves were long and ribbon-like and were cut from the plant, split into strips and scraped against a grooved stone to remove the prickles and to smooth the surface. Brugge (1956) found that such a **huari** basket was apparently common to all Piman peoples. It was used for storage of dried products and was not water-tight. In fact, the spaces between weaving elements allowed this basket type to be used for straining liquids or sifting dry products. The same basket weave was also used for making sleeping mats when animal skins were not placed directly on the ground. Another use for such Sotol mats was as surfaces for drying plant products in the sun. Small plaited baskets of Sotol were used for storing fetishes and enemy scalps. Plaited Sotol baskets were probably more characteristic of the Tohono O'odham than the Akimel because the former are known to have traded these baskets to the latter.

Another type of basket, very similar to one made by the Akimel people and using materials obtained from the Akimel people, was a tightly coiled type manufactured by weaving strips of bark of **che'ul,** Willow (*Salix gooddingii*), over a foundation of split rods of **uDawhag,** Cattail (*Typha angustifolia*). Black designs were woven into the basket using **ihug,** Devil's Claw (*Proboscidea*) fiber. Willow baskets would swell up when wet and were used whenever a shallow water-tight vessel was needed. Cultural uses of willow baskets which seem to have persisted the longest in history were for gathering moist Saguaro fruit and for distributing Saguaro wine. As a general container for liquids we usually think of pottery as being more appropriate than baskets. In other cultures the use of water-tight baskets in place of pottery indicates a people who moved about so much that pottery was apt to break. The use of water-tight baskets in the nawait (Saguaro wine) ceremony could possibly then date from a time when the Tohono were more migratory and possibly not agricultural. A theory that these people followed the Saguaro into their present habitat and then became agricultural seems consistent with the use of water-tight baskets and certain wording in the speeches of the nawait ritual.

The willow basket has now generally been replaced by the metal or plastic bucket. Coils of willow splints were obtained in trade from the Akimel O'odham although some willow could be found by the Tohono people where it grew at permanent watering spots. Most such sites were controlled by the Akimel O'odham, by unfriendly Yumans or war-like Apaches, however. After Mexicans and Anglos asserted ownership of most permanent watering places where towns could be built, the sources of willow for Tohono O'odham basketry became limited to trade with the Akimel people. This too eventually came to an end when the San Carlos project permanently altered the Gila.

Advent of the commercial bucket at the same time willow became unavailable made water-tight baskets unnecessary. The type of coiled basket which has survived with the Tohono people is one which utilizes local materials which are still plentiful, **moho** or Beargrass (*Nolina*), **takui** or Soapweed (*Yucca*), and Devil's Claw (*Proboscidea*). Such a basket, when tightly coiled, resembles a willow basket but is not water-tight. Such baskets are used nowadays as trays, sewing baskets or decorative containers for dry materials so that the water-tight quality is not needed. The result is that the sewing element (*Yucca*) woven over the split Beargrass coils is applied in an open coarse pattern to save time, to make a pattern, and to intentionally expose the Beargrass foundation. Larger baskets with such coarse stitching seem to have previously been used only as granary baskets (Kissell, 1916).

Although basket manufacture among the Tohono O'odham was women's work, the men went along on collecting trips organized to obtain basketry material of Beargrass in order to protect the women and their children from the Apaches (Bell and Castetter, 1941: p. 62).

Other Considerations. In historic time it has been commonplace for O'odham of the Tohono habitat to travel to work as agricultural laborers for the Akimel people. Castetter and Underhill (1935: p. 5) went so far as to state in the 1930s that there were only a few months of the year during which many of the Tohono people could be found at their field or well residences. These authors observed that the Tohono people might go to the Gila villages to help harvest wheat "working on shares" and return again to the Gila in July to help pick the cotton. The Gila people were not the only ones helped, Castetter and Underhill (1935: p. 5) noting that "The Altar Valley in Sonora was productive all the year and families from the north travelled down there to work for their richer kinfolk." Since traditional Tohono subsistence allowed people to be away from their homes for long periods of time, one naturally wonders if the pattern of working for whatever people controlled the fields of the Akimel habitat, might not have been well established even in prehistoric times.

Several actions of the United States government have broken down many of the cultural differences between the Tohono and Akimel people. For example, at one time the San Xavier school was closed and youngsters were encouraged to attend the Sacaton boarding school in the Gila River Akimel O'odham community. A government program in the 1920s and 1930s produced numerous deep wells with electric motors to make water more available throughout the homeland of the Tohono people. This greatly ameliorated the harshness of the habitat and eventually broke the pattern of transhumance for most families.

Gradually the Tohono O'odham tended to give up the winter home with a southern exposure in the little mountains in favor of the flatlands of the valleys even though cold air settles there at night. They adopted sturdier and warmer houses, began wearing cotton and other store-bought clothing, and a few began to grow winter wheat. Fewer and fewer continued practicing the run-off agriculture of summer. The Tohono O'odham link with Saguaro through perpetuation of the nawait ritual, which was at the heart of the Saguaro harvest and crop cycle, preserves a relictual subtropical element of their culture which reminds them of their older agricultural and fruit processing heritage.

The Akimel O'odham

Akimel O'odham who survived into the 20th century live on the Gila River in central Arizona between Coolidge and Phoenix and on the Salt River north of Mesa. The settlement of the Salt was made in the 19th century from the Gila at the request of Mormon settlers who wanted a buffer of friendly Indians between them and the Apache. The Akimel people were once distributed in a broad ecotone on either side of the eastern boundary of the Sonoran Desert where rainfall is naturally high. Fontana (1974) has traced them to occupancy on the San Pedro River, Santa Cruz River, Rio San Miguel, Rio Magdalena, Rio Concepcion, Rio Altar and possibly between the Rio San Miguel and Rio Sonora.

An extremely valuable inventory of plants used by the Akimel people was collected by Frank Russell from the Gila River people in 1901 and 1902. By this time the favorable Akimel habitats along other rivers had largely been taken over by non-Indians. Although Russell's information appears to be very good and thorough, it suffers from five potential defects. 1) Since it was collected from people who had contracted to one small part of one river, it might not be broad enough a sample to accurately define plant usage by the previously more vigorous and wide-spread Akimel culture. 2) Although Russell's informants attempted to "tell it like it was" within the limits of human memory, they obviously could not paint a picture much more pristine than what existed about A.D. 1860. But by this time there had already been extensive Hispanic acculturation and contact with Anglos which must have caused loss of some original culture. 3) Russell's chief informant on Akimel O'odham ethnobotany, Sala Hina, who "had undergone a long and exacting training in practical botany," was the daughter of a Kohadk father of the Tohono facies, although presumably her mother was of the Akimel facies. 4) At the time of Russell's work there were Tohono O'odham families living with the Akimel people.

Russell's chief interpreter, José Lewis, who Fontana (1975) has credited for much of Russell's ethnographic data, was apparently one such Tohono person. 5) A considerable degree of desertification of the shrunken Akimel habitat had already occurred by the time of Russell's visit because of Anglo water use upstream.

What emerges from reading Russell's book today is that the Akimel people had a distinctive riverine culture and that the potential defects listed above, rather than erroneously magnifying the distinctness of the culture, would tend to obscure it. That the Akimel culture nevertheless comes through strongly in the data, suggests that significant real cultural differentiation between Tohono and Akimel facies had occurred, presumably in the interval between the Salado-Hohokam extinction and settlement of the region by Mexicans and Anglos. Interestingly, the version of how Elder Brother's people marched on the pueblos of the Gila River published by Saxton and Saxton (1973) tells the way in which the victors divided the newly acquired land, the Akimel habitat going to people from the south who were already at the Akimel level, and the Tohono habitat going to their compatriots who were at the Tohono level.

A map of Akimel O'odham sites in historic time reveals that the Gila River contingent represented a westerly arm of the total distribution of the Akimel facies. Some of the Gila River people repeated a tradition to Russell (1908) that they had come from the east. Indeed, some of their ancestors even in historic time were documented as having lived east of the Sonoran Desert along the San Pedro River.

Haury's (1976) contention that the Akimel O'odham represent the descendents of the prehistoric Hohokam culture is problematic. Hayden's (1970) theory that some of the Hohokam survived as prisoners of the O'odham invaders and that the descendents of those survivors might represent the **Buzzard moiety** of the Tohono people and the **Red Ant moiety** of the Akimel people, although fascinating, assigns a rather recent origin to the entire moiety system. A variant hypothesis whereby one moiety might represent descendents of O'odham toilers who had been subjugated by the Hohokam and the other moiety descendents of invading O'odham from deeper down in Mexico, might deserve some consideration. This latter theory would not require the Hohokam to have spoken an O'odham language, as seemingly the other theory would. Possible impacts of the ancient Hohokam and Salado cultures on the O'odham will be discussed in a later section.

Control of the Gila River and Desertification of the Floodplain. Mowry (1860), in a report to Congress, wrote "There are some fine lands on the Gila and any extensive cultivation above the Indian fields will cause trouble about the water for irrigation and inevitably bring about a collision between the settlers and the Indians." As the water supply of the Akimel O'odham began to be threatened by Anglo canals upstream, the director of the U.S. Geological Survey reported that "if the water supply from the river be shut off, the Indian reservation would become uninhabitable" (Lippincott, 1900). Nevertheless, this is essentially what did occur. The great flexibility of the O'odham culture was demonstrated by the fact that the Akimel people were able to survive essentially at the Tohono level for a number of years when water was scarce.

It took many years for the United States government to rectify the situation but eventually the San Carlos project was established by the government and the large Coolidge Dam was established far upstream to control the Gila so its waters could be more equitably doled out to Anglo and Akimel people alike. The Anglo town of Coolidge was built adjacent to the lands of the Akimel O'odham, being separated from the ancient Casa Grande ruins by the canal which brought the life-giving water. It was at Coolidge that the present author (F.S.C.) grew up and went to school with Akimel O'odham youngsters, and like them marvelled at the Hohokam potsherds and artifacts that could be found along the Gila.

Unfortunately, the San Carlos project once and for all separated the Akimel people from their riparian habitat even though it did make irrigation agriculture once again possible. The project so thoroughly regulated the water of the Gila that the river became dry in the vicinity of the Akimel villages and the lush vegetation of the floodplain simply died. The former greatness of the Gila is hinted at by the fact that this tamed riverbed sometimes flowed a mighty torrent merely from runoff waters which reached the river between Coolidge Dam and Coolidge. After such heavy rains the residents would congregate on the banks of the river. The novelty of water in the river made this a real event.

Agriculture. When J. Ross Brown passed through the Gila villages in 1864, he made observations on Akimel O'odham agriculture (Brown, 1869). Travellers passing through Arizona were being fed by the Indians even prior to 1858 when the Overland Mail stagecoach lines established a stop there. The successful nature of Akimel O'odham agriculture is indicated by the fact that in the first year of this transportation company's existence it purchased 100,000 pounds of surplus wheat from these people. By 1861 the annual purchase was up to 300,000 pounds of wheat, 50,000 pounds of corn, 20,000 pounds of beans and large quantities of dried and fresh pumpkin (Brown, 1869). The villages of the Akimel O'odham were along the route by which Anglos settled California. It appears that food produced by these Indians was being used at stage stops up and down the line, probably all the way into California!

In 1862 the entire California Column of the U.S. Army, charged with protecting the western United States from the Confederacy, about 1,000 men strong, received their food "for many months" from the Akimel O'odham (cf. Brown, 1869). To the U.S. government alone in that year these people sold over **1,000,000 pounds of wheat,** aside from substantial quantities of "pinole, chickens, green peas, green corn, pumpkins and melons."

The productivity of Akimel O'odham fields was discussed by Brown (1869). The people planted wheat in December and January and harvested it before the summer rains. The same fields were then planted to corn, pumpkins, melons and other vegetables for a second crop. Both cotton and tobacco were planted "when Mesquite leafs out" in early March. Russell (1908: p. 76) asserted wheat to be the principal crop of the Akimel people at the turn of the century and that four varieties were known to them. They ground it to flour on the metate and made heavy loaves weighing ten to twenty pounds each. Tortillas and doughnuts were also made. Pinole was prepared from parched and ground wheat or from wheat which was first boiled and then parched and ground. The Akimel people also "distinguished half a dozen varieties of maize, to which they have now added the large corn brought by the Americans ... When gathering corn the women lay aside the best ears for seed ... " (Russell, 1908: p. 90). The

About 50 Akimel O'odham men and 20 wagons working at the water intake area of their irrigation canal near Olberg on the Gila River in 1915. Wagons are discharging large quantities of brush, perhaps **Pluchea sericea,** *to be used in repairing the weir. Photograph by botanist H. L. Shantz, former President, University of Arizona.*

Akimel people preserved melons all the way into January "by burying them in the sands of the river bed" (Russell, 1908: p. 91). Other cucurbits were preserved by cutting them into strips and drying them.

Brown (1869) was the first to suggest that silt from the irrigation waters renewed the fertility of the fields. He discussed how in 300 years of recorded history the same fields were known to produce bountiful crops each year without addition of manure or fertilizer. Traditional Akimel O'odham agriculture did not require rotation of crops, "the soil being so rich from silt which is periodically deposited by the river at flood stage that the idea of exhausting it has never occurred to them" (Russell, 1908: p. 87).

Akimel O'odham irrigation practices were described by Rea (1979a). By means of brush dams or "weirs" across the Gila River, they channelled water into canals which often ran for miles through level fertile terraces of the floodplain. An array of fields, canals, ditches and fence rows increased the biological productivity of the floodplain. This enhanced riverine environment provided habitat for game, encouraged edible wild plants and provided pastures for grazing stock in addition to allowing crop production on a regular basis.

Each Akimel family cultivated from one to five acres of land (Russell, 1908: p. 87). When a new piece of land was brought under irrigation, "a committee of six men was chosen to make allotments to those who had assisted in digging the ditches" (Russell, 1908: p. 88). The Akimel people waited until floodwaters turned **"half way muddy, half way clear"** (Rea, 1979a) before using the river's water for irrigation. Only this type of water would renew the fertility of the fields without leaving a muddy deposit of adobe which would crack on drying. After Father Kino introduced winter wheat to the southwest, the agriculture of the Akimel O'odham became more productive. The impact of winter wheat on the culture of the Akimel people is indicated by the fact that although one of Russell's (1908) informants in 1902 gave the traditional "Saguaro Harvest Month" (June) as the beginning of the O'odham year, another already used "Wheat Harvest Month" for May and considered this the beginning of the Akimel O'odham year. Usually the river flooded each year from snow-melt in the mountains in late winter and spring, just at the right time to provide water for crops which had been planted in winter.

Father Font described the Gila River Akimel people and their fields in 1775. The fields were "enclosed by stakes, cultivated in sections, with five canals or draws, and are excessively clean ... [These people] are not restless and nomad like other races, for to maintain themselves in their towns with their fields they themselves have contrived to hold and control the river. I also saw how they wore cloaks of cotton, a product which they sew and spin ... "

Although fields of the Akimel people might accumulate alkali "which rises to the surface in an efflorescence that resembles snow in appearance" (Russell, 1908: p. 87), the people "flooded the tract repeatedly and in this way washed the alkali out of it." Perhaps this process of leaching was mistaken by early writers who misinterpreted it as sloppy agriculture practice. "The testimony of the early writers is to the effect that they possessed canals larger than they required and that the waters flowed away from the fields in volume scarcely diminished from that of the head gates."

The Concept of the Second Garden. Rea (1979a) pointed out that biological activity, productivity and diversity increased due to the edge-effect in the ecotone where broad-leaved river woods and low desert scrub came together in complex associations with Akimel O'odham fields, fence-rows and canals. The present author (F.S.C.) has noticed that tail-water which existed from an Akimel field when it was irrigated, not infrequently was allowed to flow out and even sheet across the desert to produce a "second garden" of wild and semi-wild greens. The degree to which it was a separate entity varied. Sometimes it was merely a weed patch at the end of the field. Often it was rather extensive. This second garden didn't require the intensive cultivation of the planted field and generally was not leached of salts like the primary field. As a result most plants were relatively salt-tolerant. Nevertheless, some agricultural management seems to have occurred. Any weeds which were not edible were eliminated when time permitted so that the others would grow better. Plants were harvested for use as greens when young and tender. Older plants which had not been picked in time to eat were intentionally allowed to go to seed for the next year's self-sown crop. Edible plants of the second garden were encouraged to seed in as weeds along the irrigation ditches and in waste places. In some locations these places probably constituted the extent of the second garden. Because the Akimel people had more of an opportunity to have a second garden than did the Tohono, they seem to have kept the primary field relatively clean of even edible weeds. In this regard, it should be noted that early explorers commented on how clean the Akimel people kept their fields.

As is often the case when "wild" or semi-wild plants were irrigated by indigenous people (as for example in the Owens Valley of California), an Anglo might fail to realize that a form of agriculture was being practiced. Generally the "weeds" in the second garden of the Akimel people were plants such as Indian Potato (*Hoffmanseggia densiflora*), Amaranth (*Amaranthus palmeri*), Verdolaga (*Trianthema portulacastrum*), Lambsquarters (*Chenopodium murale*), Devil's Claw (*Proboscidea* sp.), Patota (*Monolepis nuttaliana*), Tansy Mustard (*Descurainea pinnata*), Peppergrass (*Lepidium* sp.), Chia (*Salvia columbariae*), and annual species of Saltbush (*Atriplex wrightii*) and Bursage (*Franseria* sp.).

The importance of the second garden was that it provided vitamins and minerals which were not so abundant in the starchy crops of the main field. Also, a well-managed second garden provided food to take home almost every day of the year, whereas the crops of the main field matured and had to be harvested at very specific periods of short duration.

Subsistence Ratios. If the Gila River contingent is at all characteristic, the Akimel O'odham could have lived on their agricultural products alone. The Sobaipuri contingent of the Akimel people was recorded by the Spaniards as excelling at growing crops on the San Pedro River. Father Velarde wrote that the Sobaipuri produced a wealth of cotton and foodstuffs (Wyllys, 1931). Even though they were good agriculturists, the Akimel people had numerous recipes for using Mesquite (*Prosopis velutina*), and perhaps one-fifth of their food came from this river floodplain tree. Although an additional one-fifth of their food can be estimated as deriving from hunting, fishing and gathering, most of the plants and animals utilized lived in the river-desert ecotone and in the enhanced environment of the Akimel O'odham canals, fencerows and fields. Wheat probably represented one-fifth of their food, corn and beans another fifth, with various agricultural products comprising the remaining one-fifth.

Utilization of Mesquite. Rea (1979b) showed how Mesquite was the most important native non-crop plant in the ecology and life of the Akimel people, calling it their "tree of life." Mesquite is characteristic of the riparian zone and floodplains of rivers and streams of the homeland of the Akimel people, occurring in large riverine forests called bosques. Rea (1979b) reported that one bosque extended for as far as six miles near the mouth of the Santa Cruz River. The Akimel people recognize the importance of Mesquite in their lives by naming one month of their calendar "Mesquite Leaves Month" when the tree leafs out in spring, and another "Mesquite Flowers Month" when it blooms as spring is about to change into summer.

Mesquite flowers could be eaten in May and the long thin green immature string-bean like pods could be eaten in June. However, the real harvest was not until July or August when the mature pods had fallen to the ground. When the pods were thoroughly dry they were gathered in enormous quantities and stored in granaries for later use. Stored pods were crushed as time permitted with a stone pestle in a wooden mortar made out of a two-foot log cut from Mesquite or **auppa**, Cottonwood (*Populus fremontii*). A sifting basket was used to separate flour from the crushed pod fragments. This Mesquite flour was the dried sweet pulp of the pods after the seeds and fiber had been discarded. A Mesquite loaf or cake was six inches or more thick. This **chuuk** was made by moistening repeated increments of Mesquite meal. The cake would keep through the year when thoroughly dry and hard. To eat this product it was necessary to break pieces off by hitting the cake with a stone.

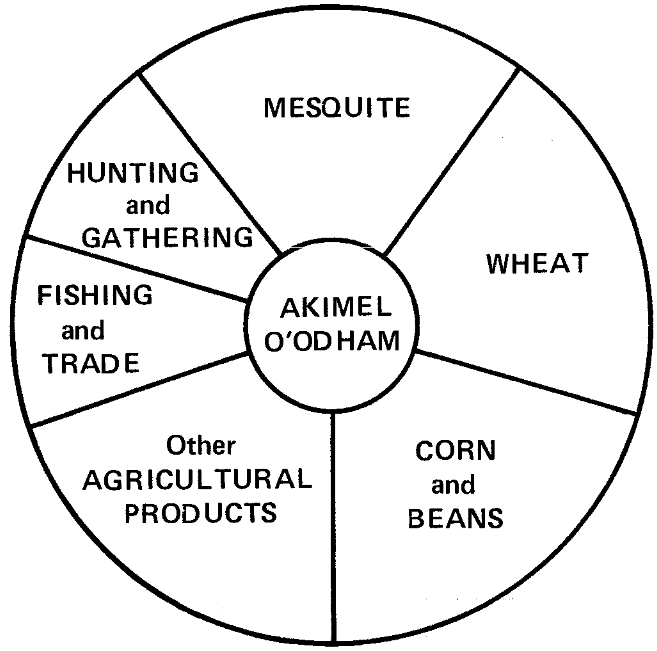
We also know other Mesquite recipes of the Akimel people from the research of Rea (1979b). A pudding made from Mesquite flour and water looked like butterscotch but was richer. Rea reported that this **vihuk hidut** tasted like Carob. Thick wheat tortillas were layered like pancakes with dried Mesquite pods in between, covered with water and cooked slowly for several hours until almost dry. The pods were discarded and the mushy **chuchumit** eaten. **Hawhawhi wichoda** was another dish. It was made by boiling dried Mesquite pods until soft, cooling, then adding whole-wheat dumplings and cooking until the dish thickened. **Vihok wongim chui** consisted of wheat pinole sweetened with Mesquite flour. A sweet drink prepared by soaking crushed Mesquite pods in water was called **vaa'o.**

Other Food Plants. Russell (1908: p. 103) explained the indifference with which the Akimel O'odham constructed their Saguaro fruit hooks as due to the fact that they "have not been so dependent upon the cactus in the past as have their nomadic neighbors." Although the Akimel people had a tradition of having used mescal from Agave as food, Russell (1908: p. 70) stated that mescal then was obtained from the Tohono people. According to Bell and Castetter (1941: p. 16), although the Akimel people had made expeditions into the mountains to gather fruit of *Yucca baccata,* frequently they received the preserved fruit in trade from the Tohono O'odham. Russell (1908: pp. 75–76) observed that though the Tohono people preserved fruits of Prickly Pear [*Opuntia phaeacantha*] by either making a syrup or by drying the fruit like that of Saguaro, the Akimel people were said to make "no further use of it than to eat it raw." Seeds of **tokih,** Cotton (*Gossypium hopii*), were parched and eaten by the Akimel O'odham or else thrown in with Mesquite beans when they were pounded in the mortar.

Hunting and Fishing. Big game such as Mule Deer and Bighorn Sheep were hunted, but these had perhaps become less common in Akimel O'odham time than during Hohokam occupation of the region (cf. animal usage in Haury, 1976). The floodplain of the river yielded Cottontail Rabbit (*Sylvilagus auduboni*), Jackrabbit (*Lepus californicus, L. alleni*), Raccoon (*Procyon lotor*), Gambel's Quail (*Callipepla gambelii*), Cotton Rat (*Sigmodon hispidus*) and Pack Rat (*Neotoma albigula*) used as food (Rea, 1979a). Fence-rows built around the fields greatly enhanced the habitat for these small animals. The fences consisted of a six-foot width of spiny brush stacked head-high. New branches were added at the top as the lower layers deteriorated. Russell (1908) recorded that Cholla Cactus (*Opuntia* sp.) was piled around the fields to discourage night marauders. Aside from the fields yielding small game, the present author (F.S.C.) observed that fish could be gathered in fields where they were left stranded from irrigation waters.

Traditionally the niche in childhood life of Akimel O'odham boys was a form of half play and half work whereby they played in the fields hunting small game for the family's larder, guarding the crops from birds and animals and amusing themselves "by a dozen games that develop skills in running and shooting with the bows and arrows which scarcely leave their hands during their waking hours" (Russell, 1908: p. 92). In contrast to the dietary habits of the Hiach-eD people who were known to eat reptiles, Russell (1908: p. 83) reported that among the Akimel people "Snakes are not eaten, even in times of famine, and the idea of eating lizards is repudiated with scorn."

Trade. Items brought by the Tohono to trade with the Akimel people were labor, Saguaro seeds, dried Saguaro fruit, Saguaro syrup, mescal in flat roasted cakes, Agave syrup, Prickly Pear syrup, wild gourd seeds, small chilli peppers, acorns, bulbs of wild lily, baskets of Sotol leaf,



Estimated subsistence ratios for the **Akimel O'odham,** *river-irrigation agriculturists, about 1750* A. D.

Sotol sleeping mats, burden baskets, Maguey fiber for ropes, dried mountain sheep meat, dried deer meat, deer tallow in small ollas, buckskins, cords of human hair, red ocher, yellow ocher, and salt (Russell, 1908). In addition, pottery made by the Tohono people was traded to the Akimel O'odham. Russell (1908: p. 92) noted that a basketfull of beans or corn was worth one cooking pot. "From the seventeenth century the Pimas sent well-armed bands through the Apache cordon to trade at the Spanish and Mexican settlements of Sonora. The latter also sent trading parties from Tucson and other towns to barter with the Gileños" (Russell, 1908: p 94).

Architecture. Houses of the Akimel people were similar to those of the Tohono except that riverine plants were used in the construction. The standard kih had forked posts of Cottonwood (*Populus fremontii*) or Mesquite with a lighter framework of Willow (*Salix*), upon which was laid Cattail (*Typha angustifolia*), wheat straw or cornstalks. "Light willow poles are set half a meter in the ground around the periphery of the circle, their tops are bent in to lap over the central roof poles, and horizontal stays are lashed to them with willow bark. The frame is then ready for the covering of brush or straw. Although earth is heaped upon the roof to a depth of 15 or 20 cm. it does not render it entirely waterproof" (Russell, 1908). Plaited mats were sometimes spread out over the exterior of the house (Fontana, 1974).

At the time of Russell (1908: p. 156) apparently each family had a rectangular storehouse with walls of either Seepwillow (*Baccharis glutinosa*), Ocotillo (*Fouquieria splendens*) or ribs of Saguaro (*Carnegiea gigantea*). The door of this structure, "made by piling up a great heap of unwieldy logs before the opening" and photographed by Russell, somehow reminds a person of the country of the

Pima Bajo or Tarahumara. Surely such a seemingly impractical door must have more religious, mythical or ethnic significance than real function.

Each village of the Akimel people apparently had a low rectangular council house that could accomodate as many as 80 persons. The last one was destroyed in 1902 (Russell, 1908: p. 155). Such a large structure was apparently never found in Tohono O'odham villages where ceremonies were customarily held out-of-doors. The Tohono ceremonial house was used for fermenting Saguaro wine and was rather small, the ceremonies actually occurring outside of it. There is some evidence that the larger council house of the Akimel people allowed the Saguaro wine ceremony to occur inside the house (Drucker, 1941).

Did the need to cooperate in digging canals and turning the water from the river require a large council house with "town meetings" or a water users association? In this regard, Father Font in 1775 mentioned that the Gila River people were having problems with their irrigation system but had told him that "to remedy this need they were all anxious to come together for a council and had already thought of sinking many stakes and branches into the river to raise the water so that it might enter the drains."

Basketry. Fine baskets were made using rods of Cattail (*Typha angustifolia*) for the foundation and Willow (*Salix* sp.) for the sewing element. A race of Devil's Claw (*Proboscidea*) with particularly long horns was cultivated by the Akimel people to provide black fibers used as weaving elements to impart design to these baskets. Baskets were cleaned of stains by rubbing them with Four-Wing Saltbush (*Atriplex canescens*), Desert Saltbush (*A. polycarpa*) or Quail Bush (*A. lentiformis*).

The Akimel people plaited basket-weave sleeping mats from Carrizo Cane (*Phragmites communis*) of river canebreaks. Large granaries placed on the roof of the kih or the watto were constructed from Arrowbush (*Pluchea sericea*) and Willow (*Salix gooddingii*). Large granary storage baskets, so large that the weaver had to stand within them, were made from coils of wheat straw sewn with strips of Mesquite or Willow bark. Sifting baskets used for cleaning seeds or straining plant pulps, were made from splints of willow tied together like miniature snow-fencing to which was added an oval rim (cf. Russell, 1908: p. 146).

Other Plant Uses. Russell (1908: p. 157) states that in primitive times the Akimel O'odham wore breechcloths (men) or knee-length kilts (women), "both made of the soft and flexible inner bark of the willow... After the adoption of the art of weaving, the cotton blanket was worn in winter, and in summer also by the women, who girded it doubled, around their waists with maguey cords, neatly woven belts, or merely tucked one edge within the other... As the blanket hung to the knees it might be converted by the men into baggy trousers by looping a cord from the girdle behind down between the legs and drawing it up front."

Akimel people used the roots of Rhatany (*Krameria*) to dye leather red (Russell, 1908: p. 118). Yellow pollen of Cattail (*Typha angustifolia*) as well as bright minerals were used to paint the face or body for dancing and ceremonies. Tufted ends of Arrowbush (*Pluchea sericea*) branches were used as paint brushes for ornamenting the face. The Kohadk gathered these branches in the Akimel habitat and took them south to trade in the Tohono habitat (cf. Russell, 1908: p. 104). Bell and Castetter (1941: p. 50) reported that when Sacaton Grass (*Sporobolus wrightii*) became scarce, the Akimel people began making their hairbrushes from *Agave* and *Yucca* as had the Tohono people. Warriors made their bows from supple springy stems of Wild Mulberry (*Morus microphylla*) obtained in the Superstition and Pinal Mountains. Ordinarily arrows were made from Arrowbush (*Pluchea sericea*). When this plant was not available, they bought *Yucca* arrows from the Tohono people (Russell, 1908: p. 96).

The Akimel O'odham made a dye from cochineal insects infesting Prickly Pear Cactus (*Opuntia phaeacantha*). Russell (1908) reported that war arrows were dyed at the ends with such cochineal dye. Wands of Greasewood (*Sarcobatus vermiculatus*) and Willow were used as paraphernalia in religious ceremonies. Russell (1908: p. 97) published an illustration of a wooden shovel used by the Akimel people for throwing the dirt out of excavations for canals. Cottonwood or Mesquite was used. The straight stems of Arrowbush were tied together like snow-fencing to make shelves, doors, bird cages and other utilitarian household items. The baby cradle of the Akimel people was made of Willow and cotton cloth. A piece of *Yucca* leaf frayed at the end was used as a brush to apply juice of Mesquite to decorate pottery before it was fired (Bell and Castetter, 1941: p. 50).

The Akimel Habitat as a Corridor

Intrusions of people into the Sonoran Desert followed river systems. A notable exception was the expedition which surveyed the U. S.–Mexico boundary following the Mexican War and the Gadsden Purchase. Indeed, this latter expedition was notable for its penetration of habitats of both the Tohono O'odham and the Hiach-eD O'odham. The color illustrations of these people in the present article are reproduced from the reports to the U.S. Congress of the results of this survey. Indeed, the Tohono and Hiach-eD habitats, by their relatively xeric nature, had been relatively impenetrable by outsiders.

Anglo settlers streaming across southern Arizona to California naturally followed the Akimel habitat, as did military excursions. The Spanish intrusion in the desert had been from one river system to another, the missions being built within the Akimel habitat. Apaches also heavily intruded the Akimel habitat from the east by means of numerous raiding parties. Previous to O'odham settlements in the Akimel habitat in about the fifteenth century and later, there had been a notable intrusion of Salado or related Puebloid culture and before this an immigration of the Hohokam. Before the Hohokam, the desert culture (cf. Sayles and Antevs, 1941; Haury et al., 1950), or that of the Amargosans (Rogers, 1966; Hayden, 1970), although nomadic, certainly used the water and plant resources of the Akimel habitat. In this regard, it is noteworthy that Haury (1976: p. 354) believed that an important Hohokam characteristic brought into Arizona was the ability to live *remote* from a natural source of water: "They, with their canals, founded villages many miles from naturally occurring water, a development shared by no other people north of Mexico in pre-Columbian times, and a kind of emancipation unique in aboriginal America." Thus, the normal pattern was to live near water. Unfortunately, the oldest cultures which utilized the lowest terrace of the floodplain probably occupied sites which were repeatedly washed away by floods.

The major difference between the tenancy of the Akimel habitat by the pre-Hohokam nomadic people and those sedents who immigrated in, was that the former undoubtedly ranged throughout the Akimel, Tohono and Hiach-eD habitats wherever permanent or temporary water was present in sufficient quantity to keep a family or even a single individual alive. The culture of the Hohokam was less of an adaptation to seasonal changes in the desert and more of a protection against them.

Christianization and Reduction of the Nomadic People

Spanish missionaries to the O'odham had an orderly program whereby people from the hinterland were concentrated at missions along the rivers to become sedentary and church-going. This was referred to technically as "reduction" of the Indians and had the very real goal of reducing their habitat so that they wouldn't move around. The idea was that the Indians would not need so much habitat if they were concentrated where agronomy and animal husbandry could be better practiced with crops and animals introduced from Spain. Supposedly if the Indians had all of their wants satisfied, they would not be aggressive. Spicer (1962: pp. 131–2) made it clear that Tohono people "from the poorer desert areas were drawn, not because of Spanish or Apache pressures, but for better living, into the missions of the center."

Desertification and Reduction of Akimel Habitat

Just as it is possible to point to historic records of movement of some O'odham from the Tohono facies to that of the Akimel, there are also records to document desertification of Akimel habitat and/or change of Akimel people to a Tohono subsistence level. San Xavier del Bac near present-day Tucson was the northernmost Spanish mission among the O'odham. During various times in history there were numerous comings and goings of O'odham into and out of a sedentary life at San Xavier. That the residents of San Xavier lived at a more or less Akimel level under the regime of the padres is rather certain. But with increased settlement of Sonora and Arizona up to the present, have come overgrazing, arroyo-cutting, lowering of the water table and desertification of much of the Akimel habitat in the Santa Cruz River valley. Nevertheless, the residents of San Xavier have apparently always considered themselves rather distinct from their compatriots further to the west. In this regard, Spicer (1962: p. 136) noted that the government agent in 1865 made a distinction between the two hundred people at San Xavier and the "nomadic" Papagos further west. Also, Spicer (op. cit., p. 144) in discussing the residents of San Xavier in the 1930s stated that they regarded themselves as "quite distinct from the 'desert people' of the Sells Reservation."

In apparent reference to overgrazing in the Akimel habitat of the Gila River, Russell (1908: p. 84) observed that "the once famous grassy plains that made the Pima villages a haven of rest for cavalry and wagon-train stock are now barren..." There is documented evidence for desertification having affected the Indians. For example, Russell (1908: pp. 20, 22, 23 25) referred frequently to a village named Ak Chin ("Akutciny") on the border of the sink of the Santa Cruz River. His oldest Akimel informants knew of it (p. 22), it apparently entered into Saguaro wine fellowship ceremonies with Sobaipuris of the San Pedro River (p. 23), it was considered an Akimel ("Pima") village (p. 25), was situated at the mouth of a wash (pp. 20, 22) where it survived on floodwaters for irrigation (p. 22) until it was abandoned about 1800 (p. 20). From Shreve (1943) it would appear that this village was ancestral to Kohadk. If so, the residents could be considered Akimel people who became desertified to the Tohono level.

Shreve (1943: p. 168), from information supplied by Alden W. Jones, traced the separation of the villages of Vaivo Vo and Chuichu from an Akimel heritage to a Tohono status as a result of behavioral change resulting from intrusion of the railroad in 1880. When the railroad was built, " . . . the Indians were pushed to both sides, so when the reservations were established, the groups that had settled in Chuichu and Vaivo Vo were separated from their relatives north of the railroad. From 1912 to 1932 these villages were under the administration of Sacaton, but since they were south of the white man's strip, they began to have more contact and intermarriage with Kohatk than with the Sacaton Pimas. In other words, the inhabitants of Chuichu and Vaivo Vo were the same as the Gila River Pimas until they were isolated in 1880 ... " The railroad obviously isolated these people not only from the Akimel O'odham but from the Gila River itself and must have precluded canal irrigation from the river. In 1932 the transformation was recognized politically and administration of the villages was transferred from Sacaton to Sells.

The fate of the O'odham who occupied favorable [Akimel] sites in the valleys of the Altar and Magdalena Rivers in Sonora was summarized by Spicer (1962: p. 133). Mexican farmers and ranchers laid claim to much of the best land. "Gradually crowded out of the Altar and Magdalena valleys into the desert, many [of the O'odham] emigrated northward into the Papago villages in the United States."

Was Differentiation of the Akimel Facies of the O'odham Ancient or Recent?

It is evident from historic records that even before missions were built in southern Arizona there were rather large populations of relatively sedentary O'odham called "Sobaipuris" already occupying Akimel habitats along the San Pedro, Santa Cruz and Gila Rivers (Spicer, 1962: pp. 126–7). Other rivers apparently had resident O'odham as well. Just how much of the culture of the Akimel O'odham derived from that of pre-mission O'odham and how much came from the Spaniards is a matter of much debate. Did the Sobaipuris learn river irrigation techniques from the Spaniards either directly or indirectly, or were they already accomplished irrigation agriculturists like the Hohokam and Salado who had occupied the Akimel habitat before them? Spicer (1962: p. 146) implied that the Akimel people of the Gila River had arisen more or less *in situ* [presumably from Hohokam ancestors?] when he wrote "They had lived along the Gila River from prehistoric times where they had irrigated their fields with an elaborate canal system. They had been augmented in the 1700s by the migration from the San Pedro River Valley of the Sobaipuris who had lived near the junction of the San Pedro and Gila rivers." At the opposite extreme, Castetter and Underhill (1935: pp. 3–4) have implied that major cultural differences between Akimel O'odham and Tohono O'odham are the result of greater contact of the Akimel people with the Spaniards, Mexicans and Anglos! Between these two extremes there is room for a third theory put forward below after a consideration of "those who are gone."

Those Who Are Gone

The Hohokam culture is best known from the excavations at Snaketown reported by Gladwin, Haury, Sayles and Gladwin (1937) and by Haury (1976). The best evidence available points to the Hohokam having immigrated to the Gila River region as a relatively full-blown culture which made pottery and brought river irrigation technology and seeds of Mexican food plants. Hayden (1970) theorized that these immigrants were closely related to the [O'odham] people who already lived in the Gila River region, being descended from their ancestors who had migrated south into Mexico and doubled back bringing several components of Mexican culture. The whole subject is rather fascinating when one considers that cerain proto-Uto-Aztecans who didn't double back would have been the ancestors of the Aztecs, a people who claimed to have descended from a simple migratory people.

Although the Hohokam had a very respectable history in the Akimel habitat for about 1500 years beginning in 300 B.C. (Haury, 1976), the "Classic Period" of Hohokam culture, such as seen at Casa Grande National Monument and numerous other sites, seems to consist essentially of an intrusion of another culture, the Salado or related Puebloid people, into the Akimel habitat that had been populated by the Hohokam. It is uncertain whether the Puebloid people amalgamated with the Hohokam or remained distinct. If indeed these two great cultures intermarried the heterosis could have produced a mighty people indeed. The ever-present question which people have asked for ages is "where did these people go?"

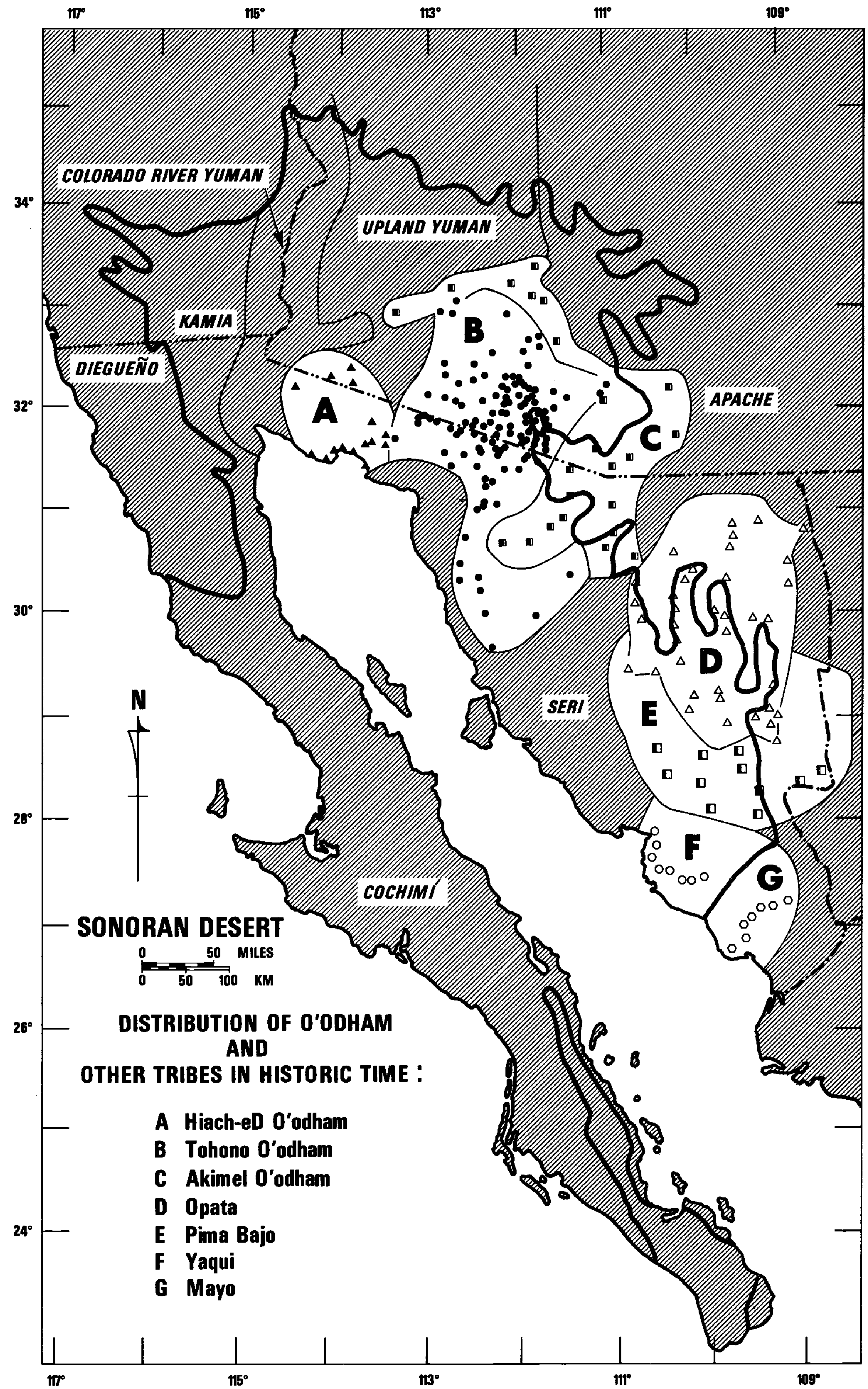
To answer this nagging question there have been two major theories: 1) that the ancient people did indeed migrate away, and 2) that they didn't go away at all but that the Pima and Papago are their descendants. Haury (1976: p. 357), in arguing that the Pima are descended from these people states that any theory to the contrary "requires the removal of the latter from the area by about A.D. 1450 and the introduction of the Pimans with an impressively similar lifeway almost immediately." But this may actually be what did occur. If the Akimel habitat were left vacant, would not the Tohono people move into it and logically develop the culture of the Akimel O'odham?

Those who argue for the derivation of the Akimel O'odham from the Tohono O'odham and who believe that the O'odham have had a long and honorable residency in the Sonoran Desert on their own, are asked to prove it by telling what happened to the Hohokam. This is hardly fair. If the best students of Hohokam culture can't say where these immigrants came from, then perhaps we can be forgiven for not knowing what happened to them. How many legions of their men marched south when retracted and subjugated Toltec families called for assistance? We do know that there were cities [e.g. Texcoco] where the most highly advanced elements of Toltec culture had fused with less well-to-do "chichimec" [culturally less advanced] cohorts. In 1427 a weak group of agriculturists known as the Aztecs joined with Texcoco in a war againt the powers which had subjugated them. Although outnumbered ten to one, heterosis, youth, vigor and training of the allies prevailed and the rest is a part of history. During this entire century in Mexico there was much upheaval (including unprecedented flooding and freezing weather followed by long severe drought) with one city turning suddenly against another. For example, when a distant city killed 160 traders from the Valley of Mexico, the Nahua quickly sent legions out for retribution and subjugation. Was the restructuring of power in Mexico in the 15th century felt as far away as the Gila? Although it is easy to see Toltec influences in the Hohokam and Salado cultures prior to 1427, the extent to which any group of Mesoamericans actually held any sway over them is not known (cf. Haury, 1976).

Because the Hohokam, the Salado and the Akimel O'odham cultures have all been present in the same Akimel habitat in the Sonoran Desert, it has been only natural for people to think that one may have descended from the other. Although there may indeed have been considerable diffusion of culture from the Hohokam to the proto-O'odham on the one hand, which enabled the proto-Tohono people to better exploit their habitat through agriculture, and to Puebloid people on the other hand to enable the Salado and perhaps similar Puebloid people to better blossom forth, certainly as a standard convention the O'odham, the Hohokam and the Salado should be considered as three different units which may have had independent genealogic origins, may have spoken different languages, and may have not significantly exchanged genes one with the other. Although as a convention we may accept different phases of a culture at a site as pertaining to a single people, nevertheless the Hohokam, Puebloid and O'odham sites in the desert are too often separate.

As the Hohokam culture expanded, the neighboring recipient cultures must have expanded and prospered as well. Haury (1976: p. 355) characterized the Hohokam as having had a thousand years of ascendency, peaking from A.D. 700–900, with Snaketown having a gradual population increase which "reached a climax just before the village died, about A.D. 1100."

Map illustrating the distribution of **O'odham cultural groups in historic time** *in relation to other indigenous people of the Sonoran Desert and adjacent regions. Not all sites were occupied at all times. Base map of Sonoran Desert courtesy of Raymond M. Turner, U. S. Geological Survey. Data compiled by author (F.S.C.) from Russell (1908), Lumholtz (1912), Spicer (1962), Fontana (1974) and other sources.*


117°
115°
113°
111°
109°
34°
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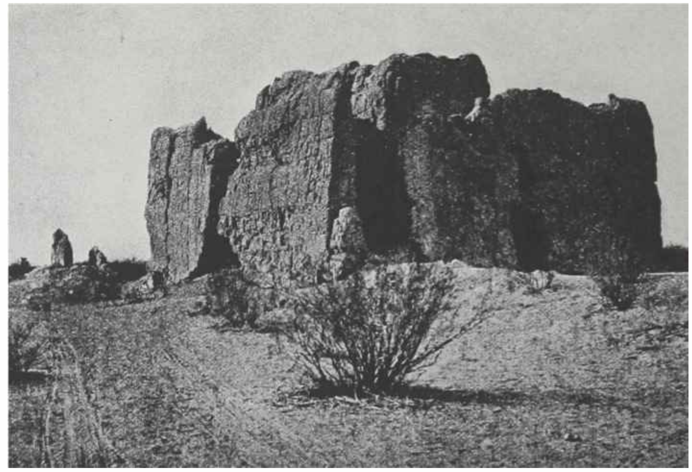
30°
28°
26°
24°
COLORADO RIVER YUMAN
UPLAND YUMAN
KAMIA
DIEGUEÑO
APACHE
SERI
COCHIMÍ
A
B
C
D
E
F
G
N
SONORAN DESERT
0 50 MILES
0 50 100 KM
DISTRIBUTION OF O'ODHAM
AND
OTHER TRIBES IN HISTORIC TIME:
A Hiach-eD O'odham
B Tohono O'odham
C Akimel O'odham
D Opata
E Pima Bajo
F Yaqui
G Mayo

Interestingly, A.D. 900–1100 was just the period when culturally enriched Puebloid people were increasing in population on the river headwaters in the highlands and were building their pueblos ever closer to the Hohokam heartland downstream! Did the Hohokam village of Snaketown weaken because pueblos upstream were diverting the river water for irrigation? Did the O'odham rise up against a weakened Hohokam? We do know that the Puebloid culture, exemplified by the ceramically visible Salado, lock-stock-and-barrel, complete with Pueblo architecture, polychrome pottery and inhumation of the dead, suddenly appeared in the heart of the Hohokam homeland to dominate until about A.D. 1450. Did the Hohokam and Salado come to an understanding and form a mutual defense pact?

While still in the highlands the Salado and their kin had been receiving products from Mexico from eastern trade routes. When they moved down into the desert they probably had much better access to the sea shells of the Gulf which they had been receiving by a more indirect trade route. They were probably quick to exploit new trade routes. It was during their presence in the desert that many aspects of Mexican culture were imported. But was this not a logical extension of the course their culture had been taking? The Salado apparently had women who were good potters. Some distinctive styles of pottery were produced and seem to have been widely traded.

We can only speculate as to the demise of the Saladoans and/or their allies. After their cultural manifestations in the region broke in the fifteenth century there were apparently potters who continued to make Salado pottery, perhaps even into historic time (DiPeso, 1953: p. 262) near the region where Arizona, New Mexico, Sonora and Chihuahua come together. There were probably still some pueblo-dwellers in the Akimel habitat of the Gila and Salt Rivers when the O'odham people began to move into that habitat. The Akimel O'odham legend of the siege of the [Salado] pueblos in the valleys of the Gila and Salt reveals that a few of the pueblo people escaped by fleeing south to the Gulf of Mexico, thence through Chihuahua to pueblo villages in New Mexico (cf. Russell, 1908: p. 229). The logic of such an escape route is uncanny. The Saladoans must have known the Gulf well from trips to collect shell for necklaces. All they would have had to do is wait for puebloid compatriots from Chihuahua, who also collected shell, to guide them to a safe land. Such an exodus was probably only of women and children and although the O'odham may have known generally of their escape route at least as far as the Gulf and east to Chihuahua, they could not have very safely followed them further. Saladoans fleeing the Gila River region may have been incorporated in small numbers into various puebloid villages and in this regard Salado pottery has been documented in old strata at Zuñi and related sites (Steen, et al., 1962).

The Akimel O'odham legend of how Elder Brother's people laid siege to the [Salado] pueblos (Russell, 1908: pp. 227–9) reads much like Joshua and the battle of Jericho with very little effective resistance: "Elder Brother's greatest enemies were the people living in the large pueblos, the ruins of which yet remain scattered about the Gila and Salt river valleys. He and his supporters approached one of the easternmost of these pueblos on



the Gila, which is now known as Casa Grande [photo], singing... They attacked and defeated... then moved on..." to the next pueblo. Elder Brother is a deity-like personage (**I'itoi**) often met with in the O'odham stories of their life and customs. The legend published by Russell was detailed to the point of telling the order in which the various pueblos were attacked and each individual war song which was sung before attacking each pueblo!

DiPeso (1958) has theorized that there may have been some degree of amalgamation of Puebloans with the Sobaipuri and has even suggested that the **viikita** ceremony of the O'odham is a result of this amalgamation, the viikita being anamagous to a pueblo harvest dance in his theory. The evidence for Pueblo-Sobaipuri intermixture was given as the fact that Sobaipuri were known to have lived in fortified villages. Although this may be true, it probably was a matter of necessity, living as they did on the border of the Apache domain. With regard to the viikita, the most ancient form may be the ceremony as held at Quitovac which was moved there from the homeland of the Hiach-eD O'odham when the old men who had been in charge of it were afraid that it would be lost because the Hiach-eD culture was declining (cf. Lumholtz, 1912; Childs, 1954). This ceremony makes prominent use of Saguaro wine.

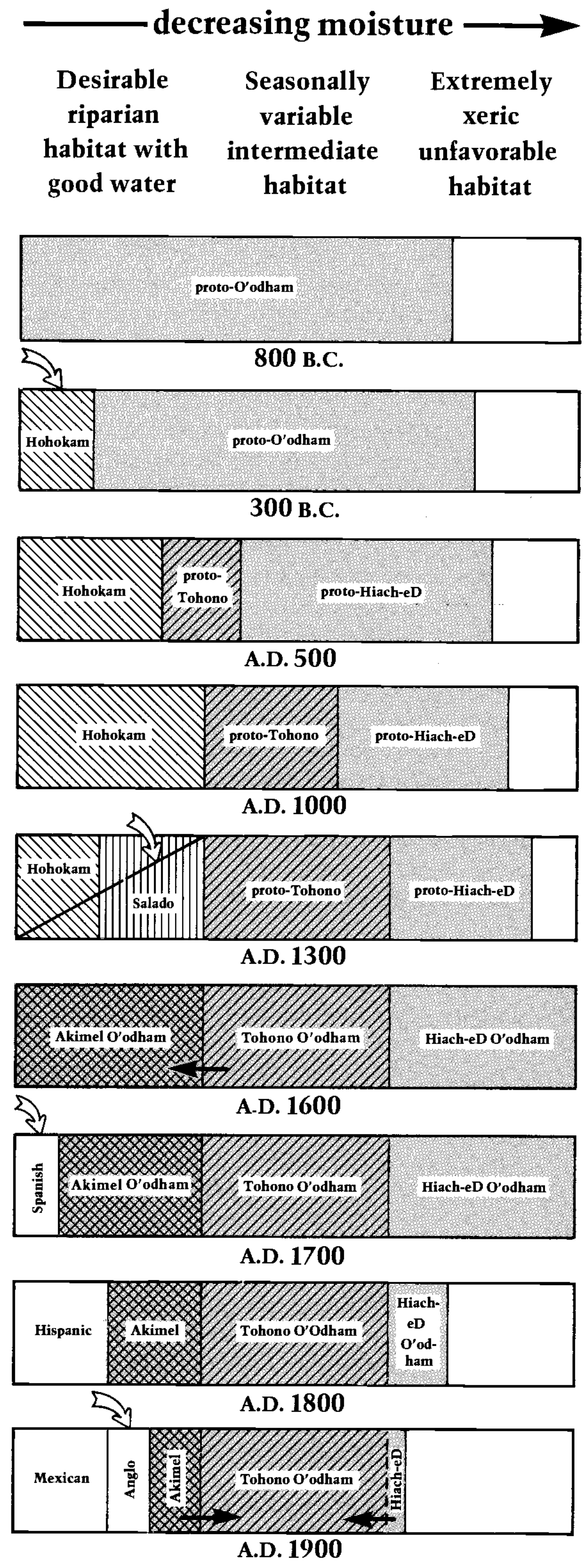
Bourke (1896: p. 114) referred to some Sobaipuris as "stone-house people" who were descended from cliff-dwellers. In other records the Sobaipuris are not distinguished from the Akimel O'odham. Since Bourke's description of the Sobaipuris brings to mind the Salado culture, which to some extent built stone houses and lived in caves, the question arises whether indeed the Salado could have in any way been ancestral to the Akimel O'odham. It should be remembered that "Elder Brother's greatest enemies were the people living in the large pueblos ... " The "stone-house people" were apparently only a few O'odham who had taken up residence in some old stone houses in Aravaipa Canyon. As further evidence of Sobaipuri/Salado dissimilarities, the opinion of the Sobaipuris themselves in the 1700's as to just who the Salado people of the 15th century had been, might be important. When Father Garces quesoned Sobaipuris as to who had built the abandoned [Salado style] ruins found from the Gila River east to the land of the Apaches, he was told that it was the Moquis [i.e. Puebloid people]. Furthermore the Sobaipuris said that they had gone to make war on the puebloid people, "and even though we attained unto their lands we did not surmount the mesas whereon they lived" (Garces, 1900: Vol 2. pp. 386–7).

Developing a Theory of Step-Wise Ecotypic Cultural Genesis Within the O'odham

If we ignore contributions from archaeology for the time being and look only at the major pattern of cultural differentiation within the O'odham when these people were being encountered by Europeans after A.D. 1600, there is a clear ecotypic basis for the three major cultural units. That is to say, the culture of the Hiach-eD O'odham clearly related to the ecology of their extremely xeric habitat, the culture of the Tohono people was fine-tuned to the ecology of the intermediate desert, and the culture of the Akimel people was closely tied to the well-watered riverine environment or to an ecotone between the Upper and Lower Sonoran Life Zones at the eastern boundary of the Sonoran Desert. This recognition on our part that the important pattern of cultural differentiation was correlated with the plant resources, the relative availability of water, as well as the severity of the habitat, is itself important. But there is some obligation to discuss the pattern observed in the "ethnologic present" with respect to the extinct cultures which have been reviewed above. Do these ancient cultures in any way help to explain the pattern of cultural differentiation of the O'odham?

In the previous section on "those who are gone" it was possible to paint a picture of the O'odham, Hohokam and Salado as ethnic groups which may have existed without significantly exchanging their genes. The complex cultures of the Hohokam and Salado, which predominate in the archaeological literature of the region, were considered unrelated to the O'odham by the ethnographer of that branch of the O'odham which most closely approaches these prehistoric cultures in trait lists (cf. Russell, 1908: pp. 87, 124, 149, 166). Nevertheless, there are powerful voices (Ezell, 1963; Hayden, 1970; Haury, 1976) to the contrary. Assuming for the time being that Russell was correct, then any apparent convergence of the Akimel O'odham culture with that of the Hohokam or Salado deserves comment. Do the traits in which the O'odham seem to converge with the Hohokam and Salado relate primarily to the environment? to religion? to household implements? to articles of personal ornamentation? to non-subsistence luxuries? to burial customs? to architectural styles?

The house of the Akimel O'odham, although distinctive from that of the Hohokam and Salado (cf. Haury, 1976: p. 74. Fig. 3.28) in overall shape as well as in orientation of the entrance, displays similarities imposed by the environment, similarities which easily could derive from use of some of the same native plants for construction. The O'odham practice of inhumation stands in marked contrast to the Hohokam practice of cremation. With regard to non-subsistence luxuries, the Akimel people lacked the wealth of copper bells, pyrite mirrors, effigies and figurines, or etched shell of the ancient cultures, but did have various rattles, scraping sticks, flutes, tobacco



Diagrams illustrating hypothetical positions of the O'odham on a climatogeographic continuum from wet to dry from the first millenium B. C. to A. D. 1900. The diagrams relate chiefly to the Sonoran Desert of southern Arizona exposed to strong Hohokam influences. The situation may have been different to the east outside of the desert or south into Mexico.

pouches and masks of their own culture. With regard to articles of personal ornamentation, the numerous necklaces, bracelets, hairpins, pendants and rings of the Hohokam and Salado were apparently not typical of the traditional culture of the Akimel people, the latter achieving their ornamentation chiefly from body painting and tattooing.

According to Russell (1908: pp. 124, 165) the designs on Akimel O'odham pottery and even basketry were copied from designs they saw on prehistoric pottery: "The potters aver that the designs are copied from the Hohokam potsherds that bestrew the mesas and that the symbolism is absolutely unknown to them." The shapes of the household items used by the Akimel people were different from those of the Hohokam and Salado, the similarities being that they were made from similar clay or plants, i.e. materials from the same environment. Stone axes left behind by the prehistoric cultures were occasionally found and utilized by the Akimel people until they were worn out, but knowledge of how to make them was unknown. With regard to religion or ceremony, the stone censors, schist palettes and pyrite mirrors of prehistoric context whenever found by the Akimel people were treated with respect, but they didn't know how to use them, let alone manufacture them (cf. Russell, 1908).

Only when it comes to subsistence and matters pertaining to the environment is there a strong similarity of Akimel O'odham culture with that of the Hohokam and Salado. Similarities are in agricultural methods and in utilization of native plants. Indeed, the ethnobotany of the Akimel people clearly demonstrates that they mastered essentially the same environment as had the Hohokam and Salado.

But even if the same living organisms were known to the Hohokam and O'odham, are there any ethnic differences that can be perceived in comparing how the two cultures looked at such organisms? Unfortunately there is no written record to show what living organisms were in the mind of the Hohokam. There are, however, abundant potsherds of red-on-buff Hohokam pottery and the designs not infrequently involve living organisms. Although O'odham pottery seems not to depict living organisms to any great extent, it is possible to obtain a sample of organisms in the mind of the O'odham by making a list of those mentioned in their myths and legends. As a final check on Hohokam-O'odham dissimilarities, the organisms depicted by the Hohokam were compared with the organisms in O'odham oral history. The two were found to be significantly different. The preliminary findings seem so promising that is is hoped that a detailed statistical study of this subject can be presented in the future.

Haury (1976) has presented convincing evidence that the Hohokam migrated into southern Arizona about 300 B.C., bringing canal irrigation technology and seeds of Mexican crop plants with them. Haury (1967) considered these farmers to be the "first masters of the American desert." If the ancestors of the present O'odham were indeed not the Hohokam, then how did these proto-O'odham obtain the seeds and agricultural technology of the Hohokam? Indeed, we might turn this question around and ask how the immigrant Hohokam obtained the O'odham knowledge pertaining to the utilization of native Sonoran Desert plants. Assuming that these two peoples did indeed have separate identities, present relationships would suggest that they must have been either neighboring sympatric or contiguously allopatric.

The first step in ecotypic differentiation within the O'odham in what is now Arizona may well have been the diffusion of agriculture from the Hohokam to the proto-O'odham with the natural limitations of the environment dictating which habitats of the desert could accept agriculture. This would have divided these people into a proto-Tohono facies which could grow crops and a proto-Hiach-eD facies which remained at the original hunting and gathering level.

The Tohono O'odham legend of how they got corn (Saxton and Saxton, 1973: pp. 27–44) states that a young man brought it from the east [the direction of the Akimel habitat and incidentally the Hohokam] and said "Tell all your relatives to come here and I will tell them where to plant this food ... At the arroyo mouths the land is moist and soft. Plant this food there." Eventually, according to the legend, "Those who were alert and industrious" took up the good land. "Coyote, however, had almost eaten up his seed. Being lazy and sleepy-headed, he had not yet looked for good land ... " (op. cit., p. 41). As Coyote finally decided to plant his seeds, there was someone in each of the good habitats to say "Get away! I've already taken the land here." This legend of the Tohono people might actually be a very vivid account of how the Tohono and Hiach-eD people came to diverge.

It is suggested that once the Hiach-eD people were limited in distribution to the sites which had no agricultural potential, they were forced to adapt closely to this less favorable segment of their previous environment. With increasing specialization in foraging activity would have come additional ecotypic adaptation and an ability to utilize some poor habitat, at least seasonally, which may have never before supported much of a human population.

Increasing populations of Hohokam and the later intrusion of Salado culture probably displaced Tohono people to less favorable agricultural sites at a time when Tohono populations must have been increasing rapidly as a result of their having assimilated techniques of agriculture. Tohono population shifts may have in turn pushed the Hiach-eD people further into the inhospitable wilderness.

As the Tohono people became increasingly adapted to the desert and became even more accomplished masters of its changing aspects, they prospered and strengthened while the less flexible Hohokam, specializing in growing large quantities of genetically uniform crops, were subject to any number of potential catastrophes. It is probably fair to assume that the trade and labor of the Tohono people with the Akimel people in the last two centuries may have had a counterpart in previous centuries of Tohono trade with and labor for the Hohokam and/or Salado.

In early centuries the Tohono was undoubtedly a recipient culture,—recipient of the largesse of the Hohokam. But as the Tohono culture came more fully into flower it must certainly have become better adapted to the desert than the Hohokam. If this is true, then in times of severe environmental change the Hohokam may have become more dependent on the Tohono people than has ever been previously suggested. This naturally follows from considerations of fitness versus flexibility.

The adaptation of the Hohokam was to be fit in a relatively narrow habitat. The adaptation of the O'odham was to be flexible in a relatively broad environment. Generally in populations of living organisms fitness is necessary for the present environment but flexibility is important to cope with changes in that environment. As fitness increases flexibility decreases and vice versa. Through ecotypic differentiation and adaptive radiation facies may become very fit for specific habitats while the overall population remains relatively flexible.

Regardless of the exact scenario, we do know that as the Hohokam declined the Tohono people seem to have pushed into the Akimel habitat to repopulate it. As these already flexible O'odham adapted their culture to the resources of the riverine environment, they apparently became the Akimel O'odham that we know today. It is suggested that by A.D. 1600 the differentiation of O'odham in the northern part of the Sonoran Desert into Tohono, Hiach-eD and Akimel facies was essentially complete, although adjustments probably continued to occur.

Although this theory may explain the observed pattern in the north, was there any relationship with the south? As the rim of Christendom in Mexico was pushed north and Indians were subjugated and forced into labor, there were shifts in population from south to north in advance of the Spaniards. Even as early as suppression of the Tepehuan revolt of 1616, many of these immigrants probably spoke an O'odham or O'odham-like language. There is evidence that the southern O'odham-speakers were as well differentiated ecotypically as the northern. Even the Hiach-eD habitat apparently became a haven for those who resented the encroachment of civilization and wanted to be left alone. Perhaps the Hiach-eD habitat could not have received these immigrants if some of the Hiach-eD people had not shifted into the Tohono habitat after some of the Tohono people had taken up the better Akimel habitat which had been occupied by the Hohokam and Salado.

Did fleeing immigrants assort themselves by habitat in the north and incorporate themselves into the proper cultural facies? Southern O'odham who were good at agriculture probably would have been welcomed by the northern Akimel people. Likewise, skilled hunters from the south probably were welcomed by the Hiach-eD people. But there seems to have been a pecking order or hierarchy among the O'odham cultural groups. Russell (1908: p. 200) observed that the Akimel O'odham " ... held possession of the best agricultural lands in their section of the Southwest, and were compelled to fight for the privilege." Also,we should remember the story of how corn came to the O'odham and how people became possessive about good land, saying "Get away! I've already taken the land here." It seems likely that a Tohono family would prefer an Akimel habitat if it were available and that a Hiach-eD family would prefer a Tohono habitat. Immigrant O'odham probably took the best they could get but probably not better than they had previously possessed.

Factors which may have promoted ecotypic cultural genesis in the O'odham are 1) time, 2) the presence of a natural wet-to-dry climatogeographic continuum in the Sonoran Desert, 3) a close relationship of the O'odham with the native plants and other components of their environment, 4) an ever-present desire to improve subsistence within environmental limitations, 5) a willingness to learn new technology in order to better utilize a habitat, 6) a tendency to readily move onto what is perceived as a better habitat, and 7) an ethnic awareness or social solidarity tied somewhat to the habitat and giving social status as well as tending to promote contact and intermarriage of people within their own habitat.

Did the Proto-O'odham Have Corn and Agriculture Before the Hohokam Settled in the Sonoran Desert?

The foregoing discussion assumes that agriculture was not being practiced in the northern part of the Sonoran Desert before immigration of the Hohokam about 300 B.C. Because of Manglesdorf's (1950) announcement in Scientific American that prehistoric corn dating back to 2000 B.C. had been discovered in Bat Cave, New Mexico by excavators led by graduate student Herbert W. Dick, many people generalized that corn was an established crop in the Southwest for two millenia before the birth of Christ. With this in mind it was not hard to envision the San Pedro Phase of the desert Cochise Culture as having corn and other cultivated crops, becoming sedentary as a result, and eventually giving rise to the culture seen in the lower strata of the Hohokam villages. If the Desert Culture had indeed given rise to the Hohokam, then it would be embarrassing for it to have persisted long enough to transform into the present O'odham unless the O'odham were thought of as descending from the Desert Culture *through* the Hohokam. Wasn't this the normal course of events, for one cultural phase to end and another to begin?

In struggling to obtain an ending date for the Desert Culture, McGregor (1965) concluded that different dates were possible depending on whether the culture was defined by a lack of agriculture or by a lack of pottery. He reasoned that if "it is regarded as ending with the introduction of occasional domesticated plants, then it must be terminated at about 2000 B.C. with the earliest introduction of corn into the Southwest." On the other hand, a prerequisite for the main thesis of the present paper is that the Desert Culture did not suddenly come to an end and certainly not by 2000 B.C. The Hiach-eD O'odham seem to have carried the main corpus of desert culture subsistence all the way to the beginning of the 20th century.

At the time Manglesdorf (1950) published on "The Mystery of Corn," the antiquity of the crop in Mexico was not known and he considered the Bat Cave corn to be the oldest known to man. Eventually Libby (1952), Jones and Fonner (1954) and others studied the Bat Cave corn and reduced the estimate of its age from 4,000 years before present to 2,600 B.P. or about 600 B.C. Nevertheless the belief that agriculture in the Southwest was of greater antiquity persisted among many members of the general public. Students of Southwestern Indian cultures now know that corn was apparently domesticated by 7,000 B.P. in Mexico, as evidenced by corn-like fossil pollen grains in the Valley of Mexico and early cave materials from Tehuacán excavated by MacNeish (Cutler and Blake, 1980). Considering that it may have taken 4,400 years for

the growing of corn to spread from Tehuacán to the people living at Bat Cave, then it can no longer be considered likely that maize agriculture was a cultural development which was either indigenous to or which explosively permeated the Southwest in a relatively few hundred years.

The present writer (F.S.C.) sees no evidence that *Zea mays* or any other Mexican crops were cultivated in the northern part of the Sonoran Desert (the O'odham homeland) before approximately 300 B.C. when the Hohokam arrived. Haury (1976) has argued convincingly that there was a two-prong movement of culture from Mexico northward in the first half millenium B.C., one path leading into New Mexico, the other into Arizona. Indeed, geography predetermined natural routes along which people moved in that day just as today, with one route extending up through Chihuahua to New Mexico and another (lower elevation) route extending up through Sonora to Arizona.

Although the New Mexico and Arizona prongs had many initial resemblances, this was undoubtedly due to the similarity of their roots in Mexico. A general idea seems to have once been fostered that there were extensive east-west ties. People thought that if there was corn in New Mexico by 2000 B.C., then it must have been present in southern Arizona at that time too because of east-west movement that was taken for granted. McGregor (1965: p. 150) summarized supposed [east-west] Hohokam-Mogollon relationships by reporting that "a careful analysis of the components of some of this plain pottery from both the Gila drainage and the Mogollon area indicated that it was essentially identical." Actually, significant east-west interaction between the New Mexico and Arizona regions seems not to have occurred to much extent until after the birth of Christ and then not on any significant scale until the Salado ascendency near 1000 A.D.

The cultivation of corn did not necessarily spread quickly from one people to another in the Southwest. Although the Paiute of Owens Valley, California practiced canal irrigation agriculture even into historic time, they never did adopt cultivation of corn despite its presence not far to the southeast. In fact they grew no truly domesticated plants, preferring to care for wild or semi-wild native species. From all of the discussion above, the present writer (F.S.C.) doubts seriously that Mexican crops were grown in the Sonoran Desert before brought there from a lowland source in Mexico in the first half millenium B.C. by the Hohokam. There would have been horticultural difficulties in trying to grow plants in the Sonoran Desert which had been selected for New Mexico climate factors. To postulate an introduction of crops into Arizona from the south (or from the east for that matter) prior to the coming of the Hohokam would merely introduce a fact not in evidence. Until there is evidence for such an introduction it should not be assumed.

Concluding Remarks

An ethnic group calling themselves O'odham peopled all segments of the dry-to-wet climatogeographic continuum in the northern part of the Sonoran Desert. By adapting closely to the environment, this group became differentiated into ecotypes each with a high degree of fitness to habitat but with the O'odham as a whole remaining quite flexible. The extinct Hohokam and Salado cultures which were associated with some of the same geography, but which lacked the flexibility of the O'odham, seem to have depended more on subjugating the environment than truly adapting to it. Subjugation probably provided leisure time and promoted contacts to the south. But these contacts may have brought them closer to the outside world and any number of unknown demands or relationships, taxes, tribute, pacts and diseases. It is suggested that these extinct cultures were developed by people who were ethnically separate from the O'odham.

While the O'odham may have borrowed features of these cultures which allowed them to better utilize their habitat, few parts of those cultures which did not relate to the environment seem to have been taken up by the O'odham. Although the O'odham may have accepted seeds of various crops (and technology for growing them) from the extinct cultures, they seem to have chosen not to adopt the lithic industries, shell industries, architecture, ball courts and other cultural hallmarks of those extinct peoples.

The pan-cultural ethnic and linguistic unity of the O'odham over a large geographic range and a respectable time depth, with clear ecotypic cultural differentiation, seems remarkable when compared with Yuman and Puebloid patterns. The Puebloid people were linguistically diverse but relatively uniform culturally, and although formally clannish, welcomed groups to live among them and share their technology. Frank Cushing, an anthropologist with the Bureau of American Ethnology, demonstrated that an Anglo willing to accept Zuñi culture could become one of them. The O'odham, on the other hand, seem from observations by Russell (1908) to have been obsessed with maintaining the purity of their heredity, killing babies born of American or Mexican fathers and babies of loose women. There was an abhorrence of what the O'odham people considered unnatural or a threat to the purity of their people. For example, Russell (1908: p. 185) states that they attempted to kill a grown man who had six toes.

It is believed that ecotypic differentiation is a better explanation for O'odham cultural patterns than intermarriage with foreign cultures. Within the O'odham, however, intermarriage between villages probably helped spread new plant uses, new discoveries and new technologies. The general O'odham culture benefited from ecotypic differentiation. There was a division of labor among the O'odham of the different habitats that resulted in the habitat-based facies working more effectively together for the good of all the O'odham than could have been possible if differentiation into Hiach-eD, Tohono and

Akimel facies had not occurred. The differentiation allowed more intensive exploitation of the environment. Some Tohono people regularly put up surplus Saguaro products to trade to the Akimel O'odham. The Akimel people regularly grew a surplus of crops to trade to the Tohono. The Kohadk facies of the Tohono people were excellent potters and traded their wares to other O'odham including the Akimel people. The Hiach-eD people by adapting to an unfavorable environment relieved pressures on the more favorable habitats and stood ready to repopulate the better habitats when conditions changed.

Different specialties apparently developed among the various groups of O'odham because of habitat differences but then may have become somewhat fixed along genealogic lines. For exampe, in Russell's judgement the Akimel people did not excel in making pottery. He thought that the best potters among the Akimel villages were of Kohadk descent. There are instances of people who were genealogically Tohono but lived in the Akimel habitat and yet excelled in Saguaro fruit processing. Likewise there are stories of people who were genealogically Hiach-eD, but who had been incorporated into the Tohono population, and yet still excelled at hunting and gathering of a Hiach-eD nature and even seasonally visited the dunes to prepare Sand Food (*Ammobroma sonorae*).

Although the O'odham differentiated themselves by habitat, they seem not to have thought of the habitat groupings as representing real ethnic separations. They were O'odham first and members of their own environmental cultural group second. When the people were more nomadic there were good opportunities for one group of families to meet another. This seems to have been call enough for celebration as long as the other people were O'odham too. One group would quietly send someone to find out all of the names of the other people. Then they would invite the other people to a joyous occasion with singing and dancing with each of their people temporarily adopting the name of someone in the other group. Whenever one group observed the nawait (Saguaro wine) ritual, surrounding groups from the east, north and south were sent for as guests. An inseparable part of the ritual was for each person to know his kinship to each other person. When offered wine a person was bound to drink it but could not drink it until voicing the kinship term to the person offering it. Such a unique system of fellowship tended to produce a strong ethnic feeling throughout the entire range of the O'odham as long as they remained nomadic. Significantly for keeping the O'odham together as one ethnic group, it was during these events that men chose wives and women chose husbands. It is common for wandering people (e.g. Jewish, Gypsy) to have a strong ethnic awareness.

According to a Kohadk woman, Anita Thomas (Shreve, 1943), **I'itoi** the Elder Brother "told the people in different villages to make certain things. In the northern villages he gave the women some pottery and showed them how to make pottery. In Santa Rosa he gave the women some basket bowls and showed them how to coil baskets. In the south he gave them mats and showed them how to make mats and plaited baskets. For a long time people in certain villages made pottery or basketry very well and then traded to people in other villages for things they wanted. But a long time ago, the people moved around so much and married into other villages, so women in all the villages learned to make bowls and pottery. But even now the women who originally came from Santa Rosa make the good baskets."

In summary, the tenor of the present paper is that O'odham cultural differentiation can be explained by the way in which these people have adapted to the Sonoran Desert, its plants, animals, habitats and water availability, and although they may have learned much from foreign and intrusive cultures, they remained ethnically quite distinct. All of the O'odham of the Sonoran Desert discussed in the present paper are considered by the author to be ethnically one although quite different in environmentally related culture.

It is here suggested that the mind of the O'odham has been fascinated with ecology and the environment and that this itself is a major ethnic distinction of these people. Just as the world of the O'odham began with creation of the Creosotebush, so too do desert plants enter prominently into the conclusion. "Before you come again, I may go to eat prickly pears beneath the sunrise ... " said an O'odham informant of Saxton and Saxton (1973: p. xiii). Sure enough, after a year he had "finished his life's journey to the east where prickly pears and mule deer are plentiful and singing and dancing never cease."

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Genotype-Environment Interactions in Two Cultivars of Spring Wheat[1]

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Abstract

A 3-year field experiment (1976 through 1978) was conducted at Yuma, Arizona and Logan, Utah to determine the effects of environment on growth and grain yield of Siete Cerros and Cajeme 71 wheat *(Triticum aestivum L.)* geotypes grown under irrigation. The growing seasons were December to June in Arizona and April to August in Utah.

Siete Cerros produced taller plants and higher straw and grain yields than did Cajeme 71; however, Cajeme 71 required fewer days from planting to flowering and flowering to maturity, at each location each year. Cultivars grown in Arizona produced taller plants, more straw, and more grain than the same cultivars grown in Utah; however, both cultivars required more days from planting to flowering and fewer days from flowering to maturity in Arizona than they did in Utah. Some plant growth characteristics of both cultivars varied from year to year but the variations were not consistent enough to suggest genetic differences between cultivars, except for plant height.

This foregoing research suggested that a 3-year period was not long enough to indicate genotype-environment interactions; however, it may be safe to conclude that spring wheat cultivars may quickly adapt into high yielding winter annuals in irrigated, semiarid regions like Arizona. *Additional Index Words.* Genotypes, Varieties, Plant Adaptation, Plant Culture.

Introduction

Breeding techniques and improved cultural practices have resulted in the production of wheat *(Triticum aestivum L.)* cultivars with high grain yield potential. The high yielding capacity of a given cultivar may not be realized unless it is grown under optimum environmental conditions. This indicates that problems of genetic response to environmental factors are of major importance in developing cropping programs for a given location. With detailed knowledge of genotype-environment interactions as a guide, plant breeders can select wheat genotypes with desirable agronomic qualities and wide adaptation.

Literature Review

Willey and Holliday (1971) demonstrated that yield potential depends on the environment and its interaction with the developing plant. Stoskopf et al. (1974) observed that the response of spring wheat in southern Ontario, Canada appeared to be limited by environment, so that superior cultivars did not express their full yielding potential. Detailed discussion on how environment affects wheat growth and development was presented by Evans et al. (1976). Thorne et al. (1968) reported that the climate of a region determines cultivar adaptation and plant response through the normal growth states from planting to maturity.

[1]Contributions from the Arizona Agricultural Experiment Station, University of Arizona, Tucson, Arizona 85721 and the Utah Agricultural Experiment Station, Utah State University, Logan, Utah 84321. Approved for publication as Arizona Agricultural Experiment Station Research Contribution, No. 3010. Received July 25, 1980. The authors gratefully acknowledge the assistance of Mengste-Ab Solomon, Research Assistant, with portions of the research involving this contribution.

Grain yield of wheat is determined by the number of heads per unit area, number of seeds per head, and seed weight. Investigations have shown that these yield components are affected by variations in environmental factors. Power and Alessi (1978) stated that grain production from many semi-dwarf wheat cultivars was severely restricted when subjected to water-stress during grain filling. For this reason semi-dwarf spring wheat cultivars are commonly grown in sub-humid regions rather than in semiarid regions (North Dakota Crop and Livestock Reporting Service, 1974). Day and Thompson (1975) reported that barley grain yields were reduced by moisture-stress. They found that moisture-stress at flowering decreased seeds per head and moisture-stress at the dough stage decreased seed weight.

The effects of temperature and light on growth and yield of wheat has also been studied. According to Sojka et al. (1975) soil temperature and aeration affect plant response, indirectly, by influencing nutrient availability and ionic species present in the soil and, directly, by influencing metabolic rates and pathways within the plant. Boatwright et al. (1976) reported that low temperatures restricted nutrient translocation through the crown node of wheat and that the restriction reduced top growth. Fisher and Maurer (1976) observed that the growth of spring wheat was retarded by cooling and hastened by heating; however, total dry weight at maturity and grain yield were reduced by increased temperatures at any stage of growth, except during the period from seeding to floral initiation. Wheat is very sensitive to temperature changes during ear development. Warrington et al. (1977) noted that plants subjected to low temperatures at heading had longer culms, larger flag leaves, and more potentially fertile florets in each spikelet than did wheat subjected to high temperatures, and that the number of florets which produced harvestable grains and the weight of the grains at maturity were reduced by high temperatures at the grain filling stage. Spiertz (1974) reported that increases in temperature within the range of 15 to 25C increased the growth rate of wheat kernels; however, the duration of the post-floral development stage was shortened, resulting in lower grain yields.

Interactions between temperature and light influence plant growth and development. Friend (1965) noticed that the number of spikelets on a differentiating inflorescence and ear of wheat at anthesis was highest at high light intensities and low temperatures. He attributed the duration and rates of apical elongation, morphological development of the ear, and spikelet formation to the differential effects of temperatures and light intensity. Friend et al. (1963) found that under continuous illumination floral initiation of wheat was earlier with each increase in light intensity from 200 to 2000 ft-c, and with each increase in temperature between 10 and 30C after floral initiation. The growth of the apical meristem was most rapid at 30C and 2500 ft-c, resulting in early heading and anthesis. Faris and Guitard (1969) reported that highest spring barley yields were obtained when plants were grown at low temperatures and short day lengths during the vegetative stage and at low temperatures and continuous illumination during the period from flowering to maturity.

The objective of the research reported in this paper was to investigate the effects of environment on the growth and grain yield of two wheat cultivars grown under irrigation in the western United States.

Materials and Methods

An experiment to study the effects of environment on growth, forage yield, and grain yield of spring wheat was conducted at Yuma, Arizona and Logan, Utah for 3 years (1976 through 1978). Two cultivars ('Siete Cerros' and 'Cajeme 71') were grown as winter annuals in Arizona and as annuals in Utah. The experimental design was a Randomized Complete Block with four replications. Replications were nested within locations and years. The harvested plot size after discarding guard rows was $0.37m^2$. The cultivars were planted in December and harvested in June in Arizona and were planted in April and harvested in August in Utah. The wheat was planted at the rate of 112 kg/ha and grown under irrigation at each location. Nitrogen fertilizer was applied before planting at rates of 56 kg/ha in Arizona and 168 kg/ha in Utah. The grain was harvested at maturity with a hand sickle at each location.

The following data were recorded for each cultivar at each location: (1) days from planting to flowering, (2) days from flowering to maturity, (3) plant height, (4) heads per unit area, (5) seeds per head, (6) seed weight, (7) grain yield, (8) grain bushel weight, (9) seed color score, (10) straw yield, (11) grain/straw ratio, (12) lodging. All data were analyzed using the standard analysis of variance. Means were compared using the Student-Newman-Keuls' (SNK) Test as outlined by Little and Hills (1975).

Results and Discussion

The average number of days from planting to flowering was 44 days earlier for Siete Cerros and Cajeme 71 in Utah than in Arizona; however, the period between flowering and maturity for the two cultivars averaged 9 days shorter in Arizona than it did in Utah. In Arizona, as the number of days from

Table 1. Average days from planting to flowering, flowering to maturity, plant height, straw yield, grain/straw ratio, and lodging for two wheat cultivars grown in Arizona and Utah for a three-year period (1976–78).

Treatments			Planting to flowering	Flowering to maturity	Plant height	Straw yield/m²	Grain/straw ratio	Lodging
Location	Year	Genotype						
			(day)	(day)	(cm)	(g)	(ratio)	(",,)
Arizona	1976	Siete Cerros	104 a+	41 a	90 a	2134 a	0.70 b	0 a
		Cajeme-71	103 b	39 b	69 b	1275 b	0.98 a	0 a
	1977	Siete Cerros	116 a	40 a	93 a	1400 a	0.66 b	0 a
		Cajeme-71	111 b	39 a	80 b	1115 b	0.83 a	0 a
	1978	Siete Cerros	100 a	52 a	101 a	1308 a	0.43 a	9 b
		Cajeme-71	97 b	46 b	83 b	1291 a	0.56 a	24 a
Utah	1976	Siete Cerros	59 a	57 a	70 a	702 a	0.95 a	4 a
		Cajeme-71	57 b	52 b	60 b	405 b	0.88 a	9 a
	1977	Siete Cerros	63 b	55 a	78 a	455 a	1.32 a	0 a
		Cajeme-71	64 a	47 b	65 b	398 a	1.30 a	0 a
	1978	Siete Cerros	64 a	52 a	79 a	382 a	1.15 a	0 a
		Cajeme-71	62 b	46 b	58 b	479 a	1.18 a	0 a
Significance of differences:								
Between locations (L)			**	**	**	**	**	*
Between years (Y)			ns	ns	**	ns	ns	ns
Between genotypes (G)			ns	ns	*	ns	ns	ns
L x Y			ns	ns	ns	ns	ns	ns
L x G			ns	ns	ns	ns	ns	ns
Y x G			ns	ns	ns	ns	ns	ns
L x Y x G			**	**	*	ns	ns	**

* ** Significant at 5% and 1% levels, respectively; ns = not significant at 5%.

+ Means followed by the same letter, within years, for the same location, are not different at the 5% level of significance, using the Student-Newman-Keuls' Test.

planting to maturity increased, the number of days from flowering to maturity decreased; however, in Utah the opposite relationship was observed in the 3 years of the study. The cultivars did not differ in number of days from planting to flowering and flowering to maturity in both Arizona and Utah. With one exception, when two cultivars were compared within years in Utah, the periods from planting to flowering and flowering to maturity were shorter for Cajeme 71 than they were for Siete Cerros in all 3 years. The same relationships were also observed in Arizona (Table 1).

Wheat cultivars grown in Arizona were 23% taller than the same cultivars grown in Utah. Both cultivars showed an increase in plant height from year to year regardless of location. Average plant heights were 72, 79, and 83 cm in 1976, 1977, and 1978, respectively. Siete Cerros produced taller plants than Cajeme 71 at both locations throughout the experimental period. This cultivar was 18 cm taller in Arizona and 12 cm taller in Utah than Cajeme 71 (Table 1).

Straw yields from wheat genotypes grown in Arizona were three times the straw yields from the same genotypes grown in Utah. There were no significant differences in straw yields due to cultivars, years, and their interactions; however, in 1976 and 1977 in Arizona and in 1976 in Utah, Siete Cerros produced more straw than did Cajeme 71 (Table 1).

The grain-to-straw ratios, in most instances, showed an inverse relationship to straw yields. Cultivars had higher grain/straw ratios in Utah than in Arizona because of the lower straw yields in Utah. Lodging was not a problem except in Arizona in 1978 and in that year Cajeme 71 lodged more severely than did Siete Cerros (Table 1).

Analysis of variance confirmed that wheat cultivars grown in Arizona produced more heads per unit area, more seeds per head, heavier seeds, higher grain yields, higher grain-volume weights, and lighter colored seeds than were obtained from the same cultivars grown in Utah (Table 2). Comparisons of mean yield components and final grain yields for cultivars in Arizona and Utah for each year showed that Cajeme 71 produced more heads per unit area in 1976 and 1977 and heavier seeds in Arizona in 1976 than did Siete Cerros. Similar results were also observed in Utah for number of heads per unit area in 1977 and 1978 and for seed weights in all 3 years. In Arizona, in 1976, Siete Cerros exceeded Cajeme 71 in number of seeds per head and grain yields. In Utah, Siete Cerros was superior to Cajeme 71 in grain yields in 1976 and in number of seeds per head and grain volume-weights throughout the 3-year period.

The two cultivars showed significantly higher vegetative growth and grain yields when grown in Arizona than they did in Utah. The only significant

Table 2. Average heads per unit area, seeds per head, seed weight, seed color score, grain yield, and grain volume-weight for two wheat cultivars grown in Arizona and Utah for a three-year period (1976–78).

Treatments: Location	Year	Genotype	Heads in² (no.)	Seeds per head (no.)	Seed weight (g/1000)	Seed color score† (10-40)	Grain yields in² (g)	Grain volume-weight (kg/hl)
Arizona	1976	Siete Cerros	750 b+	44 a	45.4 b	40	1495 a	83 a
		Cajeme-71	813 a	30 b	51.2 a	40	1256 b	84 a
	1977	Siete Cerros	457 b	38 a	52.1 a	40	906 a	78 a
		Cajeme-71	572 a	31 a	51.6 a	40	918 a	78 a
	1978	Siete Cerros	432 a	34 a	39.2 a	40	577 a	81 a
		Cajeme-71	472 a	39 a	39.5 a	40	722 a	81 a
Utah	1976	Siete Cerros	623 a	30 a	36.0 b	20	670 a	77 a
		Cajeme-71	616 a	14 b	40.0 a	20	351 b	74 b
	1977	Siete Cerros	461 b	35 a	37.0 b	20	600 a	83 a
		Cajeme-71	541 a	21 b	45.0 a	20	512 a	81 b
	1978	Siete Cerros	216 b	49 a	41.0 b	20	439 a	78 a
		Cajeme-71	426 a	29 b	47.0 a	20	565 a	77 b
Significance of differences:								
Between locations (L)			* *	* *	* *		* *	* *
Between years (Y)			*	ns	ns		ns	ns
Between genotypes (G)			ns	ns	ns		ns	ns
L x Y			ns	ns	ns		* *	*
L x G			ns	ns	ns		ns	ns
Y x G			ns	ns	ns		*	ns
L x Y x G			* *	* *	* *		ns	*

* * * Significant at 5% and 1% levels, respectively; ns = not significant at 5%.
+ Means followed by the same letter, within years, for the same location, are not different at the 5% level of significance, using the Student-Newman-Keuls' Test.
† Visual observation: 10 = very dark and 40 = very bright.

difference between cultivars, which was not affected by environment was plant height. The rest of the parameters measured indicated that there were no conclusive genetic differences between cultivars. The environmental conditions in Utah reduced the growth and grain yield of both cultivars. Similar observations were made by Stoskopf et al. (1974) in southern Canada. In Arizona, the cultivars were subjected to over 90 days of cool temperature (13–15C) accompanied by 269–516 Langlays/day of solar radiation from planting to flowering. Temperatures and light intensities were more favorable in Arizona than they were in Utah for providing the cultivars sufficient time for maximum vegetative growth, morphological development of ears, and spikelet formation (Friend, 1965). The foregoing environmental factors in Arizona resulted in taller plants, larger heads, and more fertile spikelets (Warrington et al. 1977). In Utah, the temperatures increased from approximately 13C at planting in April to 20C at flowering in late June. The sunlight hours also were increasing during this period and they reached a maximum at flowering. High temperatures and light intensities in Utah, due to long hours of sunshine, reduced the number of days from planting to flowering, plant height, head length, and seeds/head (Guitard, 1960). The number of days between flowering and maturity were shorter in Arizona than they were in Utah, probably due to higher temperatures in Arizona during this period (Spiertz, 1974). In Arizona, both genotypes produced lighter seeds than they did when grown in Utah. The temperature range between flowering and maturity in Arizona was 15–29C. High temperatures shortened the grain filling stage and resulted in lower seed weights in Arizona than those obtained in Utah (Darwinkel et al. 1977).

Straw yields in 1976 and 1977 in Arizona and in 1976 in Utah and grain yields in 1976 in Arizona showed that Siete Cerros was superior to Cajeme 71; however, the foregoing differences in time may be due to chance alone and do not suggest that a 3-year period is long enough to conclude the presence of genotype-environment interaction between cultivars.

The increased vegetative growth and higher grain yields of the cultivars in Arizona during the winter than were observed in Utah during the spring suggested that spring wheat cultivars may readily adapt themselves into high yielding winter annuals under irrigated, semiarid conditions like those found in Arizona.

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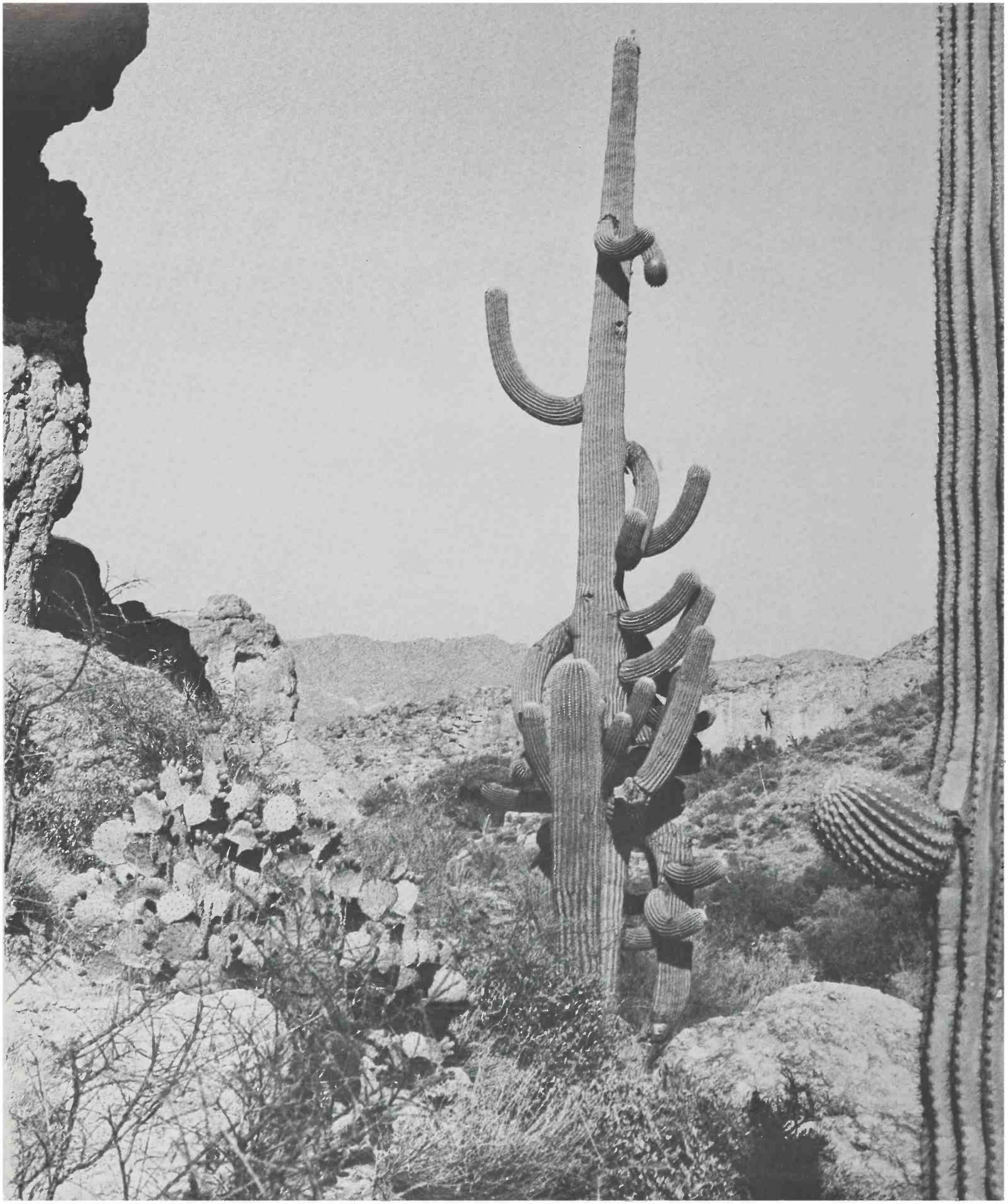

On the Cenozoic Ecology and Evolution of the Sahuaro *(Carnegiea gigantea)*

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Viewed within the perspective of an evolutionary time scale, the cacti in general and the sahuaro in particular are among the relative newcomers to the plant kingdom. The cold-intolerant sahuaro, which has the most northerly distribution (to Lat 35° 6′ N) of any of the columnar cacti, is still actively evolving under the continued powerful selective pressure of recurring critical climatic events—catastrophic freezes—that have been a dominant force in the evolution of the species. Subfreezing temperature and aridity under warm season (and bi-seasonal) rainfall have been codominant selective forces in molding the gigantine columnar cacti of the American deserts. It is not surprising, therefore, that sahuaros exhibit relatively wide variances in those characteristics that constitute adaptive strategies appropriate to survival of the species in the climatic extremes that characterize the present range of its desert distribution in Arizona, extreme southeastern California, and adjacent Sonora, Mexico.

There is little that is known with great certainty on the evolution of the sahuaro and other columnar cacti that live today in the Sonoran Desert—the species usually thought of as desert giant cacti. The family (Cactaceae) has a poor fossil record; there are no known materials older than 40,000 radiocarbon years before present (Van Devender, 1973). In spite of a poor fossil record, there is much circumstantial evidence bearing on the problem of origins. The circumstantial evidence is strong for early cactus representation in the Madro-Tertiary Geoflora (Chaney, Condit and Axelrod, 1944; Axelrod 1950, 1957, 1958, 1960, 1970, 1979).

It appears beyond reasonable doubt that the Cactaceae is a tropically-derived family. It is not surprising, therefore, that this new world plant group has strong representation in the deserts that border the tropics—the subtropical warm deserts—with relatively little continental representation beyond them. For example, cacti are either poorly represented, greatly reduced to substratum level, or nonexistent in habitats within the cold Great Basin Desert of North America and in similar habitats within its South American analog, the cold Patagonian Desert in southern Argentina.

Regarding species, in the absence of an adequate fossil record, answers to questions on evolutionary history of desert columnar cacti can be given or estimated with fair security on the basis of the circumstantial evidence. Much of the evidence lies in the known history of the Madro-Tertiary Geoflora and the evolution of the North American Desert. The following scenario for Cenozoic history of the Cactaceae is consistent with and/or drawn in part from information in Britton and Rose (1920, 1922), Bravo (1937), Chaney, Condit and Axelrod (1944), Deevey (1949), Axelrod (1950, 1957, 1958, 1960, 1970, 1979), Shreve (1951), Just (1952), Backeberg (1958), Buxbaum (1958), MacGinite (1959), Dorf (1960), Van der Hammen (1961), Raven (1963), Lowe (1964, 1966), Martin and Mehringer (1965), Felger and Lowe (1967), Hunt (1967), Wolfe and Hopkins (1967), Pascual (1970), Vuilleumier (1971), Wright, 1971), Lowe et al. (1973), Solbrig (1973, 1976), Turner (1973), Van Devender (1973), Raven and Axelrod (1975), Steenbergh and Lowe (1976, 1977), Wells (1976), Orians and Solbrig (1977), Gibson and Horak (1978), as well as Van Devender and Spaulding (1979). For a reconstruction of the Tertiary environment see Axelrod (1950, 1957, 1958, 1960, 1970, 1979); for Quaternary environment see Wells (1976) and Van Devender and Spaulding (1979).

Cenozoic History of the Cactaceae

Early Tertiary: *Paleo-Oligocene* time, 75 to 35 mybp [million years before present]. Evolution of the Cactaceae within and marginal to the widespread broadleaved evergreen Neotropical-Tertiary Geoflora. Evolution of cactus family and subfamily adaptive strategies, during approximately 40 or more million years.

Middle Tertiary: *Oligo-Miocene* time, 35 to 15 mybp. Evolution of tropical and subtropical cactus groups—involving both northern and southern sides of the tropics—in tropical and subtropical deciduous forest and scrub environments. Evolution and radiation of principal cactus growth-form strategies; establishment of higher categories of modern aspects—the major genera and groups of genera (tribes)—during 20 million years of increasing dryness, cooling, and accelerated evolution of the Madro-Tertiary Geoflora.

Late Tertiary: *Mio-Pliocene* time, 15 to 5 mybp. Widespread expansion of semi-arid and arid subtropical scrub of the Madro-Tertiary Geoflora, with derivation of larger columnar cacti out of the subtropical phylads bordering the tropics in North and South America. Speciation of major lower categories—modern species and species-groups of extra-tropical cacti—during 10 million years of expanding dry climate and increasingly seasonal climatic patterns.

Latest Tertiary: *Plio-Pleistocene* time, 5 to > 1 mybp. Continuing evolution of taxa in the arid subtropical scrub and expanding desert environment, essentially finalizing modern desert species as we know them today in North and South American deserts and bordering environments during 3–4 million years of response to increasing orogeny and expanding aridity—with progressive seasonal cooling—in southwestern regions of the continents. Selection for greater stem-mass (thermoregulatory energy conservation) progressing to gigantism in columnar cacti within progressively cooling subtropical scrub and desertscrub environments, producing inter-continental convergent evolution of gigantine adaptive form and function—including convergent thick-pithed ecological equivalent *Carnegiea gigantea* in the North American Sonoran Desert and *Trichocereus terschekii* in the South American Monte.

Quaternary: *Pleistocene* time, ca. 1 to ~0 mybp. Mixing of species compositions of biotic communities under strong secular climatic change, with biogeographic shifts of taxa in both elevation and latitude. Glaciation, with glacial periods of the order of 100,000 years duration, and interglacials on the order of 10,000 to 20,000 years. Known fossil material of cacti—the entirety of which date less than 40,000 radiocarbon years before present—indicate no difference from modern populations of taxa.

Quaternary—Late Pleistocene: *Middle and Late Wisconsinan* time, 40,000 to 11,000 ybp. Mesophytic Pinyon-Juniper woodland communities predominant across landscapes presently in the Chihuahuan, Sonoran, and Mohave Deserts, before, during and after the glacial maximum (22,000–17,000 ybp). Environmental domination by winter climate, however equitable, did not provide summer requirements for germination, establishment, and growth of the subtropical columnar cacti within Wisconsinan needle-leaved woodland. *Carnegiea* remained within latitudinally displaced subtropical scrub environments south and below the perimeter of the woodland.

Quaternary—Holocene: *Early Holocene* time, 11,000 to 8,000 ybp. Xeric Juniper woodlands under dominant winter-season precipitation persisted widely and inclusive of Southwest landscapes presently occupied by vegetation established under dominant warm-summer monsoon precipitation. *Carnegiea* remained southward in Sinaloan upland rocky sites, as it does today within such relatively frost-free subtropical communities at the southern edge of its geographic distribution in northern Mexico.

Quaternary—Holocene: *Middle and Late Holocene* time, 8,000 ybp to present. Desertscrub communities of modern aspect formed into the regional biotic communities (biomes) recognizable today under significant summer as well as winter precipitation. Rapid northward and upward deployment of floral and faunal elements into modern subtropical and warm temperate desertscrub assemblages accelerated by melting of the ice sheets and stronger development of the Azores (Bermuda) High—with increased and expanded summer precipitation—favored by warmer global temperatures. Derivation of communities of modern aspect during late Holocene, following movements of species elements into present positions during both middle and late Holocene. The presence of *Carnegiea* today in ecotone stands with junipers, oaks, and other woodland and chaparral taxa at the edge of the desert results from secondary contact during middle to late Holocene time in the current Holocene interglacial.

Freezing and the Historical Record—the Last 200 Years

Catastrophic freezes occur throughout the range of the sahuaro and are an integral component of the species-environment during the Holocene interglacial that we are currently experiencing. Such climatic events are neither "new" nor "unique" and do not in themselves indicate a climatic trend.

We examined conventional climatic data records in an earlier report (Steenbergh and Lowe, 1976). Among other kinds of diverse long-period records, the freeze-caused constrictions at the base of the largest (oldest) sahuaros provide a most important record of critical freezes dating back to the first half of the 19th century (Steenbergh and Lowe, 1977: Fig. 54). Historical observations further complement the record of such events. Of particular significance are such accounts as recorded on Papago Indian calendar sticks (Tatom, 1975):

> "*1848*—In this year happened an almost unbelievable thing. Cold weather of unheard-of intensity swooped down on the Papagos and almost snuffed them out. Snow fell to a depth of three feet on the level and as deep as the tops of houses in drifts, and lay on the ground for many weeks. Cattle and horses could not find food under the snow and the People could not find firewood. There was great suffering because the People had always been accustomed to warm winters.
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> *1870*—Snow again fell to a remarkable depth. It remained on the ground only two days before melting away."

The historical record of freeze-caused damage to the subtropical citrus and other agricultural crops in Arizona constitutes another important, and previously unexamined indicator of the impact of catastrophic freezes on the subtropical sahuaro and other cold-sensitive native plant populations in the Sonoran Desert during this century (Table 1). It is apparent in our observations over the last three decades in the Sonoran Desert that the severity of damage to sahuaros and similarly cold-sensitive native plant species by a given freeze is closely reflected by the concurrent damage to citrus crops.

Hilgeman (1965) in a brief historical review of citrus in Arizona notes that "Severe freezes in '13, '37, '49, '50, '62, and '63 have caused extensive fruit losses ... " A more complete record of the effects of freezing on citrus (and

Table 1. Chronology of critical winter freezes and reported crop damage in Arizona. The following climatic briefs are from U.S. Weather Bureau summaries for the period 1895 to 1957. Tucson minimum (min.) temperatures (F°) shown are for the University of Arizona Station, 2423 ft (739 m).

1895—Tucson December min. 14°.
1897—Lowest temperature of the year. Tucson Dec. min. 16°.
1899—January snowfall in Salt River Valley. Crop of orange fruit sustained no serious injuries. Tucson min. 17°.
1901—December Tucson min. 10°.
1902—Principal cause of the light orange crop was cold weather in December 1901 which caused considerable damage to trees.
1904—January Tucson min. 15°.
1905—December temperature greatly deficient. Tucson min. 11°.
1910—Unusually cold January 3-8. Tucson min. 15°.
1911—Tucson January min. 16°.
1913—January freeze most severe in history of the state. Considerable damage to citrus groves in Salt River Valley—orchards killed, set back, fruit frozen. Tucson min. 6°.
1916—December—unusually cold and dry. Tucson min. 15°.
1919—December—coldest month since 1892. Tucson min. 20°.
1922—January—an unusually cold month, citrus fruit frozen. Tucson min. 17°.
1924—January nights unusually cool, heavy frost but negligible damage to citrus fruits. Tucson min. 24°.
1925—Damaging January frost and freezes in all sections. Tucson min. 18°.
1929—January freeze damage to citrus and cantaloupes in Yuma Valley. Tucson min. 22°.
1931—December killing frosts, much damage to citrus trees and fruit. Tucson min. 23°.
1932—January—citrus fruits and young trees severely damaged by cold weather. Tucson min. 19°.
1933—February cold wave caused extensive damage to lettuce and citrus crops. Tucson min. 18°.
1934—Slight damage to lettuce and citrus by November-December cold wave. Tucson min. 22°.
1935—Slight January damage to citrus trees in Salt River Valley. Tucson min. 21°.
1937—January—the coldest month on record, 40 to 60 percent of citrus crop frozen. Tucson min. 15°.
1939—Coldest February for all years of record. Lettuce growth retarded and citrus injured by cold. Tucson (UA) min. 25°; 20° at Magnetic Observatory station.
1940—Light January freeze in citrus belt—little damage. Tucson min. 22°.
1942—Slight January frost damage to citrus, Salt River Valley. Tucson min. 26°.
1945—December freeze damage to citrus and winter truck crops. Tucson min. 19°.
1947—Severe January cold damage to orange crop in Salt River Valley. Tucson min. 22°.
Considerable December freeze damage to cabbage and broccoli, slight damage to lettuce. Tucson min. 24°.
1949—Damaging freeze on January 4th, 5th, and 6th. Bitter cold all month. Heavy losses to fruits and vegetables in southern portions of the state. Tucson min. 16°.
December—heavy frosts, moderate damage to citrus and vegetables. Tucson min. 22°.
1950—January freeze most severe since 1913. Citrus and truck crops severely frozen. Many citrus trees sustained considerable damage. Entire Phoenix area citrus crop damaged. Tucson min. 18°.
1953—December—some injury to citrus due to repeated frosts. Tucson min. 24°.
1956—February—some frost damage to melons, frost protection necessary for citrus and truck vegetables. Tucson min. 24°.
1957—December—narrative weather summaries discontinued.

other crops) reported in U.S. Weather Bureau summaries (1895–1940, 1940–1957) is summarized in Table 1. This weather-integrated record is, in some respects, more revealing of the impact of such climatic events on sahuaros—and other cold-sensitive native plant populations—than are temperature values available from official climatic data records.

The degree of freeze-caused damage to cold-responsive citrus and other crop plants represents an *integrated* measure of intensity and duration of the particular freeze as well as the immediate post-freeze (re-warming) thermal environment. The succulence and surface-volume ratio of citrus fruits provide thermal characteristics similar to those of sahuaros—especially with respect to small juveniles, albeit of often different position in the thermal profile. The severity of damage to citrus and other cultivated crops produced by each of the climatic events as noted in Table 1 is a reliable indicator of the seriousness of the impact of these same critical events on sahuaro populations. This is true not only for northern populations of the sahuaro, but also—in progressively reduced degree southward—for sahuaro populations growing in central and southern Sonora, Mexico.

These diverse records leave no doubt that the sahuaro and other associated tropically derived species have, during the last two hundred years, been subjected to a series of irregularly occurring, intermittent, catastrophic freezes. Neither the historic record nor the status of existing sahuaro populations suggest that these events, in themselves, indicate a climatic trend. Rather, they tell us that freezing continues to operate upon these populations as a powerful selective force. Furthermore, the structure of sahuaro populations and the continued presence of sahuaros throughout the historic range of the geographic and ecologic distribution of the species are the final and conclusive evidence that adaptive evolution of increased natural resistance to freezing is a continuing process appropriate to the survival of the species.

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Arboretum Progress

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Two or three months will elapse between the writing of this article and its publication. During those months the Arboretum will have published its annual report for fiscal 1980–81 in the form of the "Director's Report" to the interested administrators of the three sponsors. Highlights of that report are shared here with the readers of Desert Plants.

It was a year of many pluses and a few minuses. The biggest plus was the construction of a new parking lot. The lot is located just inside the entrance gate. It will replace three existing, smaller, dispersed and unorganized lots. Construction is underway on a pedestrian walk from the new lot to the Visitor Center. The existing entrance road and the small lot adjacent to the Visitor Center were upgraded by a one-inch overlay of asphaltic concrete during the surfacing of the new parking lot.

The minuses were all related to the loss of trained staff with a combined total of 20 years of service. Leslie Ely, assistant to the Director and supervisor of physical plant maintenance, and Mary Ely, lead secretary, chose "semi-retirement" effective May 1. Reduction in funding of the federally supported Young Adult Conservation Corps (YACC) resulted in the elimination in April of the work supervisor position filled by Joe Rodriguez. These reductions followed the resignation in February of Keith Teater who worked as a laborer but who volunteered many other skills.

The loss of key people so well trained in the operation of the Aboretum created considerable disruption from which the staff is not fully recovered, but the success in recruiting replacements is one of the bright spots of the year. We have added to our staff this spring both Jeff Clark and Barbara Mulford, two recent graduates at the Bachelor of Science level who have been willing to share some of the labor needs of the Arboretum, but who more importantly are enhancing both the horticultural and interpretive programs in the way that Kent Newland has contributed so much over the years. The lead secretary is now Jane Rua, who has a biology background in undergraduate study and has done substitute teaching while raising a family in the nearby town of Superior. Gary Kuhn replaces Les Ely, having transferred here from Patagonia Lake State Park in southern Arizona. His experience there and education at the Bachelor of Science level in natural resources management have both been most helpful in assuming his duties here. With the valuable assistance of the remaining experienced staff and faculty, the work goes forward in a commendable manner.

Despite the loss of the work supervisor, the YACC program continues with supervision of the enrollees provided by the Arboretum staff. Through the year these enrollees have contributed a great deal to the daily maintenance and garden work at the Arboretum. In addition, they quarried rock with which to build a seat wall and patio in front of the Visitor Center, a project now scheduled for 1981–82. Much work was accomplished in the construction of a trail through the area designated for development into plant communities representative of various North American deserts. They completed the installation of the primary water delivery lines for the irrigation of this new area. The Arboretum staff completed the installation of pumping and filtering facilities for that irrigation project.

Hours of service to the public at the Arboretum were extended during the year. The facilities are now open to the public from 8:00 a.m. to 5:30 p.m. every day of the year except Christmas Day. Admission fees were increased to $1 per adult. Children under 17 are admitted free if they are accompanied by a responsible adult.

The academic program of the Arboretum continued to grow. Traditionally we have offered lectures and tours arranged in advance for all levels of formal classes and for any interested organized group. In addition, a series of lectures, tours and demonstrations were initiated in mid-June on a regular schedule to serve anyone interested in the announced subjects. These were scheduled through the summer, at 9:00 a.m., to take advantage of the cooler morning temperatures. The Tucson chapter of the Audubon Society held a highly successful Institute of Desert Ecology at the Arboretum for the third consecutive year. The annual Arboretum plant sale this year was attended by more people who took away with them more desert plants for landscaping than any previous sale. Research work continues with ground cover trials and the first steps toward establishing a research collection of desert legumes. The publication of Desert Plants speaks for itself.

The Arboretum is moving toward the development of a master plan. Additional work was accomplished this year in the design of a demonstration garden and the parking lot and ingress pattern from it, particularly with regard to its relation to the development of the area in front of the Visitor Center. Implementation of certain elements, already agreed upon, such as the parking lot and the North American desert plant communities, are going forward during its development.

The 1980–81 fiscal year was difficult but very productive. The Arboretum staff and faculty are confident that the Arboretum programs will continue to progress in 1981–82.

Wetland Trees of Arizona for Possible Oasis Use in Arid Regions

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Editor's Note

Recently Warren Jones (Desert Plants 3(1): 17–28) has pointed out the value of the "mini-oasis" for human outdoor comfort in desert regions. In a quite independent basic research project Jon Rodiek has surveyed Arizona's wetlands for the presence of certain plants. Wetlands in Arizona often represent virtual oases surrounded by desert. In the present article Dr. Rodiek has sifted through the findings of his basic research to select what he considers the ten most successful trees in Arizona's wetlands. He reasons that these species may be specially adapted to oasis-like settings within arid regions. By making suggestions concerning possible landscaping values, he is showing how basic research in environmental science can result in applied benefits for man.

Introduction

Water fluctuations in desert pools, plant regeneration along river courses, the population of migratory waterfowl and sandhill cranes, or the ability of elk to survive the cold, dry winters in the coniferous forests in the White Mountains, all of these events fall within the realm of environmental studies. These phenomena represent a small sample of the knowledge base natural resource scientists are accumulating in an attempt to understand our environment. Herein lies some of the challenge of the study of the natural world.

An expanding population base in the Southwest has brought with it a variety of problems that seriously threaten the future picture of this environment. This brings to mind the question of whether it is wiser to continue expanding our understanding of the environment or to apply this understanding of the environment to the basic problems that directly confront us here in the Southwest. Most natural resource scientists believe that they are obliged to deliver benefits to the society that supports them. The problem is to determine the relative contribution to society of theoretical and applied science.

To abandon the pursuit of pure environmental research in favor of immediate problems could be judged a grave error of short sightedness. History has shown that solutions to environmental problems are many times extracted from basic knowledge developed for more theoretical purposes. The National Wetlands Inventory Project is contributing information that benefits both applied and theoretical lines of environmental research.

Values of Wetland Plants in an Arid Setting

One product emerging from the Wetlands Inventory carried out in Arizona is the identification of those plants associated with the wetland landscapes. Plants that survive extreme temperatures and water fluctuations of wetlands within an arid environment are important for many reasons. For example, such plants provide the majority of Arizona's wildlife with a primary source of cover and food. Furthermore many of these plants can be adapted to grow in man-made landscapes while maintaining the ecological and visual integrity of the surrounding native environment. Plants, especially the larger trees and shrubs found in and around wetlands, provide the recreationist and naturalist with a habitat unequalled in any other part of the arid landscape.

The identification of the dominant tree species found in and around Arizona's wetlands has value in the applied and theoretical realms of environmental study. The U.S. Forest Service is currently conducting research within the riparian environment. This work will benefit wildlife and wildlife habitat. Similar efforts have been carried out by the National Park Service and the Bureau of Land Management. These three federal agencies manage the bulk of the land contained within Arizona. These agencies have recognized the disproportionate value riparian and wetland landscapes play in maintaining the biological processes that sustain life in the southwest environment.

Tree species provide cover or shade and visual relief and diversity to our urban areas as well. Man has the option of modifying the desert environment in one of two general ways. In one, the man-made landscape is constructed and maintained in a manner that denies the arid condition. In another, the man-made landscape accepts and conforms to the limitations of the desert. Tree species play a key role in both cases. The difference is found in the types of species selected and their ability to cope with physiological and climatic stress and varying amounts of available water.

Climate and growing conditions continue to change over time within any given landscape. Arizona's environment whether it be desert (43.5%), grassland (23.5%), woodland (25.0%), or forest (8.0%) is sustained in part by plants that can survive these changes. In the short run the dominant plants that populate an environment do so by adjusting to the normal cycle of temperature and water fluctuation. In the long run plants must be biologically capable of readjusting to changes in these normal cycles.

Trees found in association with Arizona's wetlands represent one versatile kind of plant type. In the natural setting these plants must be able to establish themselves where surface and subsurface water supplies are adequate enough to maintain them against the high losses of water through evaporation and transpiration. These plants must be durable enough to withstand strong winds, heavy erosional forces of water flow and soil compaction that often occurs underneath their vegetative canopy. Finally these plants must have an effective reproductive strategy that insures their future survival despite these harsh growing conditions.

Inventory field checks were carried on throughout the state (Sept. 78–Sept. 79) as part of the National Wetlands inventory project. Two hundred and ninety-five field sites were visited during that time. Three hundred and sixty-five observations of trees were recorded. The primary purpose for conducting such a survey was to confirm the continued presence of water in the landscape. These indicator trees helped substantiate the judgements made from aerial photographs that in fact a given site was a bonafide wetland. The top ten tree species are listed in Table 1. Two of the species identified (Tamarisk, Eleagnus) were introduced into Arizona. All others are native to the state. By searching in the natural environment to see just what plant species there are and how they survive in their own habitats it is possible to develop a list of those plants to use when planting a degraded natural landscape or urban landscape.

Riparian and wetland habitats that possess a dominant canopy layer offer the greatest opportunity for wildlife in the arid environment. A primary reason for this is the occurrence of available water and diverse plant species, plus complex vegetative layering and microclimate variation. Research biologists use the knowledge of plant species in formulating an assessment of the wildlife habitat condition throughout a given region. Through the techniques of habitat manipulation it is possible then to maintain a level of a desired wildlife species.

Land planners could also benefit from this information. Most of these tree species are tolerant of urban growing conditions established within desert habitats. In fact with some minor supplemental irrigation most species will thrive quite nicely. The costs of maintaining a man made landscape in the desert setting will eventually force the urban dweller to select the most water and energy efficient plant species. To date the strategy of plant selection for urban use is based upon costs, availability and ornamental appeal. These tree species if used properly could adequately substitute for less efficient plant species now being used.

Consider the following trees the next time there is an opportunity to plant in the desert. They may prove to be just what is needed to achieve the intended landscape effect.

Table 1. Trees Associated with Wetlands.

	Genus	Species	Common Name	% of Total	Size
1.	Tamarix (3)	pentandra aphylla gallica	Salt cedar	29%	Medium tree (30 feet)* (naturalized)
2.	Populus	fremonti	Fremont cottonwood	13%	Large tree (up to 70 feet)
3.	Salix	sp.	Willow	12%	Shrub to small tree
4.	Prosopis (3)	juliflora torreyana juliflora velutina pubescens	Western honey mesquite Velvet mesquite Screwbean mesquite	11%	Small to medium tree (up to 40 feet)
5.	Populus (2)	angustifolia acuminata	Narrowleaf cottonwood Lance leaf cottonwood	10%	Medium to large tree (60 feet)
6.	Platanus	wrightii	Arizona sycamore	4%	Medium to large tree (35–50 feet)
7.	Salix	gooddingii	Gooddingii willow	3%	Medium to large tree (40–50 feet)
8.	Juglans	major	Arizona walnut	3%	Medium tree (up to 50 feet)
9.	Eleagnus	angustifolia	Russian olive	2%	Small tree (15 to 20 feet) (naturalized)
10.	Fraxinus	velutina	Velvet ash	1%	Small tree (15 to 20 feet)

*Average height of species observed in field.

This Fremont Cottonwood survives dry conditions on the grassland plains in Santa Cruz County, Arizona by tapping groundwater supplies.

Arizona Sycamore indicates the presence of an underground water supply near Patagonia.

Arizona Sycamore, Velvet Ash, Fremont Cottonwood, Hackberry and Willow crowd the stream's edge near Buchman Canyon.

***Tamarix* sp. (Salt Cedar)**

This naturalized tree species is common to our desert landscapes. It survives along man-made waterways in the lower elevations of the state. The plants are drought resistant although they are found commonly along our major rivers and stream channels. The tree can tolerate extreme temperature ranges (to below freezing) and low water supplies. It requires pruning and cleaning in planted areas.

***Populus fremontii* (Fremont Cottonwood)**

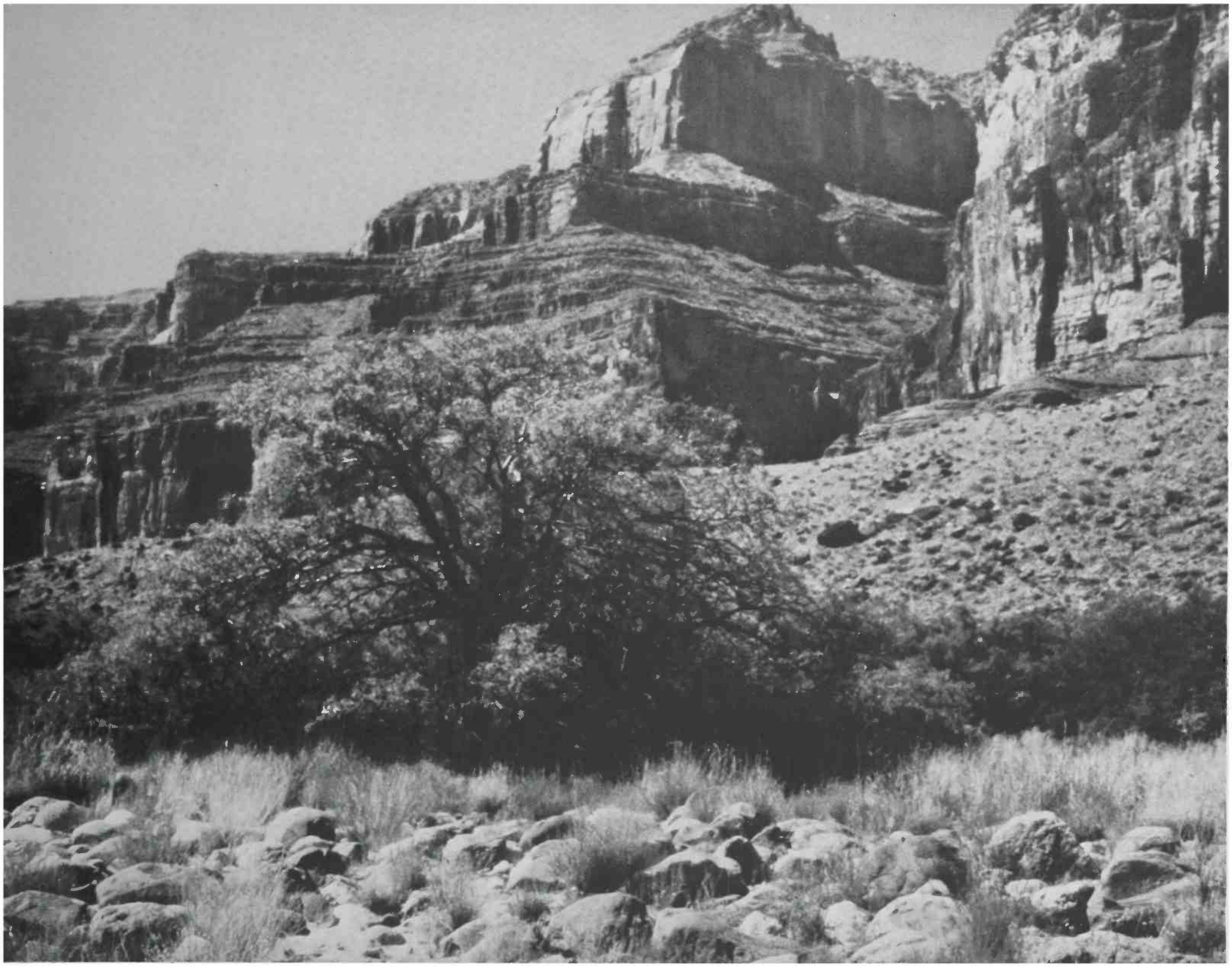
This native thrives in our drainageways and along live streams seeps and lakes. The tree grows rapidly but it must have a constant supply of subsurface water to survive the heat. It is common up to elevations of 6,000 feet. It is one of the most important trees for wildlife in Arizona. It cannot tolerate fire and is vulnerable to grazing by livestock. The tree can do well in large open park like spaces if supplied with moderate amounts of water.

***Prosopis* sp. (Mesquite)**

Mesquite trees are found along our desert washes and bottom lands, in the desert grassland and occasionally into the woodlands. They rarely extend higher than 4,500 in elevation. These trees are normally small and poorly developed where water supplies are low. They will develop a very healthy foliage when water is plentiful. The foliage, bark and fruit (beans) are taken by many wildlife species. The mesquite bosques which formerly occupied our desert riverways were home for many bird species. Mesquites do very well in our desert urban areas with a minimum supply of water once they become established. They are susceptible to very low temperatures but generally survive all but the severest of winters.

***Salix* sp. (Willow)**

There are many shrubs and small trees in the Salix family that survive the arid environment. These species are found along live stream courses and washes. They are common to the grasslands, woodlands and even the coniferous forests. Most species require an underground supply of water in order to sustain themselves against summer heat. Salix is commonly found in the wetland landscapes in association with other species such as Populus, Tamarisk, Fraxinus and Juglans. The foliage and bark are a valuable food source for a variety of wildlife. Most species would do



This rugged Mesquite endures high temperatures along the Colorado River in the Grand Canyon.

well in urban landscapes as background plants. They require moderate water through the dry months to be most effective.

***Eleagnus angustifolia* (Russian Olive)**

This introduced tree grows naturally along waterways or washes below 6,500 elevation. It remains a small shrub-like tree where wind is high and water supplies are low. Seeds are readily taken by many bird species. The foliage is occasionally browsed by livestock and deer. The plant will form excellent cover when foliage is dense. The tree will do moderately well on its own where rainfall exceeds 14 inches per year. It will provide an excellent windscreen or backdrop plant in urban settings. Russian olive requires some pruning and watering when used as a specimen tree.

***Fraxinus velutina* (Velvet Ash)**

Velvet ash does well along washes and drainageways in canyon areas. It has a pleasant fall foliage (yellow) and can produce a generous canopy when groundwater supplies are adequate. It is primarily an intermediate elevation tree (2,500–6,000) in its natural habitat. Cultivated varieties are well suited to the desert landscape. It does require supplemental irrigation and occasional pruning so as to maintain a healthy branching structure.

***Juglans major* (Arizona Walnut)**

Arizona walnut is another intermediate elevation tree. It occurs in the washes and canyons at 3,000–6,500 elevations. This is the only walnut species found commonly in the southwest. The nuts are consumed by squirrels and rodents but because of their scattered occurrence they do not make up a major portion of any wildlife species diet. The wood is of high quality for wood working when available. Its primary value is for wildlife cover.

***Platanus Wrightii* (Arizona Sycamore)**

Arizona sycamore commonly occurs between 1,000–6,000 in elevation in washes and drainageways. It tolerates desert heat when water is available. The tree can grow to magnificent proportions in the upper elevations along live stream courses. It is most commonly used as ornamental shade trees in urban settings. Its use should be restricted to natural settings and where well formed alluvial soils occur. This tree will enhance a setting when growing conditions are adequate.

A Climatological Summary for Punta Cirio, Sonora, Mexico

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Abstract

Climatological data have been collected at several stations in the general vicinity of Puerto Libertád, Sonora, Mexico at various intervals from 1925 to the present. The general area is a focal point for both research and teaching activities. For this reason and because the Sonoran Desert coastal climate is distinct from that of other portions of this desert, the data from these stations are here summarized and discussed. They are presented here primarily to make them available to future students of the area.

Introduction

Ecological studies of organic communities depend, even more than studies of individual species, on a knowledge of the prevailing environmental characteristics. When data of these kinds have not been obtained prior to initiating synecological research in a specific area it is often necessary to include time, effort and cost in collecting them to provide the environmental background for a particular study.

When research is carried out in well-known or long-settled areas most of the basic climatologic or other fundamental environmental information is usually available from various library sources. The more remote or sparsely populated the area of study, however, in general the fewer become the desired data and the more difficult they are to locate.

When few or no additional investigations are planned or likely in a specific locale there might be little or no justification for collating various kinds of environmental data. When, however, an area possesses unique characteristics or biota that give it unusual scientific interest a collation of this sort is of value, and is often justified.

Objective.—The object of this study is to summarize for future reference all meteorological data available for a restricted portion of the Gulf of California coast in Sonora, Mexico.

Time Interval Included.—Various time-span segments from 1925 through 1979 are included here although none of the records covers the entire 54-year interval.

Locale.—The meteorologic stations are located near the Gulf of California in the state of Sonora, Mexico. The northernmost was the Mexican government's station of Puerto Libertád, a small fishing village 250 km by air southwest of Nogales, Arizona. From Puerto Libertád the stations extended down the coast for some 24 km and inland for 9 km. Except for Puerto Libertád, all were located in a low coastal mountain range known as Sierra Cirio (Fig. 1).

Reason for Collating and Publishing the Data.—This area supports the only stand of cirios (boojum trees) (*Idria columnaris* Kellogg) growing on the mainland of Mexico. In addition, it provides a habitat for a variety of Sonoran Desert plants and animals with restricted distribution. Bordering the Gulf of Mexico, as it does, the climate is strongly marine influenced, thus presenting characteristics that are atypical of most of the Sonoran Desert and that have been largely or entirely unmeasured elsewhere along the Sonoran coast.

Punta Cirio early attracted the attention of workers from the Carnegie Desert Laboratory and the University of Arizona in Tucson. For many years, in part as a result of publications from these institutions, the region has become a kind of ecological classroom and laboratory for students from both in-state and out-of-state schools and museums. Both research and classwork are still active here and should continue to be long into the future. A knowledge of the region's climatic characteristics will be of value for both of these kinds of activities.

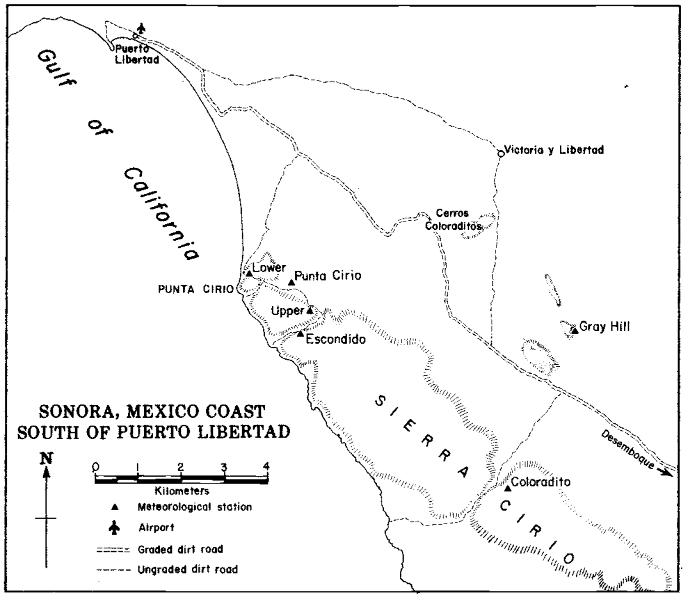

Figure 1. *Map showing locations where climatological data were obtained.*

Methods

Kinds of Data Collated Here.—Three kinds of meteorologic data are summarized here: precipitation, temperature and open-pan evaporation.

Meteorologic Stations.—The specific stations are here designated (1) Puerto Libertád–Mallery; (2) Puerto Libertad–Mexico; (3) Punta Cirio–Mallery; (4) Punta Cirio; (5) Lower; (6) Upper; (7) Escondido; (8) Gray Hill; and (9) Coloradito (Fig. 1 and Table 1).

The Carnegie Desert Laboratory had two rain gauges within the Puerto Libertád-Punta Cirio area (Mallery, 1936a, 1936b). These were established in April, 1935 as part of a series of 22 gauges that extended southwesterly from Tucson, Arizona to Puerto Libertád, Sonora and west from Tucson to a point 10 miles south of Wellton, Arizona, near Yuma. Data from the two gauges within the Puerto Libertád-Punta Cirio area were collected from April 1925 to December, 1935 and are summarized in Table 1.

During the period from November 26, 1967 to the present I have been recording precipitation data from the last six gauges listed in Table 2. These were tapered, plastic gauges sold under the TRU-CHEK brand name. They were read at irregular intervals but evaporation was prevented by pouring a small amount of lightweight motor oil into each after every reading. Each was mounted on the cut-off top of a cactus and so located as to be free of any obstruction that might affect collection of precipitation.

Four of these gauges were established in conjunction with four hygrothermographs designed to obtain data for another study (Humphrey & Marx, 1980).

Analysis

Mallery's winter rainfall season includes the months November through March; his summer season covers the balance of the year, April through October (Mallery, 1936a). Using this seasonal breakdown, Mallery noted that 39% of the Libertád precipitation fell during the winter, versus 61% in the summer. His Punta Cirio data were rather similar: 35% in the winter and 65% in the summer. A similar analysis of the longer-period Puerto Libertád-Mexico data resulted in a more nearly equal seasonal breakdown: 47% winter and 53% summer (Secretaría de Recursos Hidráulicos, 1961–1976).

In contrast with this slight disparity in favor of the summer season the winter rains are, with little question, much more effective as a factor affecting plant growth than those of the summer. Two factors appear to be of prime importance in this: (a) the summer period has markedly higher temperatures and consequently lower relative humidity than the winter; and (b) the summer rains occur largely as intense short-period storms, with much of the precipitation often lost by runoff and evaporation, in comparison with lower-intensity, longer-duration rains during the winter, a much greater percentage of which is usually absorbed and retained by the soil.

Although the summer analysis includes a longer period than the winter (7 mos. vs 5 mos.) three of the summer months, April, May and June, receive no effective rainfall. Only once, in the 16 years of record included in the Puerto Libertád-Mexico data of Table 3, did any rain fall during April. This yielded an average of only 0.2 mm; May received rain only twice (average 0.9 mm); and although a measurable amount fell once during June, this was so little as to average out at only 0.125 mm for the 16 years of record.

Both the evaporation and temperature records at Puerto Libertád-Mexico support the foregoing observations regarding relative effectiveness of the summer and winter rains. Employing the same monthly breakdowns, the mean-monthly winter and summer evaporation records (Table 4) show 126 mm per month during the winter vs 242 mm during the summer, ie—twice as high in the

Table 1. Precipitation data from Carnegie Desert Laboratory in vicinity of Puerto Libertád, (1925–1935).

Station	Average precipitation (mm)		
	summer	winter	annual
P. Libertád—Mallery	62.0	40.0	102.0
Punta Cirio—Mallery	68.0	36.0	104.0

Table 2. Location and elevation of meteorologic stations.

Station	Distance (km) air-line from P. Libertád	Distance (km) air-line from coast	Elevation above sea level (m)
Libertád—Mallery	0.02	0.02	31
Libertád—Mexico	0.0	0.01	7
Punta Cirio—Mallery	7.1	0.10	55
Punta Cirio	7.8	1.5	76
Lower	7.1	0.15	12
Upper	8.9	1.6	162
Escondido	9.4	0.8	85
Gray Hill	14.7	7.4	198
Coloradito	16.2	2.9	303

Table 3. Precipitation (mm) at Puerto Libertád—Mexico.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
1961	50	0	0	0	0	2	0	0	0	6	3	36	97
1962	52	T	2	0	0	NR*	0	T	28	0	0	38	120
1963	2	0	0	0	0	0	0	46	0	33	8	0	89
1964	2	23	4	0	0	0	18	5	0	57	14	NR	117
1965	0	8	0	3	0	0	9	0	0	0	0	56	76
1966	27	12	0	0	0	0	0	0	59	9	0	16	123
1967	0	0	2	0	0	0	7	48	10	30	27	43	167
1968	3	3	3	0	0	0	0	23	0	0	6	0	38
1969	30	0	3	0	14	0	21	16	18	T	19	6	127
1970	2	10	0	0	0	0	25	11	13	0	0	0	61
1971	0	10	0	0	0	0	0	20	6	0	12	8	56
1972	0	0	0	0	0	0	4	28	0	73	14	1	120
1973	0	37	0	0	1	0	0	2	0	0	0	0	40
1974	16	0	2	0	0	0	2	0	10	3	0	0	33
1975	NR	0	6	0	0	0	5	T	14	1	0	2	26
1976	0	2	0	0	0	0	3	1	18	1	9	2	36
Total	184	105	22	3	15	0	94	200	176	213	112	202	1,326
Ave.	12.3	6.6	1.4	0.2	0.9	0.0	5.9	13.3	11.0	13.3	7.0	13.9	82.9

*NR—No record.

Table 4. Evaporation (mm) at Puerto Libertád—Mexico

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
1961	71.7	127.5	157.4	216.8	236.9	233.1	275.3	231.4	229.5	185.3	127.9	75.3	2168.1
1962	108.9	93.4	147.5	202.7	236.7	<u>234.8</u>*	281.2	250.8	209.7	184.9	158.0	91.0	2199.6
1963	82.3	140.3	164.5	174.8	271.0	252.3	<u>258.2</u>	<u>262.0</u>	<u>233.0</u>	146.9	141.2	85.3	2211.8
1964	70.1	68.1	<u>172.3</u>	<u>196.5</u>	<u>236.2</u>	<u>234.8</u>	<u>258.2</u>	<u>262.0</u>	<u>233.0</u>	<u>192.7</u>	<u>138.3</u>	<u>102.6</u>	2164.8
1965	<u>101.5</u>	<u>116.0</u>	<u>172.3</u>	<u>196.5</u>	229.9	<u>234.8</u>	267.6	251.1	232.4	207.5	129.3	121.0	2259.9
1966	107.2	116.3	<u>172.3</u>	<u>196.5</u>	<u>236.2</u>	<u>234.8</u>	295.6	246.0	204.2	188.5	127.7	113.3	2238.6
1967	106.7	138.8	173.5	193.1	252.5	225.3	232.8	271.0	224.3	164.0	106.9	70.4	2159.3
1968	93.1	101.3	159.8	<u>196.5</u>	159.1	150.1	150.8	238.9	242.0	209.4	167.1	95.8	1963.9
1969	117.4	129.3	136.4	<u>196.5</u>	329.1	329.4	312.4	319.2	240.3	198.8	119.1	97.7	2525.6
1970	100.2	115.4	257.6	263.5	274.9	262.6	276.3	272.7	259.5	217.1	128.0	111.1	2538.9
1971	120.8	129.8	188.7	164.6	215.3	228.9	251.7	245.4	250.3	255.2	138.6	160.1	2349.4
1972	138.3	116.0	165.5	160.2	156.8	196.7	238.8	293.1	237.7	162.1	177.5	107.7	2150.4
Total	1218	1392	2068	3341	2835	2818	3099	3144	2796	2312	1660	1231	
Mean	101.5	116.0	172.3	278.4	236.2	234.8	258.2	262.0	233.0	192.7	138.3	102.6	

*Underlining indicates extrapolated data obtained by averaging the recorded observations and using this mean as the best approximation of the missing records.

Table 5. Mean Monthly Temperatures (°C) at P/uerto Libertád—Mexico.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
1961	14.0	14.0	14.7	18.4	20.5	25.7	27.8	28.5	26.9	20.9	15.9	13.5	
1962	12.3	14.1	12.4	21.0	22.9	—	28.8	30.2	28.3	22.8	19.0	15.1	
1963	11.7	15.1	14.6	17.6	22.7	22.8	29.2	29.2	28.3	24.3	17.6	13.8	
1964	10.8	11.2	13.6	17.4	20.1	23.9	29.2	28.8	27.3	24.7	20.1	—	
1965	13.0	13.0	13.4	17.4	19.8	21.6	28.2	29.5	27.0	23.0	19.4	15.0	
1966	12.1	11.9	15.2	19.2	23.5	22.2	29.5	30.0	28.8	21.4	17.7	13.4	
1967	10.8	13.9	15.6	15.7	21.2	22.9	29.4	29.3	27.3	23.3	19.2	11.2	
1968	12.5	15.2	15.8	19.4	20.1	24.8	30.0	27.8	26.6	21.6	17.2	17.6	
1969	13.6	12.8	13.8	18.4	22.0	24.8	28.9	30.8	29.0	21.0	16.6	12.7	
1970	11.7	13.6	14.6	15.6	20.8	23.9	29.1	29.9	26.7	20.3	16.1	13.0	
1971	10.0	11.8	14.6	16.2	19.3	23.5	28.9	28.9	27.5	20.2	15.1	11.8	
1972	10.6	13.2	16.9	17.5	21.1	24.8	29.3	28.2	26 5	22.1	15.3	12.4	
1973	11.5	14.2	13.5	16.0	21.2	27.7	28.2	28.6	25.9	21.1	16.4	11.8	
1974	12.4	13.0	16.8	19.4	20.8	23.2	24.1	24.5	24.7	20.4	15.5	11.2	
1975	11.7	12.8	14.8	15.3	20.5	24.9	29.4	30.0	29.7	21.6	16.2	12.2	
1976	14.1	12.9	15.3	18.8	23.5	23.5	27.5	28.9	25.7	22.2	16.1	13.5	
Total	192.8	212.7	235.6	283.3	340.0	360.2	457.5	463.1	436.2	350.0	273.4	198.2	
Mean (°C)	12.0	13.3	14.7	17.7	21.3	24.0	28.6	28.9	27.3	21.9	17.1	13.2	

Table 6. Precipitation (mm) of Humphrey Sonoran Coast Rain Gauges

Date read	Lower	Punta Cirio	Upper	Escon-dido	Gray Hill	Colora-dito	Period Total	Period Mean
11-26-67	Installed		Installed					
2-15-68	140.97		152.4				293.37	146.7
4-14-68	20.32		17.78				38.10	19.0
6-15-68	0.0		0.0				0.0	0.0
8-16-68	6.35		10.92				17.27	8.6
10-15-68	3.81		1.01				4.82	2.4
12-30-68	5.08		not read				5.08	2.5
Total	176.53		182.11					
3-27-69	15.24		20.32				35.56	17.8
7-25-69	3.30		5.33				8.63	4.3
Total	18.54		25.65					
2-14-70	17.78		92.71				110.49	55.2
7-22-70	27.94		24.13				52.07	26.0
8-26-70	19.30		12.70				32.00	16.0
11-28-70	36.83		35.56				72.39	36.2
12-18-70	0.0		0.0				0.0	0.0
Total	138.93		216.40					
3- 9-71	6.60		4.57				11.17	5.6
9- 6-71	59.69		53.34				113.03	56.5
12-13-71	27.94		23.36				51.30	25.6
Total	94.23		81.27					
6-11-72	4.57	Installed	4.57				9.14	4.5
8-5-72	0.76	0.60	1.77				3.13	1.0
9- 6-72	39.87	29.97	21.08				90.92	30.3
10- 8-72	31.75	27.94	21.33				81.02	27.0
11-11-72	40.64	45.72	40.64				127.00	42.3
12-11-72	5.84	5.58	4.31				15.73	5.2
Total	123.43	109.72	93.70					
1-11-73	3.55	3.55	3.55				10.65	3.5
2-11-73	4.82	5.84	5.08				15.74	5.2
3-11-73	38.10	36.83	34.29	Installed	Installed	Installed	109.22	36.4
4-10-73	17.78	22.86	16.00	19.05	15.24	11.68	102.61	17.1
5-10-73	17.78	10.66	10.66	9.90	15.24	11.68	75.92	12.6
6- 7-73	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7- 6-73	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8- 3-73	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8-25-73	0.0	0.0	0.50	0.50	0.0	1.52	2.52	0.4
9-21-73	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10-20-73	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11-18-73	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12-12-73	2.79	2.54	1.52	0.25	3.04	4.06	14.20	2.4
12-28-73	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	84.82	82.28	71.60	29.70	33.52	28.94		
1-25-74	24.13	26.67	25.40	20.06	29.21	26.67	152.14	25.3
2-22-74	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3-21-74	8.63	12.44	12.70	5.08	9.14	13.20	61.19	10.2
4-25-74	0.76	0.50	0.0	T	0.76	0.60	2.62	0.4
5-21-74	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6-21-74	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7-18-74	4.06	4.06	4.06	2.79	4.31	2.79	22.07	3.7
8-15-74	0.0	5.58	12.95	8.12	7.11	7.11	40.87	6.8
9-12-74	0.0	0.50	0.76	0.76	0.50	1.01	3.53	0.6
10-13-74	2.03	3.04	2.03	2.03	0.50	0.76	8.36	1.4
11-16-74	0.0	3.81	2.54	2.03	0.76	1.01	10.15	1.7
12-21-74	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	39.61	56.60	60.44	40.87	52.29	53.15		
1-20-75	5.84	7.36	7.11	6.85	6.35	7.62	41.13	6.8
2-17-75	1.52	2.03	0.76	1.27	2.03	.05	7.66	1.3
3-17-75	6.85	7.62	6.85	5.58	12.70	8.12	47.72	7.9

Table 6. (continued)

Date read	Lower	Punta Cirio	Upper	Escon-dido	Gray Hill	Colora-dito	Period Total	Period Mean
4-13-75	0.76	1.01	6.35	0.76	0.50	0.76	10.14	1.7
5-11-75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6- 8-75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7- 7-75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8- 4-75	3.55	5.08	3.30	2.54	10.66	5.08	30.21	5.0
9- 2-75	0.0	0.0	0.0	0.0	1.01	0.0	1.01	0.2
10- 1-75	0.0	0.0	0.0	0.0	5.84	7.87	13.71	2.3
10-28-75	2.28	0.76	0.0	0.0	0.0	0.0	3.04	0.5
11-24-75	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	20.80	23.86	24.37	17.00	39.09	29.50		
4-12-76	22.86	25.4	13.97	16.25	35.56	24.13	138.17	23.0
7-26-76	5.84	10.16	16.76	3.81	11.68	6.60	54.85	9.1
10-24-76	21.33	33.02	23.87	25.40	76.20	26.67	206.49	34.4
12-23-76	5.58	12.95	9.65	8.63	21.33	17.78	75.92	12.6
Total	55.61	81.53	64.25	54.09	144.77	75.18		
4-11-77	31.75	33.02	28.44	30.48	53.34	35.56	212.59	35.4
10-24-77	46.99	43.18	39.37	38.10	64.77	55.88	288.29	48.0
Total	78.74	76.20	67.81	68.58	118.11	91.44		
1-25-78	31.49	31.75	24.13	26.67	31.75	26.67	172.46	28.7
5- 2-78	40.64	50.80	48.26	35.56	66.04	60.96	302.26	50.4
8- 4-78	17.78	12.70	8.63	8.63	25.40	23.36	96.50	16.1
10-19-78	1.27	1.77	1.01	1.01	0.0	1.01	6.07	1.0
1- 6-79	114.30	116.84	110.49	101.60	158.75	135.89	737.87	123.0
Total	205.48	213.86	192.52	173.47	281.94	247.89		
4- 6-79	46.99	54.61	46.48	38.10	69.85	52.07	308.10	51.3
5-18-79	2.54	2.54	1.27	1.27	1.27	2.54	11.43	1.9
11-14-79	59.69	54.61	40.64	34.29	33.02	30.48	252.73	42.1
Total	109.22	111.76	88.39	73.66	104.14	85.09		
Grand Total	1033.17	755.81	1061.59	457.37	773.86	611.19		
Divisor	11.97	7.40	11.97	6.68	6.68	6.68		
Mean Annual	86.31	102.13	88.68	68.46	115.84	91.49		
Overall Mean Annual Average								92.15
Deviation	−5.84	+9.98	−3.47	−23.69	+23.69	−0.66		

summer as in the winter. The mean-monthly winter: summer temperature differences (Table 5) show a similar effect: a winter mean of 14°C vs a summer mean of 24°C.

Because my six gauges were read in part at intervals that do not coincide with seasons, the resultant precipitation data do not lend themselves as a whole to the same kind of seasonal analysis as those of Mallery and the Departamento de Hydrometría. They do, however, show several precipitation characteristics that are of interest.

These six gauges, separated from each other as they are, by distances ranging from 1.35 to 6 km, and ranging in elevation above sea level from 12 to 303 meters provide, and will continue to provide, a unique record of precipitation-distribution data for this area.

Although all the gauges were not in operation for identical time periods (three for 6.68 years, one for 7.40 and two for 11.97), a fact that could affect the results somewhat, a comparison of the mean-annual rainfall at the various locations is of interest.

The six stations have an average mean-annual precipitation of 92.15 mm with deviations around this mean of −5.84, +9.98, −3.47, −23.69, +23.69 and −0.66 for the various gauges in the order in which they are listed in Table 6. It might be expected that these deviations would bear some consistent relationship either to elevation or to distance from the gulf, but this did not prove to be the case.

Although minor deviations from the overall mean-annual average are to be expected and may not indicate real, long-time differences, the departures for both Escondido and Gray Hill exceed what might be considered as minor, insignificant values. Escondido, for example, averaged 23.69 mm less than average, while nearby Punta Cirio exceeded the average by 9.98 mm. Yet these gauges were separated spatially by only about 1.5 km, both were essentially equidistant from the gulf, at about the same elevation, and both were on the north slope and near the base of individual mountain segments.

The markedly lighter rainfall at Escondido cannot be attributed to one or a few individual low-intensity storms,

Table 7. Statistical analysis of differences in precipitation amounts between stations.

	Lower	Punta Cirio	Upper	Escondido	Gray Hill	Coloradito
Lower		2.43	12.63	0.30	0.26	1.89
Punta Cirio			0.01	0.00	1.24	45.10
Upper				0.92	1.27	2.56
Escondido					0.02	0.07
Gray Hill						0.07
Mean Annual Precip (mm)	86.31	102.13	88.68	68.46	115.84	91.49

since the amount recorded there was consistently less than at Punta Cirio. During the period April 10, 1973 to November 14, 1979 both gauges were read 49 times at intervals of approximately one month or longer. Seventeen of these readings recorded no rain in either gauge. During 29 of the remaining 32, or 90% of the time, however, Punta Cirio received more precipitation than Escondido.

This raises the question: are there local, sometimes proximate relatively dry "pockets" where precipitation may be markedly less than the norm? This analysis would suggest an affirmative answer. Indeed, in an extremely rugged terrain of the sort encountered here, differences of this sort, rather than essential uniformity, might readily be the norm.

In contrast with the deficiency noted at Escondido, it will be seen that the amount received at Gray Hill coincidentally exceeded the overall average by the exact amount that Escondido fell below it.

A study of Table 6 suggests that this positive deviation is due more to occasional periods of heavier than usual rainfall than to consistent precipitation differences. A marked excess at Gray Hill over the amount received in any of the other gauges occurred only 5 times: in the readings of 3-17-75, 8-4-75, 4-11-77 and 1-6-79.

The period of record is too short to conclude that the area represented by Gray Hill does have a true, long-time average greater than that of any of the sites closer to the coast, but this is suggested. The gauge is located in a wide inland basin, about 5 km northeast of the crest of the Sierra Cirio. Convection currents may influence the amount of precipitation received here as the moist air rises and is carried inland over the mountains.

A precipitation characteristic brought out by the Puerto Libertád-Mexico record (Table 3) as well as by my six gauges (Table 6) is the long duration of totally rainless periods or of periods with no effective rainfall. Note, for example, that there was no effective precipitation at Puerto Libertád from February until December 1961; from February through August, 1962; and from January through July, 1963. Several other of the 16 years during the period from 1961 through 1976 were almost as dry and may have received no effective rains for equally long periods.

Severe droughts may be protracted, covering several years. Note, for example, that during the period from 1973–1976 the total annual precipitation at Puerto Libertád ranged from a minimum of 26 mm (1.02 in.) to a maximum of 40 mm (1.57 in.). The effect of a protracted drought of this severity can be devastating to both plant and animal life, even in an ecosystem that has developed through unknown millenia under stresses of this sort. Nonetheless, in an area where the mean-annual precipitation is in the range of 83–92 mm, protracted droughts are to be expected and should be considered as normal.

The data in Table 6 were analyzed statistically to determine whether or not the differences in the mean-annual precipitation between stations are significant. Since the data are not normally distributed, the non-parametric Wilcoxon matched-pairs signed-rank test (Siegal, 1956) was used for this purpose.

The results are summarized in contingency table form in Table 7. The numbers given in the body of the table represent the percentage probability that the means for the selected two stations could have come from the same population. The application of the Wilcoxon test may not be completely appropriate here because the paired data were not always for the same time span. From August 1972 through November 1975 the gauges were read about once a month. Before and after that time anywhere from one to six months passed between readings. As long as the time interval between readings is not correlated with the sign and magnitude of the precipitation differences, which seems very likely, there should be little bias in the results.

The statistical analysis indicates that Escondido and Gray Hill are significantly drier and wetter, respectively, than the other four stations. Gray Hill apparently does experience a real increase in rainfall due to its location on the lee side of the Sierra Cirio. The aridity of Escondido is probably also terrain-induced. Apparently even small variations in the topography can produce significant differences in the rainfall regime.

Among the other four stations, Punta Cirio and Coloradito are significantly wetter than Upper or Lower. However, the range of values, 15.82 mm, is probably too small to produce noticeable vegetation differences.

Acknowledgements

I want to acknowledge and thank Dr. William D. Sellers, Department of Atmospheric Sciences, University of Arizona, for his critical reading of the manuscript and contributing the statistical analysis of the Table 6 data. I also want to thank my wife, Roberta, for her many weeks of help and companionship in the field and for her painstaking hours of data tablulation and manuscript preparation.

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Cousins to the South: Amphitropical Disjunctions in Southwestern Grasses[1]

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The study of plant distribution can be a rewarding and stimulating endeavor. Such investigations can tell us much about the plants themselves—where they grow, why they grow there, what special adaptations they possess—and also much about their relationships to other organisms—the plant and animal communities in which they occur, the history of their association, and often some of the evolutionary processes leading to their development. This field of scientific investigation (termed biogeography or, when dealing with plants, phytogeography) involves more than just recording the geographic distribution of a particular species. The explanation of that distribution often requires a synthesis of data from many disciplines, including morphology, cytogenetics, physiology, reproductive biology, ecology, and geophysics. Thus, the careful researcher often finds himself at the heart of intriguing and many-faceted problems.

Some of the more interesting distribution patterns to be found in plants are disjunctions; that is, geographic range discontinuities where populations of plants are separated by large geographic gaps. Among the most fascinating disjunctions are those with widely separated intercontinental populations. For example, *Larrea tridentata* (Creosote Bush) occurs throughout the Chihuahuan and Sonoran deserts of North America; its close relative, *L. divaricata* (some consider the two to be one species), is found in the deserts of Peru, Bolivia, Chile, and Argentina. Also, *Plantago patagonica* (Plantain, Indian Wheat), a common component of the prairies and plains throughout much of western North America, may also be found in similar habitats in Argentina and Chile. Likewise, *Koeberlinia spinosa*, one of the pernicious crucifixion thorns, has identical populations of plants in the deserts of both North and South America. Indeed, Raven (1963) has listed approximately 160 plant species with amphitropical (on both sides of the tropics) range disjunctions such as these.

Pielou (1979), in an outstanding new text on biogeography, lists five ways that plants might achieve a disjunct distribution. 1) Through movements of the earth's crust, formerly adjacent land masses may be separated (continental drift). This helps explain the similar floras of certain regions of South America and Australia which were contiguous land masses before the separation of the continents. 2) Associated with the changing positions of the continents may be a climatic change. In a very widespread species, a climatic deterioration of the central portion of the range can leave the peripheral populations as disjuncts. 3) During the adaptation process of a species, geographic isolates may be differentiated from the parent species. If the selection forces acting on the isolates are similar, then they

[1]Journal Article No. 814, Agricultural Experiment Station, New Mexico State University, Las Cruces 88003.

may evolve into more-or-less identical populations. Extinction of the ancestral species will leave only the disjunct descendants. A mechanism such as this is suggested by Raven (1963) for some species of *Acacia* found in the Chihuhuan and Sonoran deserts of North America and in the Chilean and Peruvian deserts of South America. 4) Many species of plants are adapted by a variety of ways to long-distance dispersal. Seeds of *Asclepias* (Milkweed) bear a light tuft of silky hairs at one end and are easily carried by the wind for several, or perhaps in open country, hundreds of miles. Some propagules of grasses have been found in the atmosphere several thousand feet above ground (Polunin, 1967); there is certainly a potential for long-distance dispersal in plants such as this. 5) A quick check of many floristic treatments will reveal many plant species reported only as ballast weeds in various ports. It is clear that man has played a significant role in the distribution of many plants, either introducing them deliberately for ornament or agriculture (for example, *Medicago sativa*, Alfalfa), or unwittingly in ballast, seed packets, packaging materials, or on transported animals. An interesting example of accidental dispersal involves *Cuscuta suaveolens*, a parasite of alfalfa that has followed this important crop plant around the globe.

Many grass species common in the Southwest exhibit remarkable amphitropical range disjunctions, with populations of plants in arid regions of both North and South America (Table 1). Many of these species have been discussed elsewhere (see Pielou, 1979; Raven, 1963; Thorne, 1972) and will not be considered here. But, it is instructive to analyze in detail the distribution pattern of one group of grasses prevalant in much of the Southwest, and to see what factors are brought to play in determining this pattern.

The grass genus *Bothriochloa*, familiar to many as "Bluestem," is common throughout much of the plains and rangelands of the western United States. These grasses were formerly included in the genus *Andropogon*, as the section *Amphilophis* (Hitchcock, 1951). A number of features (chromosome number and panicle morphology, among others) justify its segregation as a distinct genus, and it is so considered by most taxonomists throughout the world.

Bothriochloa may be roughly divided into two groups: those native to Australia, southern Europe, and southern and southwestern Asia (the Old World species); and those native to North and South America (the New World species). We will be concerned here with only the New World species (Table 2).

Most species of New World *Bothriochloa* are markedly amphitropical in distribution (Figs. 1–18). The distribution patterns are centered in the southwestern United States, Mexico, and the West Indies in North America; and in southern Brazil, Uruguay, Paraguay, and northern Argentina in South America. The two regions are at approximately equivalent latitudes of 25–35 degrees. Only *B. "parvispicula," B. saccharoides* var. *saccharoides*, and *B. alta* occupy interevening latitudes.

Table 1. Some grasses with amphitropical disjunctions in the semi-arid to arid lands of North and South America. Partially compiled from Raven (1963) and Thorne (1972).

Species	Distribution
Bouteloua aristidoides (H.B.K.) Grisb. var. *aristidoides*	Southwest US, Mexico; infrequent in Bolivia, Brazil, Colombia, Ecuador, Paraguay; common in northern Argentina
Bromus trinii Desv.	Coastal and intermountain US; Chile, Argentina, Peru, Bolivia
B. unioloides (Willd.) H.B.K.	Throughout southern half of US; temperate South America
Chloris ciliata Sw.	Texas, Mexico, Caribbean Islands; Argentina, Uruguay
C. crinita Lag.	Southwest US, northern Mex.; Argentina, Bolivia, Paraguay, Venezuela
C. pluriflora (Fourn.) Clayton	Texas, Mexico; Central America; southern South America
Cottea pappophoroides Kunth	Southwest Us, Mexico; Ecuador, Peru, Argentina
Digitaria insularis (L.) Ekmann	Southern US, Mexico; south to Argentina
Enneapogen desvauxii Beauv.	Southwest US, Mexico; Argentina, Bolivia, Peru
Eragrostis lugens Nees	Texas; Mexico; northern Argentina, southern Brazil
Leptochloa dubia (H.B.K.) Nees	Southern US, Mexico; Argentina
Muhlenbergia asperifolia (Nees & Mey.) Parodi	Midwest & western US, Mexico; southern South America
M. torreyi (Kunth) Bush	Southwest US, Mexico; Argentina
Panicum hirticaule Presi	Southwest US, Argentina; Chile
Phalaris angustata Trin.	Southern & Southwest US; southern South America
Schedonnardus paniculatus Steudel	Central Canada south to Texas and Arizona; Argentina
Scleropogon brevifolius Phil	Southwest US, central Mexico; Chile, Argentina
Stipa speciosa Trin. & Rupr.	Southwest US; Argentina, Chile
Stipa tenuissima Trin.	Southwest US, Mexico; Argentina
Trachypogon secundus (Pres1) Scrib.	Southwest US, Mexico; Argentina
Tripogon spicatus (Nees) Ekm.	Texas, Mexico; southern South America
Wilkommia texana Hitchc.	Southern Texas; northern Argentina

Distribution patterns such as this prompt several questions: How did the disjunction come about? When did the disjunction occur? What was the method of dispersal? And, in what direction was the dispersal? We will try to arrive at some plausible answers to these questions using evidence from morphology, cytogenetics, reproductive biology, dispersal mechanisms, ecology and habitat, and past geological events.

Table 2. Species of *Bothriochloa* native to the New World.

Taxon[1]	2n	Distribution
B. alta (Hitchc.)	120	Texas, New Mexico; Bolivia, Argentina
B. barbinodis (Lag.) Herter	180	Southwest US, Mexico; Argentina, Uruguay
B. brasiliensis (Hack.) Heur	?	Southern Brazil, northern Argentina
B. campii (Swallen)	120	Southern Mexico; Ecuador
B. edwardsiana (Gould) Parodi	60	Texas; Argentina, Uruguay
B. exaristata (Nash) Henrard	60	Louisiana, Texas; Argentina, Bolivia, southern Brazil, Paraguay
B. hirtifolia (Presl) Henr.	60	Mexico
B. hybrida (Gould)	120	South Texas, northern Mexico
B. imperatoides Herter	60	Northern Argentina, southern Brazil, Uruguay
B. laguroides (Sw.) Herter	60	Mexico, Guatemala, Honduras, Panama; southern Brazil, Uruguay, northern Argentina, Paraguay, Chile
B. "parvispicula"[2]	(60)[3]	Northern Argentina, Bolivia, Chile, Peru, Ecuador, Colombia, Venezuela, Guatemala
B. reevesii (Gould) Gould	120	Central Mexico
B. saccharoides Sw. var. *saccharoides*	(120)	West Indies, southwestern Mexico, Central America south to Ecuador and Peru
B. s. var. *longipaniculata* (Gould) Gould	120	Texas, Louisiana, northern Mexico; possibly Argentina
B. s. var *torreyana* (Steud) Gould	60	Central & southwest US, northern Mexico; Argentina
B. schlumbergeri (Fourn.) Henr.	180	Mexico
B. springfieldii (Gould) Parodi	120	Southwest US; Argentina
B. wrightii (Hack.) Henr.	120	New Mexico, northern Mexico

[1]The nomenclatural status of many of these names is currently under re-evaluation. I have followed the most accepted usage, such as found in Gould (1975) and Burkart (1969).

[2]This taxon was originally named as *Andropogon saccharoides* subsp. *parvispiculus* Hitchc., but the combination in *Bothriochloa* has not yet been made. Preliminary studies indicate a close relationship to *B. alta*. Its correct disposition in *Bothriochloa* awaits further investigation.

[3]Chromosome numbers in parentheses were inferred from pollen diameters (Allred, 1979).

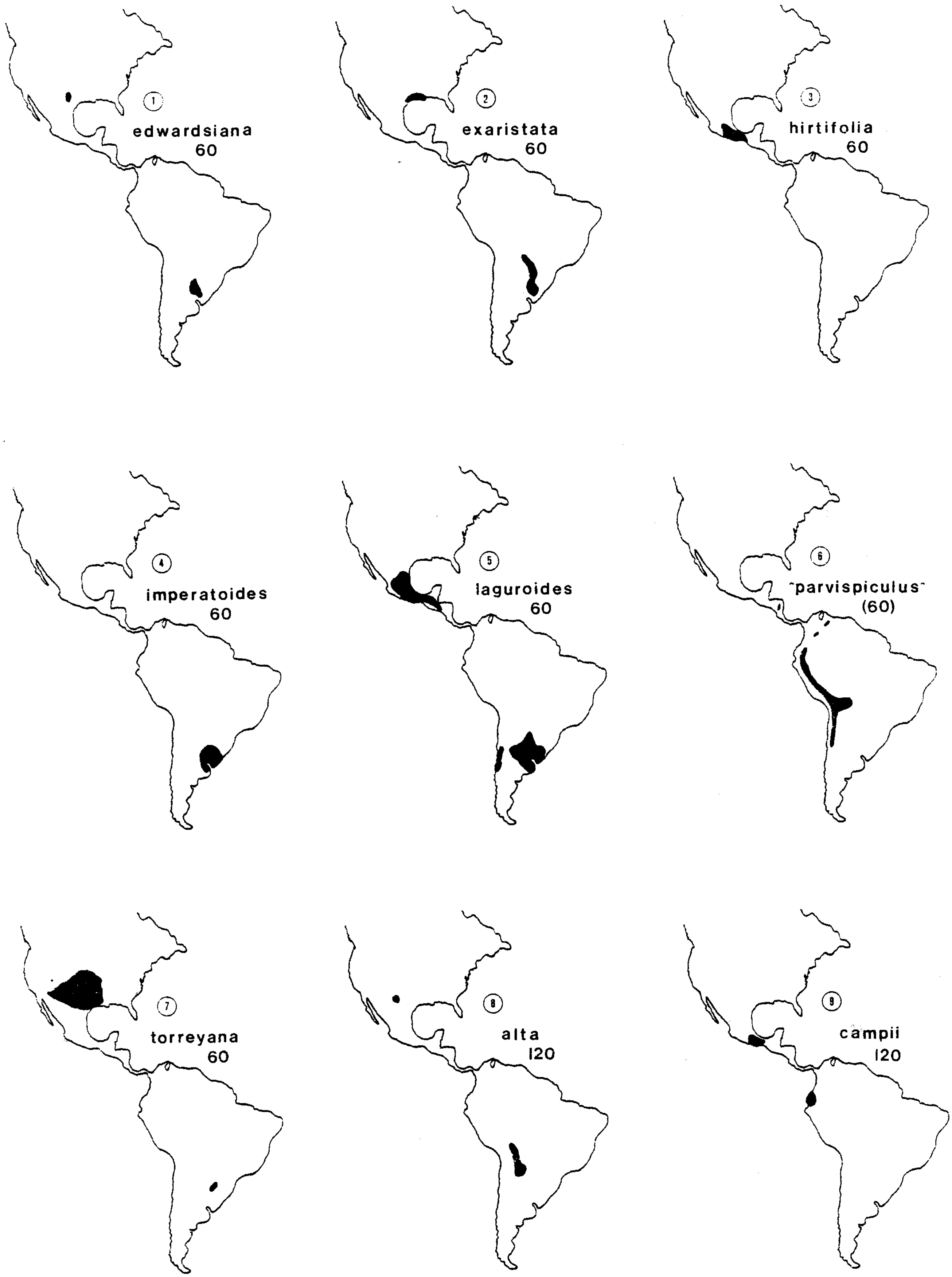
Morphology. Studies of the morphology of these species (Allred, 1979, and unpublished data) indicate that the disjunct populations are essentially identical. Plants of *Bothriochloa laguroides* from South America, for example, look just like the plants of this species from North America. Apparently, no visible evolutionary divergence has taken place. One would certainly expect to find some differences between populations that had been isolated for long periods of time. The absence of such differences implies that the disjunction was achieved in recent times.

Some *Bothriochloa* may be classed as vicarious species or vicariads. *B. alta*, for example, occupying a bicentric distribution, is very similar morphologically to *B. "parvispicula,"* which is restricted to the southern continent. The two vicariads appear to have been derived from the same genetic stock. *B. imperatoides* and *B. springfieldii* show a similar relationship. Comparative studies of these vicariads should help to determine if they are really separate species, or if they represent intermediate stages in the speciation process. The second conclusion would warrant their merger into a single species with two subspecies or varieties.

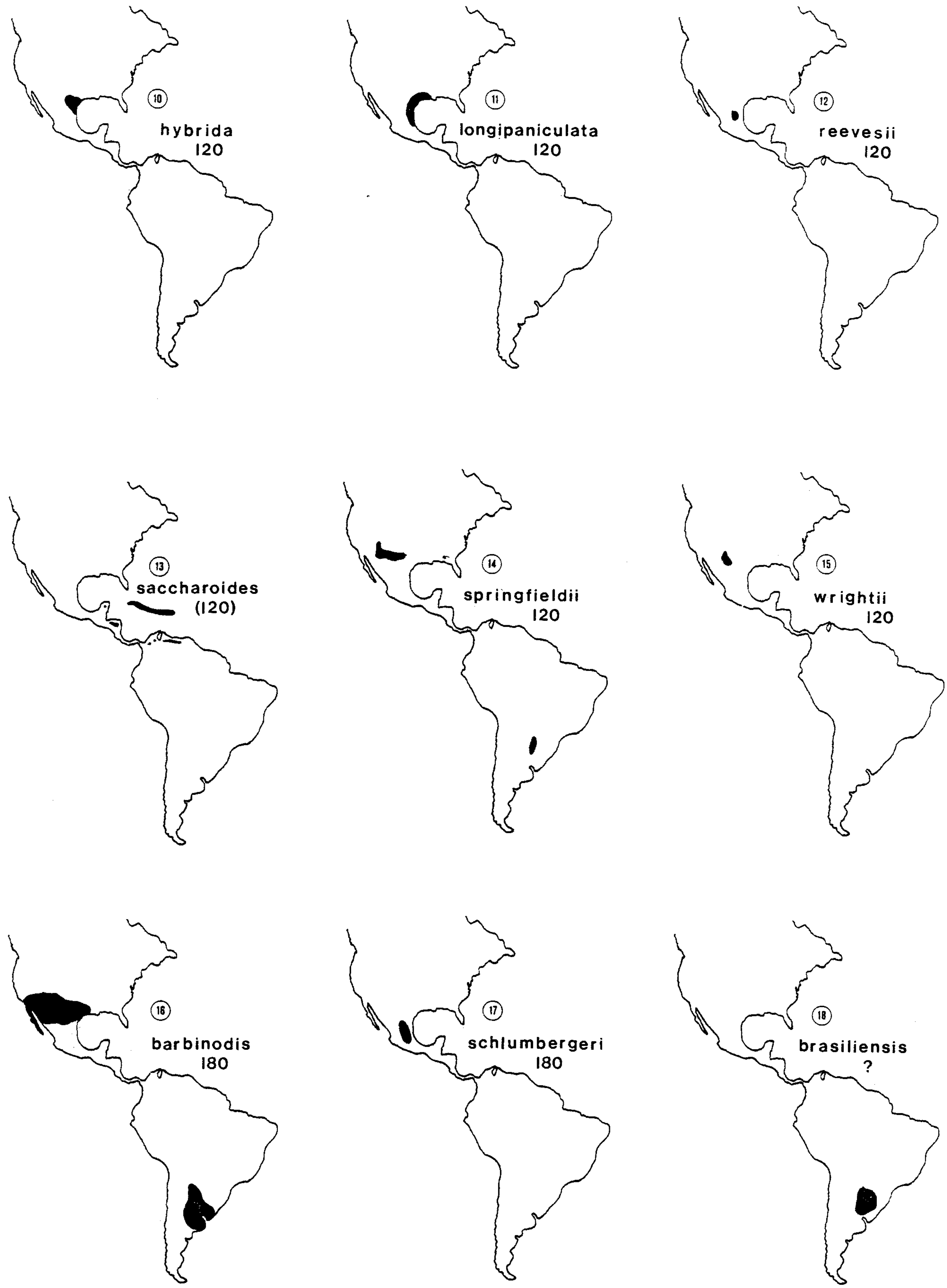
Cytogenetics. The study of chromosome numbers helps to refine the conclusions based on morphology alone. The New World *Bothriochloa* exhibit a remarkable polyploid superstructure with multiplication of a basic chromosome complement of 60 (Table 2). If we compare the distribution of the hexaploids (2n=60) with that of the duodecaploids (2n=120), we find that almost without exception the hexaploids are present in South America (and many also in North America), but most of the duodecaploids are restricted to North America. Assuming the lower polyploids to be ancestral to the higher polyploids, this distribution pattern suggests a South American origin for the complex, with migration proceeding northward. Raven (1963) suspects the same to be true of most desert plants with an amphitropical disjunction, in contrast to the presumed North American origin of many temperate (non-desert) and polar disjuncts.

Reproduction. Available evidence for about two-thirds of the species indicates that these grasses reproduce sexually with a self-compatible pollinating system (Allred, 1979: Gould, 1956, 1957; deWet et al., 1963). Self-compatibility bestows a great advantage to any colonizing species: a single propagule may effectively establish a new colony of plants. Dependence on other plants for cross-pollination or on specialized pollinators is eliminated. Self-compatibility accounts in part for the weedy tendencies of many *Bothriochloa*. They are common along roadsides and other disturbed area where competition to an invading seedling is reduced. The successful introduction of a single plant in such areas establishes a permanent seed source for a future population.

Seed production is apparently high in this group of grasses (Allred, 1979). It is estimated that a single inflorescense of Silver Bluestem (*Bothriochloa saccharoides* var. *torreyana*) might contain as many as 160 viable seeds; a mature plant will produce about 3–4 such inflorescences in a growing season; this results in a potential of about 550 viable seeds being produced each year by one plant. Even a very low seedling establishment percentage of 0.5% could result in a population of 30 plants in 3 years time, from a single introduction.



Figures 1–9. *Distribution maps for New World species of Bothriochloa. Chromosome numbers follow the names and are placed in parentheses if inferred from pollen diameters.*



Figures 10–18. *Distribution maps for New World species of Bothriochloa. Chromosome numbers follow the names and are placed in parentheses if inferred from pollen diameters.*

Figure 19. *Propagule of Bothriochloa. Left: pedicel. Center: spikelet (with seed) with pedicel and rachis. Right: rachis.*

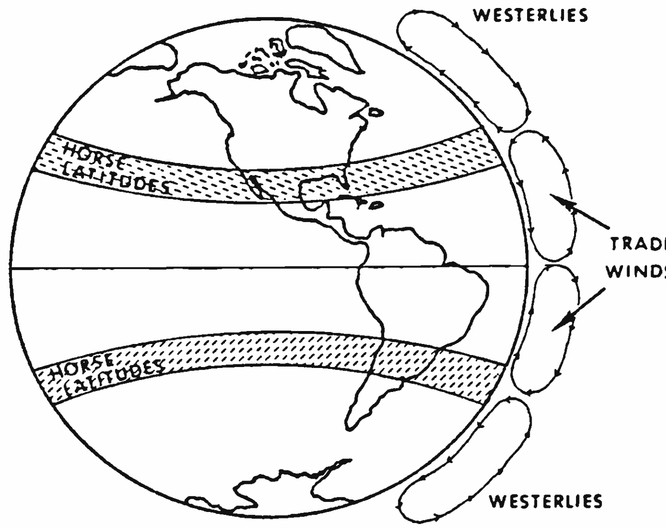


Figure 20. *Position of the Horse Latitudes and atmospheric wind currents in the New World.*

Apomixis (the production of seed without fertilization of gametes; ie., asexually) has not been reported in the New World *Bothriochloa*, although it is extremely common in the Old World species (de Wet et al. 1963). The occurrence of apomictic reproduction would further enhance a plant's colonizing ability, as the vagaries of wind pollination would be circumvented, and seed production would approach 100% efficiency.

Self-compatibility and high seed production do not, by themselves, implicate one method of disjunction over another. But, the predominance of these two biological features accord with a hypothesis of long-distance jump dispersal involving few propagules.

Dispersal Mechanisms. The dispersal unit, or propagule, in *Bothriochloa* is a compound structure comprising a spikelet with seed, a section of rachis, and a pedicel (Fig. 19). The rachis and pedicel are densely plumed with soft, white, silky hairs. The whole structure is extremely light and easily airborne and rafted by the wind.

As Darlington (1957) pointed out, it is easy to underrate the potential of wind as an agent of dispersal. A small propagule of *Bothriochloa* has an extremely large surface to weight ratio when compared to that of larger objects. As size increases, surface increases by the square, but weight increases by the cube. With our immense size (when compared to a *Bothriochloa* propagule!), it is difficult for us to appreciate the extreme effect wind may have on very small, light objects. Surface winds are certainly capable of lifting the plumed propagules of *Bothriochloa* above the ground and into atmospheric zones of rising air currents, where they may be carried for long distances.

Long-distance dissemination by wind offers one mechanism for the disjunction in *Bothriochloa*. On both continents, the arid and semi-arid regions inhabited by *Bothriochloa* are located at the Horse Latitudes (Fig. 20). These are zones of descending air masses that become warm and accumulate moisture rather than deposit moisture. Consequently, much of the land area in the Horse Latitude are deserts. Conceivably, propagules from South America could be transported northward by the tradewinds and deposited in a favorable environment by the descending air masses at the Horse Latitudes.

Birds have been proposed as dispersal agents to explain similar amphitropical distributions in other plant groups (Cruden, 1966; Raven, 1963). This would require the seed to be either carried outside the body, by adhesion to mud, debris, or feathers, or to be carried internally and to be resistant to digestion or breakdown. There is some controversy concerning the actual effectiveness of long-distance transport by birds, with Löve (1963) summarizing the arguments against, and Ridley (1930) and Polunin (1967) stating the case for.

In either case, *Bothriochloa* do not appear to be candidates for long-distance bird dispersal. In view of the significant adaptations developed for wind transport, it would seem unlikely that a second suite of adaptions for bird dispersal would evolve independently.

Ecology and Habitat. Most of the New World *Bothriochloa* are distinctly weedy, comprising a major floristic component of disturbed or modified environments. In North America, at least, they are common along highways and ditchbanks, near agricultural fields, in old fields and abandoned lots, and wherever man has bared the soil and disturbed the habitat. Most species also form an integral, though not a dominant, part of prairies, savannahs, and deserts throughout the Southwest. These are all "open" habitats in which establishment following long-distance dispersal is made easier.

The prairies and desert grasslands of North America apparently originated only since Pliocene times, roughly 10–12 million years ago (Axelrod, 1958; Dix, 1964). This means the disjunction of North and South American *Bothriochloa* was also achieved during the last 10 million years, when the climatic and vegetational factors in the Southwest would have been similar to what they are now. The present widespread distribution of many *Bothriochloa* species (Silver Bluestem, for example) has resulted from an expansion of an earlier restricted range,

Bothriochloa springfieldii *in West Texas.*

undoubtedly heavily influenced by man's disturbance of the habitat.

Past Events in Geologic Time. A study of the geologic history of the earth (see Kummel, 1970, for an excellent treatment) discloses many, often drastic, changes in the earth's crust, the position of continents, climate, and the life forms that inhabited various regions. Many of these changes affected only indirectly the distribution of *Bothriochloa* in the New World, but some can be brought to bear on our case study.

Several different times during their long history, portions of the North and South American continents were covered by the sea. During the late Cretaceous period, a vast epicontinental sea inundated roughly what is now the great plains region of the Midwest, stretching from the gulf coast to the Arctic, and divided North America completely in two. By about this same time, the oceans had also encroached upon the east and west coasts of South America (Fig 21). Smaller seas have covered various portions of both continents since that time, generally flooding the coastal shelf areas. The latest inundation of these coastal areas probably took place during the Pleistocene, with the furthest advance inland presumably coinciding with the last warm interglacial period about 8–10 thousand years ago.

The distribution patterns of *Bothriochloa* seem to be concentrated in these areas of past epicontinental seas. Such taxa as *B. exaristata* and *B. imperatoides* are currently somewhat restricted in range to coastal (or once-coastal, in South America) areas and have failed to extend their ranges.

The extensive glaciation that took place in North America during the Pleistocene had the effect of compacting the climatic and vegetational zones, and of pushing these zones southward toward the equator. Glaciations in South America, though not as extensive, may have had similar effects, although much of the shift in zonation may have been east-west rather than north-south. The

Bothriochloa barbinodis, *Cane Bluestem, in West Texas.*

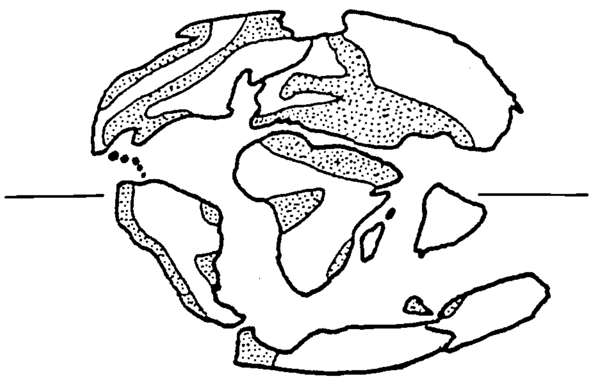


Figure 21. *Position of the continents at late Cretaceous. The stippled areas show the locations of past epicontinental seas. Redrawn from Pielou (1979).*

result was that suitable habitats in North and South America were closer together than they are now, and the chance for floristic exchange was at its greatest.

Conclusions. The disjunction of the New World *Bothriochloa* is most likely a recent event. Speciation within the group has apparently proceeded by way of polyploidy events, a rapid process compared to the gradual differentiation of populations through natural selection and reproductive isolation. Even though the disjunct populations are separated by nearly 5000 kilometers, the disjunction is recent enough that no morphological differentiation has taken place. The prairies and desert regions inhabited by these grasses originated by at least the Pliocene, but were accessible to uninterrupted invasion only since post-Pleistocene times when the sea retreated for the last time. Increasing aridity and the expansion of open habitats provided suitable environments for invading grasses such as *Bothriochloa*. Greater species diversity and the relative deficiency of higher polyploids (2n=120, 180) in South America also implies a southern origin with migration proceeding northward.

Long-distance dispersal is made possible by the extremely light, feathery propagules of nearly all species of *Bothriochloa*. They are easily airborne and capable of being carried long distances by the atmospheric wind currents. Because of self-compatibility and high seed production, even a single propagule could give rise to an established population. The efficiency of wind dispersal is attested by such widespread taxa as *Bothriochloa barbinodis* (Cane Bluestem) and *B. saccharoides* var. *torreyana* (Silver Bluestem). The latter taxon has made its way over the Rocky Mountains westward into eastern Utah, and up the Colorado River drainage into southern Utah, both distant outposts from the main geographic assemblage in the Great Plains and Southwest. This range extension into Utah is represented by only a very few plants at two stations, and apparently occurred during the last half-century. The populations were discovered in 1972 and 1978 in areas that were well-collected in the past, and are restricted to disturbed ground along major highways. In addition to wind dispersal, man's activities are probably playing a role in the current distribution of *Bothriochloa*. Open environments where competition is at a minimum are constantly being made available, and human transport to these environments, along the major roadways, is likely.

The factors involved in the distribution of *Bothriochloa* are typical of most of the desert amphitropical grasses that we find in the Southwest. It is unusual, however, to find a genus in which so many of the species possess such a remarkable bicentric distribution. The Old World species of *Bothriochloa* also pose several interesting questions. Why is it that the two groups are so completely separated on different continents, yet have maintained enough similarity to be classed in the same genus? Has long-distance dispersal also played a role in their distribution, or must we invoke some other causative agent? And, when did the two groups separate, was continental drift involved, and will further biogeographic studies shed some light on the origin and development of this interesting genus? A detailed study of *Bothriochloa* will not only provide some answers to these questions, but, it is hoped, suggest new questions as well.

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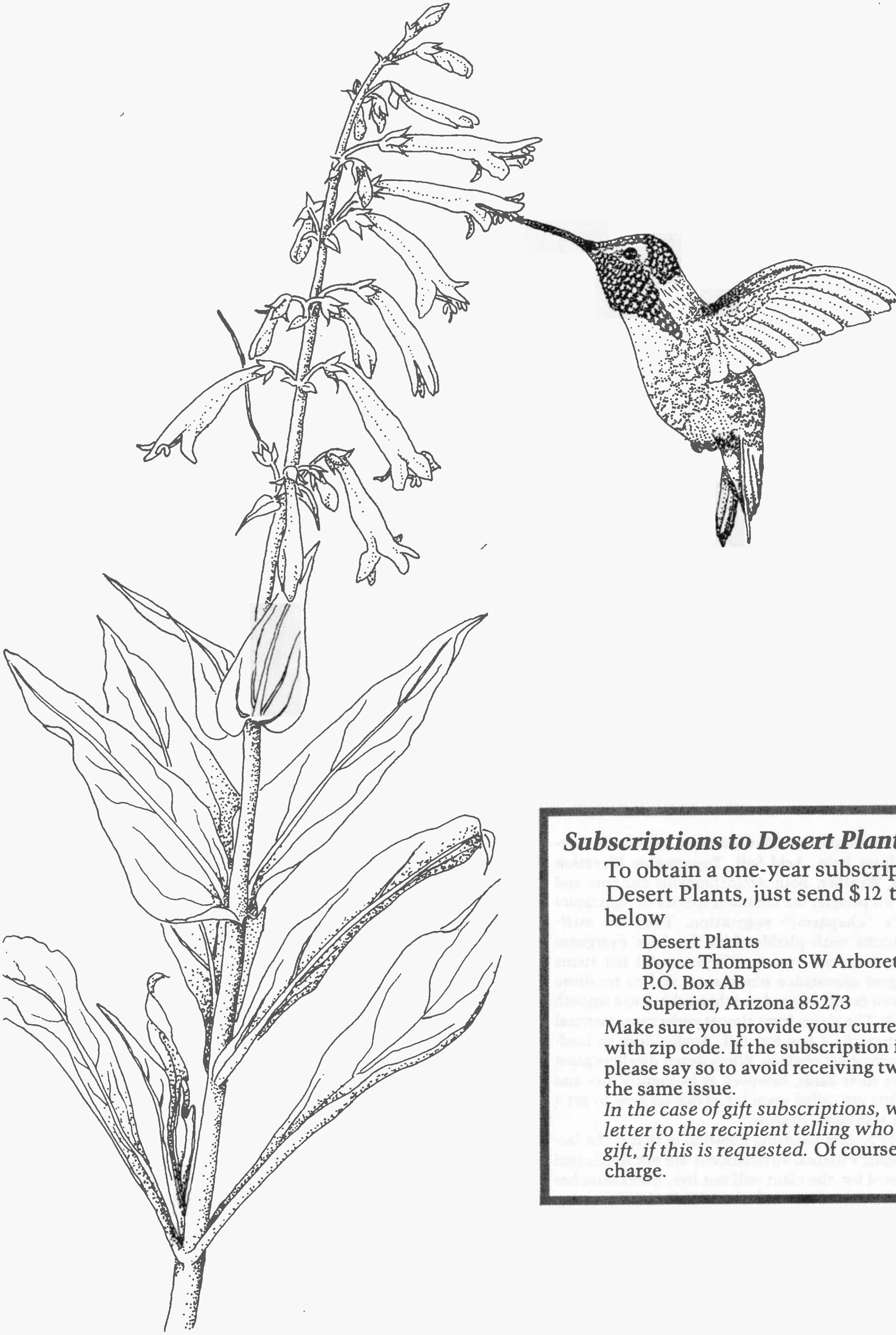

Manzanita (**Arctostaphylos pungens**) *in the chaparral about twelve miles northeast of the Boyce Thompson Southwestern Arboretum.*

How the Distribution of Manzanita in Arizona is Governed by Winter Rain, Acid Soil, Topographic Elevation and Freezing Weather. Both *Arctostaphylos pungens* and *Arctostaphylos pringlei* are common species of Manzanita in Arizona's "chaparral" vegetation. They are stiff-stemmed shrubs with pliable thick leathery evergreen leaves and a deep root system. The beautiful red stems have an elegant appearance reminiscent of fine furniture which has been deeply stained and then rubbed to a smooth mellow finish. The plants form almost perfect symmetrical rounded hummocks a few feet tall. Applications in landscape architecture are obvious. When desert dwellers plant Manzanita in their yards, however, it frequently dies and plant scientists are called upon for advice on how to get a replacement Manzanita to grow.

The answer to this recurring question is that if the factors of the plant's natural environment are not duplicated or compensated for, the plant will not live. Manzanita has the characteristics of an arid plant. Indeed it is a true sclerophyllous xerophyte because of the water-conserving anatomy of the leaf. The plant endures long hot summers and can live months with no rain at all. But this is deceptive. Gardeners need to become better acquainted with the factors that govern its distribution to determine if they are capable of growing it in their habitat.

First, Manzanita belongs to the Heath Family of plants, the **Ericaceae.** Species in this family generally are limited to **acid soils.** This is true of *Arctostaphylos* as well. Therefore it will grow on soil derived from granite or its extrusive equivalent (rhyolite) or a siliceous sedimentary rock such as many sandstones. It will not grow well on alkaline soils of the Phoenix-Tucson area and particularly not where caliche ($CaCO_3$) is present. Manzanita has a deep root system which must be in contact with moisture at all times. The "chaparral" vegetation to which Manzanita belongs is found only in parts of the world where there are dry summers but rain in the winters. The evergreen sclerophylls grow and make food in winter and are rather dormant through the summer dry season. Winter daytime temperatures need to be high. The seeds need a cold treatment for germination, so winter nights should be in the freezing range.

Rather dependable precipitation should fall in winter to charge the soil with moisture to last for many months. At elevations of 3,500 feet or more in Arizona there is usually sufficient orographic effect for seasonal precipitation to fall from Pacific cyclonic systems which are forced to rise up to pass over the regions of topographic relief. Manzanita occupies the dry sites in these regions, being replaced by oaks and conifers where moisture is more abundant or by cacti where freezing temperatures are not so severe.