Final Report

Restoration of Abandoned Farms Project

Part I

Ecosystem-level consequences of Farming and Abandonment: A Restoration Strategy based on Landscape Processes

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Submitted by

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DISCLAIMER

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CONTENTS

SUMMARY

This paper recounts the ecological history of the lower Santa Cruz Valley in Pinal County, Arizona, which experienced rapid agricultural development in the 1940s, followed by gradual decline and abandonment of 26% of all cultivated areas by 1983. In order to restore some of the original desert saltbush ecosystem (Turner 1974a, b; Brown 1982), it is necessary to understand its former and current dynamics. Agricultural development changed many fundamental properties of the valley: flooding frequency, intensity, and geographical pattern were altered by the creation of a canal in 1910, and then by channelization or removal of major and minor natural drainage networks later in the century. Eighty to 90% of the desert habitat was eliminated, and the remaining areas are mostly small, isolated fragments that are ineffective in transporting seeds long distances for recolonization. Soils were altered structurally and biotically by tillage, irrigation and pesticide use. Groundwater levels were reduced by 30-120 m (100-400 feet) or more throughout the valley. Human memory of the former ecosystem resides with an aged population who cleared the desert land for farming without having lived in it long enough to understand its former dynamics.

Three nested strategies are proposed which place priority on restoration of watersheds. While many aspects of the ecosystem will have been changed irrevocably by the loss of permanent flow in the Gila River, it is possible to partially restore surface hydrology by reintegrating parts of wash systems, and linking patches of desert with restored abandoned land along washes. Channelized washes could be redesigned to disperse floodwaters across abandoned fields seeded with native plants. Alternative (2nd priority) strategies emphasize the importance of landscape pattern. These strategies connect existing patches of desert vegetation with one another through re-seeding of abandoned farmland between them. The advantage of this strategy is greater effective habitat areas for animals, especially predators. A 3rd priority strategy would approach restoration as a human-oriented, recreational activity, and would focus on popular recreation spots or areas near population centers.

LIST OF TABLES.. Page

LIST OF FIGURES .... Page

INTRODUCTION

Central Arizona's lower Santa Cruz valley, like many other valleys across the state, once supported a booming farm economy. Today the area is littered with signs of failure--rusting irrigation pumps and cotton gins, decaying rural hamlets and, in some places, abandoned fields stretching dully to the horizon, a few weedy shrubs clinging to the grid of crumbling irrigation ditches and decades-old furrows. It is easy to imagine, from the wreckage, what this place looked like in its heyday. It is more difficult to imagine what it looked like before that. Will it ever recover? Just as a grand but neglected Victorian house compels some people to scrape off the old paint, remove the tacky shag carpeting and restore the house to its original grandeur, this abandoned farmland calls to some of us to to repair the damage. We feel a sense of obligation to put things back the way they were, to alleviate an eyesore which daily accuses us of creating a wasteland.

Ecosystems, however, are different from Victorian houses, because their structures--the plants, animals, soils, and their interrelationships--are not rigidly fixed, but elastically tied to dynamic, interlocking processes. These processes may include fire, flooding, climate, food webs, and soil development, and they change over different time scales. Restoring process is as important as restoring structure. Ecological restoration is an attempt to repair damage to ecosystem structures and processes, but this implies we know what an ecosystem should look like and how it should behave. We have to deduce what is "natural".

It has been common practice among ecologists to judge the character of nature by mentally extrapolating from pieces of land whose human use is merely unrecorded. For example, many areas of rainforest in the Amazon, once said to be "virgin," are actually living grocery stores of useful plants, sought after, collected, and transplanted by indigenous people (Stevens, 1990). The more human influence an ecosystem has sustained, the more time and effort must be spent reconstructing its "nature" before attempting to restore it. In order to reconstruct radically modified ecosystems such as that of the Santa Cruz Valley, we need a rigorously documented and independently corroborated timetable of human-induced changes, placed in the context of constantly changing climates and soils. The first step in ecological restoration of a place is the re-telling of its history, from the ecosystem's perspective.

Instead of tracking ideas, leaders or movements of people, an ecological history traces the changes in rivers, soils, climate, vegetation, fire regime, and populations of animals and plants, as they are affected by humans and one another. My purpose is to construct an ecological history of the lower Santa Cruz Valley. I describe the agricultural use of the lower Santa Cruz valley from 1886 to the present, and its affects on vegetation, surface waterways and groundwater. Then, I present three nested strategies for restoration based on these findings. The results of experiments to test different methods for establishing a few key species of desert plants native are presented in a separate paper.

METHODS

The lower Santa Cruz valley (Pinal County, Arizona, 32°30'-33°00' N, 111°22'30"-112°00' W) is a basin surrounded by mountains that has filled up with alluvium from the Gila river, the Santa Cruz river, and tributary drainages. Elevation ranges from 347 m to 610 m. The climate is hot and dry. Mean annual precipitation is 150-250 mm; 40% falls in locally intense summer thunderstorms from July to September, and the balance in more widespread and predictable winter rains from December-March. Mean maximum temperature in July is 40.5 C (105°F); mean annual temperature is 20 C, and the mean frost-free season is 240-325 days (Sellers and Hill, 1974). Figure 1 shows the approximate location of the Santa Cruz river and surrounding irrigated agriculture in Pinal County, Arizona.

Mapping and Quantifying Land Use from Aerial Photos

I wanted to find out if I could correctly determine from aerial photographs whether a given site had been cultivated at one time, or whether it was necessary to combine aerial photo interpretation with field surveys. I obtained a complete set of historical aerial photos (1936, 1949, 1954, 1964, 1970, 1979 and 1983) and 7.5' topographic maps (USGS 1961-1983) for a 2330 ha (9 square miles) area centered around the intersection of Federal Interstate highway 10 and Toltec Highway. This area had a mixture of abandoned fields and apparently undisturbed vegetation. I visited all parts of this region, judging land use from field surveys, and comparing field notes to recent and historical aerial photos and topographic maps. A similar field/photo/map method was applied to a second 2300 ha area near the intersection of I-10 and Valvista Road, in a contrasting vegetation type.

Within the areas of intensive study, most fields were abandoned after 1949, and these were all clearly identifiable in field surveys by the presence of weedy vegetation, furrows and irrigation ditches. They were equally obvious on aerial photos by the presence of parallel ridges (furrows) often accentuated by weedy vegetation; and on topographic maps by leveled topographic contours and irrigation pumps. One field in the study area was abandoned between 1936 and 1949. That is, the 1936 aerial photo showed no sign of cultivation, and the 1949 photo showed a neglected field. This field was independently identified as abandoned in the most recent (1983) aerial photo, and confirmed in a ground survey. Only one field abandoned before 1936 was detected in the 1936 photos; this was also was correctly identified on 1983 aerial photography as abandoned, but incorrectly judged in a field survey. Thus, aerial photography was more dependable than a ground survey. This was probably due to the sparse vegetation. Large scale patterns of vegetation following old furrows are not always apparent on the ground but are obvious from the air, as are subtle field boundaries.

This procedure only tested my ability to identify fields abandoned within a few decades of the earliest aerial photos, but probably not before the turn of the century. This was demonstrated by my experience in the east side of the valley, where I repeatedly visited an area (T7S R8E Section 11) in order to study the diverse desert vegetation. After over a year of study, I finally recognized the ancient irrigation ditches and furrows in association with 800-year-old Hohokam civilization artifacts (R. Breunig, personal communication). Therefore, my judgements of land use history based on brief field surveys were dependable for the period of European settlement in this century only.

In addition to this intensive study, I examined 1936 and 1983 photos for the entire study area, visiting as many native desert stands and abandoned fields as possible. In all field surveys I noted species composition and distribution, and compared these to the aerial photos. This made it possible to recognize land use consistently on aerial photos of the entire region.

Aerial photo interpretation and mapping

I quantified recent land use patterns by interpreting 1:24,000 scale 1983 aerial photos of the eastern half of the Pinal County farming region and its bordering lands (Figure 2; 32°30- 33°00'N, 111°22'30"-111°45'W). I examined each section (one square mile or 259 ha) of the 388 sections (228,407 ha) in the region, and recorded on a 1:24,000 topographic map the outlines of land use for each section. Land uses were classified according to 6 categories: native, cultivated, abandoned, developed, cultivated-developed and native-developed based on the experience with photos and field studies described above.

"Native" or never-cultivated parcels showed rough-textured vegetation that follows natural topographic patterns, and showed no sign of development or cultivation (buildings, excavation, furrow lines, dead-level topography, or presence of an irrigation ditch or well). "Cultivated" areas had even, dark coloration indicating a crop, or an even-textured light surface indicating bare, weed-free soil. "Abandoned" land shows uneven vegetation, often densest in the lowest areas of the fields, and signs of cultivation as described above. In addition, it showed no signs of subsequent activity such as homes, industries or golf courses. "Cultivated-developed" land showed clear evidence of having been cultivated and then converted to another use. In most cases, old fields were platted out for housing developments that never materialized. "Native-developed" land showed no signs of cultivation, but was developed for houses, mining (e.g. a gravel pit), or other industry. Some remnant native vegetation existed in these areas, but was reduced in density and structure. Topographic map symbols (roads, buildings, wells, mines, and topographic contours) were very helpful in identifying land use up to the date of their publication (1963 for some areas; 1981 for others).

In order to determine the amount of abandoned farmland and native vegetation from the map, I measured the total area of each land use category in each mile square section. In most cases, fields and other land uses were regular polygons. In these cases the size in hectares of each land use category within a section was determined by measuring the dimensions of the polygons and calculating area. For irregular shapes, area was determined with a dot counter. Distortions in area estimates caused by the photos were avoided by adjusting the measured land area in each land use category on a proportionate basis so that each section always totaled to 259 ha. This was preferable to using orthophotoquads (photos corrected for areal distortion) because the quality of these is too poor to adequately judge land use.

Land use information on the topographic maps was first color coded for land use type, then digitized on separate layers for each land use, and printed using AutoCAD 12.0 (Autodesk Inc., 1991). Initial drawings were checked against the original data maps for digitizing errors. Then they were checked against 1991 water rights maps provided by the Arizona Department of Water Resources. Any land that we mapped as "cultivated", but did not posses a right to use groundwater for crops, was reclassified as abandoned. This procedure helped to correctly identify land which looks cultivated, but is in fact no longer farmed. Land that appeared weedy and abandoned on 1983 aerial photos, but possessed water rights and was occasionally farmed, was incorrectly identified. Figure 3 shows the results of the mapping study for native (never cultivated or developed) and land that has been cultivated at one time. Figure 4 shows the distribution of abandoned and cultivated-developed land in the study area.

Groundtruthing. With the help of an assistant, in November 1991 I checked a portion of the land use map in the field by driving two, north-south transects on the western edge and in the center of the mapped area, and noting present land use. Using binoculars, I was able to determine land use on both sides of the road up to one-half mile into the section. Current land use was marked on the same topographic map as that used for recording data based on aerial photography. We drove 79.5 km (48.5 miles) through the center of two quadrangles, "Eloy North" and "Eloy South" and thus were able to directly observe 159 linear kilometers (97 miles) of fields and approximately 12,560 ha (48.5 square miles).

Of twenty-two locations mapped as native, 20 were confirmed to be native in the field survey and two were actually abandoned fields. Of 86 fields mapped as cultivated, 51 were cultivated and 36 were abandoned. Of 52 fields mapped as abandoned, 50 were still abandoned and two were cultivated. The large number of errors in identifying cultivated land are probably due to new abandonment between 1983 and 1991, rather than an incorrect assessment of the aerial photos. Thus, our map is conservative in its estimate of currently abandoned land.

Quantifying landscape features. In order to further quantify the patterns of native and abandoned land within the agricultural area, I intensively sampled the middle portion of the mapped area, an 11.5 x 41.1 km band comprising three USGS 7.5 minute quadrangles ("Coolidge," "Eloy North" and "Eloy South") totaling 46,620 ha (Figure 5). The perimeter and area of each native stand was measured by AutoCAD (Autodesk Inc., 1991). I measured the distance from each patch of native vegetation to its nearest neighboring patch, using a 1:24,000 scale reproduction of the land use map.

— Following the methods of Smith et al. (1993), I quantified the distance from open (cultivated or abandoned) points to a source of native shrub seeds. I established a grid with lines 100 m apart, and generated 45 random coordinates within each quadrangle that fell within abandoned or cultivated land. Then I measured the distance from each point to the nearest native desert patch, regardless of whether in fell within or outside of the core study area. The distances were not normally distributed, and several transformations failed to normalize the data, so median distances are reported.

Interpretation of Agricultural Statistics

In order to independently assess the accuracy of the mapping study, I consulted the 5-year U.S. Census of Agriculture for the years 1944-1987 (U.S. Bureau of the Census, various years). The census data did not provide comparable statistics prior to 1944. Additional data were obtained for the period 1905-1987 from the Arizona Agricultural Statistics Service (various years) and the Arizona Crop and Livestock Reporting Service (1966, 1981), and from annual reports of the Arizona Agricultural Experiment Station from 1949-1954 (Barr 1950, 1951, 1952, 1955). Using these data I plotted total hectares harvested over time to determine the maximum extent of cultivation (Figure 6). The maximum was in 1952-1953, dates also reported by Shapiro (1989).

The lower Santa Cruz valley is completely contained within Pinal County (Figure 1), and is the major farming region in the county, so county statistics were useful in drawing conclusions about the area. However, two other smaller farming regions, the Gila River Indian Reservation, which operates farms along the Gila river, and the Magma area north of the Gila, also fall within Pinal County. Therefore, county-wide statistics were influenced by factors other than those I was able to directly observe in field studies.

To estimate the amount of land that is no longer cultivated, I compared "total cropland" in the Census of Agriculture for 1954, near the peak of agricultural production, with the latest available 1987 Agricultural census (U. S. Bureau of the Census 1954, 1987;

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Table 1; Figure 7). The "total cropland" census category had a consistent definition in both surveys, and appeared to refer exclusively to land which was cultivated at some time. "Total cropland" included both land from which a crop was taken, an orchard or nursery; pasture (as distinguished from "rangeland"), land on which all crops have failed, land enrolled in commodity set-aside programs, cultivated fallow land, land in cover crops, and "idle" land. "Idle" land was not precisely defined in either census, but based on all other types of land in farms, it appears to be cleared land that was not currently in use.

The difference between total cropland in 1987 and 1954 reveals the amount of land that is no longer censused (Figure 7), but not the fate of the missing area. There are three plausible fates. First, it could have been turned into housing developments, golf courses, or other "developed" purposes. Second, the land could have been used for grazing. Third, it could have been abandoned. Although urbanization has eliminated much cropland in Maricopa County (the Phoenix area) and some cropland in Pima county (the Tucson area), this is not the case in Pinal County. About 3100 ha (12 square miles) were initially developed for houses, complete with street names and water hookups, but almost no one built a house there. This fate was documented in the aerial photo mapping as "cultivated-developed." Grazing cannot be detected in aerial photos, so I had no formal way to assess how much formerly cultivated land is grazed rather than abandoned. In field surveys I have observed sheep and cattle grazing on a few old fields in the winter and spring during years of above average rainfall, but the practice was not widespread.

Two other census statistics were used to characterize changes in land use and the valley ecosystem. "Woodland" is defined as "all wood lots and timber tracts and cutover land with young trees which have or will have value as wood or timber." "Brush pasture," probably meaning desert scrub vegetation, was specifically excluded from this category. Since the only commercially valuable timber existed on the valley floors or at high elevations outside the county, "woodland" was a good indicator of the extent of mesquite (*Prosopis velutina*) forests. "Other . . .wasteland" included "tilled and untilled areas that were not cropped or grazed, around houses, outbuildings, roads, and ponds." While this definition was ambiguous with respect to the status of native vegetation and did not indicate the degree of disturbance, it may to some extent reflect the occurrence of small patches of native desert persisting within farms.

Documenting Changes in Surface Hydrology

Most reports of the Santa Cruz river vaguely describe it "sinking into the desert" just north of Tucson, and rarely emptying into the Gila River. Many published maps, in direct contrast, indicate a single channel flowing northwest from Tucson to its confluence with the Gila. However, no such channel exists over most of the area indicated. Likewise, most maps omit the flood control channels which carry most of the water (personal observations).

These contradictory images and descriptions of the lower Santa Cruz reveal a general confusion about the river's location and dynamics. Information about the river's former course, flooding pattern and frequency is anecdotal, and I found no descriptions at all prior to 1911 (Forbes 1911). The historical location of ephemeral streams was obtained from the first complete county soils map (Poulson et al. 1941). Field work for this map was accomplished in the mid-1930s before most clearing had taken place. I also studied aerial photos taken in 1936 to confirm the location of specific waterways. In order to depict an undisturbed hydrological map of the valley, I traced the streams from the Poulson map, omitting the two obvious canal-and-reservoir systems (Figure 8). (Obviously, since ephemeral streams frequently shifted course, (Poulson et al. 1941; Eckman et al., 1920), this picture only represents the general character of surface hydrology, rather than precise paths of water flow for 1885.) Then I attempted to establish a date for the earliest system. Green's Canal and Green's Reservoir were built in 1910-1911 at the south end of the valley (Forbes 1911). A canal from the Gila River near Florence to Casa Grande was present and in use by European settlers "after 1885" (Forbes 1911, Eckmann et al. 1920). It is possible, however, that the canal system was taken over from Native American canals and expanded by the new settlers, as occureed in the Salt River Valley about the same time.

Information for the second (1930) map (Figure 9) comes from 1963 U.S.G.S. 7.5 minute topographic maps and 1936 aerial photos. In this map I hypothesize that hydrological modification was limited to a narrow band north of the Florence-Casa Grande Canal and Picacho Reservoir system. This is supported by statements of Poulson et al. 1941, and Smith 1940. The maximum width of the band of farming along these canals was apparently determined by the water supply from the San Carlos Project (beginning in 1929). The 1963 U.S.G.S. topographic maps show small waterways running 2-4 km (1- 2.5 miles) north of the northernmost canal, and within one mile south of the southernmost canal. These coincide precisely with the extent of farming around the canals in 1936 (from aerial photos). Therefore, I deduced that the waterways shown on the topographic maps were the same ones used in 1930 for delivery from the Florence-Casa Grande canals. It is unlikely that this canal system was changed or expanded greatly between 1930 and 1963, since the amount of surface water available to irrigate the area did not increase.

The 1930 map also shows Green's Canal and the outline of Green's reservoir, which was destroyed in a flood soon after completion in 1911. The location of these features is found on numerous maps including the Poulson et al. map (1941) and the USGS topographic series.

Data for the 1980 map (Figure 10) were also taken from the USGS 7.5" topographic maps of 1981 (photorevised). These maps indicate ephemeral streams and human-constructed waterways. I traced all such waterways in the study area. The actual date of their construction was probably between 1930 and 1963 (the first map series), since all new structures after 1963 were printed in magenta to indicate photorevision, and these structures were all blue.

The final map (1990; Figure 11) adds the canal system of the Central Arizona Project, an irrigation scheme to bring Colorado River Water to Central Arizona. Most of the structures were built in the 1980s. Data for the location of these canals was compiled from a real estate company's map (Cowboy Land Inc., 1987), and county road maps, and may thus be incomplete. Curiously, the Central Arizona Irrigation District which delivers water through these canals, could not provide me with a complete map of them.

RESULTS

The Santa Cruz Valley Ecosystem Before Pioneer Agriculture

Settlers who ventured south from the long-cultivated floodplains of the Gila River into the "desert" of the Santa Cruz valley in the late 1880's probably met people who had been grazing cattle and sheep since Civil War times. Washes draining the Picacho Mountains, stored in a reservoir at their base, would have provided water for ranchers, their livestock and probably occasional crops. This may have been supplemented by windmills or steam driven pumps tapped into shallow groundwater. Poulson et al. (1941) note that the "pioneer type of agriculture" began in the desert (i.e. outside of the Gila river bottoms) when canals were constructed beginning in 1886, with wells drilled on homesteads after 1910. The available supply of irrigation water was overestimated, however, and it fluctuated widely with the annual seasonal rainfall, so a lot of land was temporarily abandoned in this region (Poulson, et al. 1941).

In these early years, the agriculture of both the pioneers and indigenous peoples were governed by the limitations of soil and rainfall, and the unpredictable nature of the Santa Cruz River and its associated washes. An understanding of the frequency and nature of flooding and its relationship to groundwater, soils and vegetation would have required long term residence, since intervals between floods varied from months to years. Ignorance of the nature of the valley's hydrologic system may have been norm. In 1891, when the Southern Pacific Railroad first went through the valley, their engineers thoughtfully aligned its route in order not ot cross the (historical) northwest flow of the Santa Cruz. However, the tracks washed out that same year between Newman Mountain and Picacho Peak, where washes run perpendicular to the tracks (Dobyns 1981) and railroad service was spotty through at least 1917 (Eckman et al. 1920). Further evidence of early engineers' lack of appreciation of the power of flooding comes from the failure of Green's Reservoir, built in 1911, to hold back even one storm's floodwaters (F. M. Barrios, undated, unpublished manuscript).

-- The valley was essentially an inland delta, receiving water and silts from the surrounding mountains and only rarely delivering any water to the Gila. Drainage was dispersed and indistinct, and these conditions--usually dry but sometimes inundated for days or weeks --created barren, high sodium "slick spots" where nothing would grow. At the time of early settlement, groundwater may already have been dropping. According to Poulson et al. (1941):

> "Floodwaters of the Santa Cruz River cross the area in a northwesterly direction and join the Gila River through numerous shallow ill-defined channels and elongated playalike depressions . . .
>
> ". . . the chief activity of the Santa Cruz River is deposition of materials during floods. Though water does not remain long on the surface of the land after floods, the soil materials are charged to various degrees with salts left by the evaporating water. . . . at present the water table is nearly everywhere more than 25 feet below the surface, and it is 150 or more below the surface in the higher parts of the valleys. It seems probably that the water table has been lowered by the cutting of the channel of the Gila River [1890's]. Many of the intermittent streams, or desert washes, do not reach the main stream but spread out in sheets, sorting and depositing the materials . . . ." (pp. 4-5)

This supposition about groundwater levels is supported by the observations of Eckman et al. (1920) whose field work was conducted 20 years before the later survey. Eckman's group emphasized the imperfect drainage much more than Poulson's group, and it is possible they saw a wetter valley:

> "Drainage is also poorly developed locally in the shallow and imperfect drainage ways of the desert. Here the gradient is low, and the run-off and percolation much retarded. . . . Little attempt has been made to provide drainage for the broad flats of the desert, cultivation being confined to the better drained soils. . . .
>
> "Many of the barren alkali flats are interrupted or bordered by slightly higher lying soils of lighter texture, which are frequently free from surface accumulations of alkali. The flats receive runoff from the adjacent soils, and the water remains until removed by evaporation or percolation. Both the suspended sediments and the salts in solution are deposited, and upon drying form a smooth, hard, surface which greatly retards the movement of the salts." (p. 32-33).

Forbes' 1911 map of water resources in Arizona shows the entire lower Santa Cruz valley had groundwater within 15 m (50 feet) of the surface, but he offers no evidence for this representation.

The earliest settlers had to choose between coarse-textured soils on high ground with poor water-holding capacity, or fine-textured soils, with good water-holding capacity, easier access to irrigation and floodwaters, but high salt content and poor drainage. One farmer told me that the early settlers preferred to clear land covered with creosotebush (*Larrea tridentata*, a species requiring better drainage and absence of a shallow caliche layer) than land with desert saltbush (growing on finer-textured soils) even though more irrigation water was needed (B. Hooper, 1992, personal communication.)

Figure 8 shows the lower Santa Cruz valley as it may have looked prior to any modification of waterways by European settlers. The main channel of the Santa Cruz flowed north-west and then disappeared into the "Santa Cruz Flats," a broad, flat region lacking obvious drainage. The dispersed waters of the Santa Cruz then flowed around Casa Grande Mountain through various shallow, ephemeral washes, and converged west of the town of Casa Grande, about 31 km (19 miles) from the channel's disappearance. In addition to this drainage, there were two apparently independent wash systems to the east and one to the west. Both eastern system may have been called McClellan Wash. The southernmost one began on the East side of the Picacho mountains and flowed south to the pass between Picacho Peak and Newman Mountain. Then it made a U-turn and flowed north through the Santa Cruz valley, seeming to disappear before reaching the Gila River to the North. The northern McClellan's Wash originated in runoff from the Picacho Reservoir and emptied into to the Gila River near the town of Coolidge. A soil series was named after it in the oldest soils map (Eckman et al., 1920).

The far southwestern drainage, called Green's Wash since 1910, was apparently fed by runoff from the Sawtooth and Silver Reef mountains. Two permanent Indian villages, Shopishk and Chuichu, were located along its length, suggesting this wash was of some importance historically. I have been unable to determine the original name of the wash, which was renamed after an investor involved in a canal and reservoir project. I was unable to determine whether or not Green's Wash received floodwaters of the Santa Cruz to the east prior to the opening of Green's Canal canal.

The Santa Cruz and Green's Wash stream systems met at the site of an Indian village, Ak Chin, or "mouth of the wash," which successfully practiced floodwater agriculture at one time.

Pre-settlement vegetation. There is little evidence of the pre-grazing vegetation of the Santa Cruz Valley, but it is unlikely that this area shares the history of widespread conversion of grassland to shrubland that is so well documented in southeastern Arizona (Hastings and Turner 1965). First, there are no comparable accounts of rapid vegetation change near the turn of the century. Second, the climate is less conducive to grass. The elevation is lower, temperatures are hotter, and rainfall is 200-250 mm, as opposed to 300-350 mm in southeastern Arizona. Third, fewer remnants of grassland vegetation exist to support the notion.

Two areas within the valley have been reported as grassland. The Sasco Flats, where the Robles and Santa Cruz washes converge in the extreme southeast portion of the valley (just out of range of Figure 8); once supported dense stands of Johnsongrass (*Sorghum halepense*) intermixed with velvet mesquite (*Prosopis velutina*) up through the 1930s (Smith 1940). Smith indicated that Johnsongrass, a European weed, took over after the flood of 1916; originally this area may have contained giant sacaton (*Sporobolis wrightii*; D. James, personal communication). The second documented area of grasses was located in a small dune field about 10 km (6 miles) south of Arizona City) where populations of big galleta (*Hilaria rigida*) can still be found. Topographic maps show old ranch sites, are strategically located next to these grassland areas. All other reports suggest that the rest of the valley was a shrubland composed primarily of desert saltbush (*Atriplex polycarpa*), creosotebush (*Larrea tridentata*), velvet mesquite (*Prosopis velutina*) and wolfberry (*Lycium spp.*) (Eckman et al., 1920; Shantz and Peimeisel 1924; Poulson et al. 1941; Turner 1974 a, b; Brown 1984, U.S. D.A. Soil Conservation Service 1990, and National Cooperative Soil

Survey 1991). Table 3 lists th species that have been documented in undisturbed desert patches throughout the valley (P. Comus, 1993. Unpublished data.)

Agricultural Conversion, 1910-1954

Little conversion of desert for cultivation occurred in the early 1900s, and the main limitation was, not surprisingly, water. The Pinal County soils map of Eckman et al. (1920; field work completed before 1917) reports that "Only small patches are cultivated in the desert section." Greater agricultural expansion in the Santa Cruz valley was limited even after the Coolidge Dam was completed in 1929, due to poorer-than-expected water yields.

By the late 1930s, pumping technology had improved and electric and gas service became widely available (Shapiro 1989). For the first time, the great, dry floodplain south of the Florence-Casa Grande Canal was open for agriculture.

Smith's (1940) account of the development of the Eloy district is suggestive of the character and speed of changes going on more or less throughout the valley.

> "The first drilled well in the region of Eloy was drilled in 1916 . . . but was only 110 feet in depth. The first deep well was drilled 2 years later for the promoters of Cotton City (now Eloy) and was 320 feet in depth.
>
> "About 1924 it was discovered that the overflow and other recently deposited alluvial lands were adapted to winter vegetables, the "black lands." By 1930 about a dozen wells of large yields were in operation in the Eloy district. The pumping lift was over 100 feet but the high value of the lettuce crop justified the high cost of water. In 1934 the growing of lettuce was abandoned due to the spread of a destructive fungus in the district. Peas, asparagus, carrots,, and some other crops were continued. The total area cultivated in 1930, however, did not exceed 4,000 acres.
>
> "The big development occurred in 1936 and 1937 and was the result of four factors. The price of cotton advanced in 1935 and 1936; notable improvements had been made in the design and efficiency of deep-well turbine pumps; pumping plants were offered on a credit basis; and electric power rates were reduced.
>
> "About 4,000 acres of newly cleared land were planted in 1936 and 13,500 acres additional in 1937. Forty-four new wells were drilled, all of them 20-inch diameter and nearly all of them to depths of 400 to 600 feet . . .By 1939 there were 90 wells in operation.

The Arizona Crop and Livestock Association's estimates of area harvested in Pinal County shows a sharp increase beginning in the mid-1930's (Figure 6); this is accompanied by an equally large increase in water pumped (Hammett 1992). The yearly expansion of crops harvested in Pinal County ceased in 1953 when, according to Shapiro (1989), the end of the Korean War brought lower cotton prices and government acreage limits. Barr (1955), summing up the past seven years of agricultural development for Agricultural Experiment Station, reports that about 78,900 ha (195,000 acres) of desert were cleared in Pinal County between 1947 and 1954. This is a rate of 30 hectares (76 acres) per day, or 6% of the total arable land each year.

The rapid clearing left very little land suitable for agriculture untouched (Figure 4). The mapping survey revealed that 17% of the total mapped area was never cleared, but this included land on the outskirts of the valley which was probably never unsuitable for irrigation. In the interior of the valley (Figure 5) only 9% was left untilled. Unlike surface water irrigation, which required a legal water right plus membership in a cooperative irrigation association or company, acquisition of groundwater was unregulated, and its exploitation was individualistic. This must have been a great attraction to investors.

Characteristics of desert habitat islands. The size and distance between habitat patches in agricultural landscapes can have important implications for wildlife use and persistence of species (several studies in Bunce and Howard, 1990, and Vos and Opdam 1993). In order to learn more about the islands of native habitat that were left in the center of the valley, I studied the three quadrangles running north-south down the center of the map. There were 77 such islands; Figure 12 shows their size distribution. The distribution is highly skewed, with the 54 of the 77 patches under 100 ha in size, and over half of those under 20 ha.

These islands were also relatively isolated from one another. While nine patches located along the Florence-Casa Grande Canal adjoined a neighboring patch at one corner (in practice, a county road usually separated them) and thus had nearest neighbor distances of zero; the mean minimum distance to another among other habitat islands was 524 m (+/- one standard error, 417 - 660 m). Thus, with the exception of the very small canal patches, remaining desert habitat was small and isolated.

Abandoned and Idle Cropland, 1954-1987

Between 1952 and the mid-1980s, the area harvested fluctuated within 70-94% of the record high, but the downward trend was slight (Figure 6). However by 1987, total cropland as reported by the U.S. Agricultural census was down 26% from 1954 (Table 1; Figure 7). The minimum amount of farmland either abandoned completely or transformed to nonagricultural uses between 1987 and 1954 was 47,779 hectares. This number does not include the land abandoned before 1954, and the new cropland land cleared after 1954. Based on observations and work by Karpiscak (1980), land abandoned before 1954 accounts for 10% or less of all old fields. It is not possible to determine how much new land was cleared after 1954 from available published statistics, but it not likely to be great.

The rate of abandonment in Pinal County was disproportionately greater than Arizona as a whole (Table 1). Pinal county accounted for 28% of the state's agricultural land in 1954, and 20% in 1987 (U.S. Agricultural Census 1954, 1987).

Not only was cropland lost from the survey, but more cropland in the survey was unused. In 1987 "idle" cropland accounted for 48,575 ha, or 35% of all cropland compared with 12-16% in the early 1950s (Table 1; Figure 7). According to the Arizona Department of Water Resources (R. Edmund, personal communication, 1993), farmers now set aside about 20% of active farmland in any given year. Thus, it is possible that about 15% or 20,585 ha of the remaining "idle" land is no longer in regular rotation and is also permanently abandoned.

Our estimates of land use based on 1983 aerial photos for the eastern portion of the valley were similar to the Census results. Of 72,158 ha of land in the study area that were once cultivated, 24% of the cultivated land was abandoned, and 3.6% was "developed" into housing districts which failed to attract residents. Thus, our results (27.6% vs. the Census estimate of 26%) are in close agreement. These data, however, are already over ten years old. A follow-up study with 1992 aerial photos and the 1992 census data in press would be very helpful.

These results differ substantially from the estimates of Cox et al. (1983) who used the decennial U.S. census data in a similar manner to estimate abandoned farm land. In 1950, Cox and colleagues reported a maximum of 352,768 ha in production, and in 1980 a minimum of 89,684 ha, for a loss of 263,084 ha in Pinal County. The 1950 figure is much greater than the maximum number of arable hectares in the valley (Turner 1975; Van Cleve Associates 1963) as well as the maximum number of harvested hectares according to the Arizona Crop and Livestock Reporting Service (127,883 ha in 1952) and the maximum area of cropland, including idle land, based on the agricultural census (185,012 ha in 1954; U. S. Bureau of the Census 1956.) I cannot account for the large discrepancy between the numbers of Cox et al. and my own.

<u>Location of abandoned farmland</u>. Figure 4 shows the location of abandoned land as of 1983. Most abandoned farmland is in the southern portion of the county, where development of farmland is most recent. This is also the region which was up until recently served entirely by pumped water rather than surface water. Figure 13 shows the location of groundwater decline between 1940 and 1970 (source) in relation to abandoned regions. It is evident that abandonment was not associated with the *degree* of groundwater decline alone, because there appears be no more farm abandonment in areas with high (60-90 m) versus moderate (40-60 m) groundwater decline.

The proximity of abandoned farmland to natural vegetation plays a major role in their recovery. In order to quantify the distance between abandoned land and its nearest source of native seeds, we measured the distance between 135 random points located in the open, and the nearest patch of native desert. Of 135 random points located in the open, 89 were in cultivated and 46 in abandoned land. The mean distance between random points in cultivated land to the nearest native desert patch was 860 m, while the mean distance from abandoned land to native was 1291 m (T=3.008, p = .003; distances square-root transformed for analysis). Thus, abandoned land was distant from native seed sources, and negatively associated with desert patches. I have no reasonable explanation for why cultivated land should be closer than abandoned land to the native patches. This pattern emphasizes the need to reestablish seed sources near old fields, since most seeds do not move 1291 m from the parent plant.

Recovery of Old Fields: Implications for Restoration

If abandoned fields recovered on their own, there would be no need for restoration. Karpiscak (1980) studied rates of vegetation recovery of old fields in the Avra and Santa Cruz Valley. He found that reestablishment of the formerly dominant saltbush (*Atriplex spp.*) or creosotebush (*Larrea tridentata*) was highly variable. In some fields, virtually no plant cover existed 25 years following abandonment. I have visited the same sites and found this is still true more than 10 years later. In most of these old fields, annuals and short-lived shrubs have persisted, and the formerly dominant long-lived shrubs are still absent. This is true even in areas that were not originally "slick spots," barren flats with highly sodic soils.

A few fields, however, had recovered their original species composition and had achieved at least half of the plant density of surrounding native vegetation. I noticed that these fields were always adjacent to native vegetation, and were often traversed by a wash. This landscape position was unusual, due to the distribution of native patches of vegetation within agricultural areas (Figure 3). I began to notice a pattern in old fields: the presence or absence of a perennial shrub or tree species seemed to be related to its potential for long distance dispersal, and the distance to the nearest seed source of that species. Table 4 summarizes these observations. These observations are not conclusive because they were not carried out in any systematic way throughout the valley; I offer them only as a hypothesis to be tested.

— I was able to demonstrate the importance of distance from seed source to old field in one species, however. Creosotebush (*Larrea tridentata*) for instance, has a heavy seed moved by small mammals over small distances (<30 m). My estimates of creosote invasion into nearby abandoned lands shows that after 30 year, an old field could have creosotebushes recolonize only 100 to 300 m. Density of creosotebushes in the interior of a 30 year old field were 1 % of their density on the field edges and 0.1% or less of their original density (Figure 14). The steep, negative exponential shapes of the distributions indicate the absence of frequent long-distance dispersal. I have observed two old fields more than a km from the nearest creosotebush with small populations of the species (in one 65 ha field last farmed in 1949, one plant; in another field of similar size abandoned in the 1960s, 5 plants), but these were unusual.

Loss of Woodland and "Waste" Areas, 1949-1987

Figure 15 shows the loss of woodland area reported on farms before and after 1954. In 1950, the U.S. Agricultural Census reported the existence of commercially valuable woodland occurred on 50 farms occupying almost 2% of all land in farms. By 1987, woodland occurred on only 4 farms, and occupied less than 0.01% of land in farms. Thus, the loss of woodland was not due to a loss of total land in farms. The absolute loss was greatest between 1950 and 1954, when rapid clearing was taking place. However, the relative rate of loss (hectares per remaining hectare) of woodlands remained high even after new land clearing slowed after 1954. Seventy-one percent of woodlands were lost between 1949 and 1954, while in the following three 5-year periods, 61%, 50%, and 70% of remaining woodland was lost. Thus, deforestation barely slowed down after all of the land for agriculture was cleared. Some of this woodland loss was undoubtedly due to groundwater decline, which left phreatophytic mesquite bosques high and dry (Judd et al., 1971; Reichhardt 1992; see discussion of groundwater decline, below).

"Wasteland" on farms was defined by the Census as houses, lots, ponds, roads, and "waste" land. This did not include cropland, idle cropland, woodland, pasture or rangeland. During clearing, between 1950 and 1954, the amount of wasteland reported by farmers in Pinal County decreased 47%, from 45,562 ha to 24,214 ha. Since 1954, the area reported as wasteland has been reduced another 49%, to 12,247 ha. Since it is not likely that the number or size of houses, ponds, roads and other infrastructure has declined greatly, these data suggest that since 1954, scraps of land not used for farming have been put in to production or some other category. These scraps may have once provided some desert habitat.

Modification of Hydrology

Early reservoirs and canals

With the exception of the canalworks near Casa Grande National Monument, the site of a large prehistoric Hohokam settlement near the Gila River, virtually nothing is written about native American agricultural modification of the lower Santa Cruz Valley. The Hohokam clearly farmed with canals from water sources other than the Gila, as evidenced by canalworks, pottery and stone tools found east of Eloy. Whatever modifications they made to the surface hydrology of the valley have been obliterated by modern agricultural activity. The role of native Americans in the previous century is also unrecorded. Thus, while it would be foolish to assert that the first human modifications of the lower Santa Cruz valley were accomplished by European settlers from Mexico and the U.S., written accounts of it appear to be unavailable. (Alternatively, my training in historical research techniques may be inadequate to the task.)

While Forbes (1911) and Eckman et al. (1920) state that the canal between Florence, on the Gila River, and Casa Grande were built soon after 1885 by the Florence Canal Company, they do not mention the origin of Picacho Reservoir. It is possible that both the canal and the reservoir were there before 1886. Picacho reservoir is an ideal location for passive storage of seasonal floodwaters from the Picacho Mountains (U.S. G.S. 7.5" topographic series, Picacho Quadrangle), which may have been exploited and modified by the Hohokam or later Native American farmers. An elderly resident of the valley told me that he once spoken to a person who began cattle ranching "between Casa Grande and Eleven-Mile Corner," an area now fed by the Florence Canal, after the Civil War. This suggests the presence of the canal by the late 1860s. Roberts believed that before it was linked to the Gila River (1886) the reservoir functioned as a local catchbasin.

Second, the Florence-Casa Grande canal snakes along a subtle divide between the original path of the Santa Cruz, and that of the McClellan wash to the east and north. Its complex curves (as opposed to the straight 1911 canal dug further south by the Santa Cruz Canal Company) seem to suggest engineers who took full advantage of local microtopography and soils to make the job easier or more efficient. The canals would have originally cut through thick layers of rock-like caliche, also arguing for a careful choice of route (National Cooperative Soil Survey 1991). Would newcomers to the area, virtually ignorant of the nature of this desert floodplain (as Dobyns 1981 has argued), have been able to ascertain this route and quickly build the canal? Given the sophisticated knowledge and techniques of native American desert farmers, I suspect that both Picacho reservoir and the canal leading west from it are originally of their design, whether ancient (Hohokam) or more recent.

In 1908 an ambitious group of investors called the Santa Cruz Reservoir Company and partly financed by Colonel William Green, sought to draw the waters of the Santa Cruz out of its northern course and bring them 24.6 km (15 miles) west, to a reservoir constructed against the slopes of the Sawtooth mountains. The 2,438 m (8,000 ft.) earthen dike, finished in 1911, was designed to hold 30,000 acre-feet of water in "Green's Reservoir" and irrigate 4,050 ha (10,000 acres) of cropland, but the company failed and the dike soon fell into disrepair. However, Green's Canal began to deepen its channel downstream, working its way up (headcutting) until it intercepted the original Santa Cruz channel.

The effects of this gradual process were not felt until after 1931, when 90% of the Santa Cruz flow was still flowing in its original channel, and passing through Eloy (J.A. Roberts, personal communication; Smith, 1940). Significant floodwaters were still reaching Eloy in 1939 (Smith 1940). Now, Green's Canal is larger and deeper than the original Santa Cruz channel. It has "stolen" the Santa Cruz waters and redirected them into the western part of the valley via Green's Wash (F. M. Barrios, unpublished manuscript; J. A. Roberts, personal communication).

This new channel also affected the "Sasco Flat," an area of 1300-1600 ha (5-10 square miles) of mesquite trees (*Prosopis velutina*) and Johnson grass (Sorghum *arvense)*, southeast of Green's Canal. Smith (1940) warned that

> "The overflow into the [Green Canal] channel has started many new gullies and some of them have grown backward nearly a mile. If the cutting continues it may reach through the flat to the main channels of the Robles Wash and the Santa Cruz River. . . . . The intricate control problem should be resolved as soon as possible. If the water spreading is continued, the utilization of the flat for growing feed as at present can be continued, and the spreading undoubtedly slows down the floods and flattens the flood crests materially, a result of much benefit, since farther downstream the new land use has left no definite place for the floodwaters to go."

These control measures did not take place, and current vegetation is devoid of large trees and grass.

Leveling, Channelization and Obstructions to Surface Flow

In order to clear the deserts, irrigate them and protect their crops and irrigation infrastructure from flooding, farmers found it necessary to carefully level the fields. The earliest fields abandoned before 1949 did not appear to have been leveled precisely (based on visits to four or five such fields), but all fields farmed since then lacked significant microtopography other than furrows. As a consequence of leveling, the original landscape pattern of dendritic ephemeral washes was converted to a Cartesian grid of ditches. Figure 15 shows a portion of the eastern edge of the valley in which leveled and unleveled land lie adjacent to one another. (In the center of the valley, not shown, essentially all of the land has been leveled and so the contrast is not as evident). In this illustration, farmed land can be determined simply by the contour lines, which are perfectly straight. Abrupt dips in the contour lines reveal ditches along roads or between fields. The density and type of desert vegetation, so closely tied to small differences in water availability due to soils and topography, can never be the same where the land has been leveled. In addition to channeling water movement, the grid of ditches, roads, berms and leveled fields block and compartmentalize local runoff, creating ponding where it never existed before.

Channelization of washes occurred throughout the valley between time of first settlement and dates of the first topographic maps in the 1960s (Figure 10). Aerial photos from 1936 show washes running through many cultivated fields. Two fields abandoned between 1936 and 1949 near Toltec appear to have been built around wash systems, possibly to take advantage of floodwaters. The natural waterways were turned into northwest-trending irrigation ditches, from which waters were turned out downhill on both sides of the ditch, to the north and west (Jackson et al., 1992).

However, this practice was not carried on into the 1940s, and all major washes were straightened and channelized (Figure 10). The McClellan Wash, running northwest from Picacho Reservoir into the Gila river, is treated as a major landscape feature in the Eckman et al. (1920) soils map. Smith (1940) shows it as a wash which regularly received floodwaters and nearly formed a channel at its northern extreme; this wash was visible in a 1963 University of Arizona map as a "canal;" and occasionally shows up on even more recent maps (U.S. Geological Survey, 1983); but no longer existed at the time of the U. S. G. S. 7.5" topographic series (1969). The date of its disappearance is unknown.

The southern McClellan Wash, Red Rock Wash, and the Santa Rosa Wash at its convergence with the Green were also highly modified. Other, smaller systems were simply obliterated. These drainages now probably go down county road ditches.

I did not pursue documents of the local drainage and flood control boards, which could give more accurate records of channelization. In the event that restoration plans are made, it would be extremely important to meet with flood control engineers to determine the exact location and function of all flood control structures, and the volume of water they accommodate.

Groundwater decline and mesquite death.

In 1940 Smith warned that by 1936, pumping operations near Eloy were twice the sustainable yield of water, and that by 1937 they were 3 times the rate of groundwater recharge. The regions near Eloy with groundwater less than 18-27 meters (60-90 feet) from the surface in 1917 was designated a critical groundwater area in 1949. By 1977, the groundwater level had declined to 90 to 150 m (300-500 feet; Smith 1940, U.S.D.A. 1977).

Judd et al. (1971) documented the death of mesquite (Prosopis velutina) along the Gila River after upstream channelization and groundwater pumping caused groundwater to drop from 13 m (44 feet) in 1923, to 30 m (100 feet) in 1952, to 46 m (150 feet) in 1960. Mesquite stumps up to 1 m in diameter, some with a few small live branches, are scattered in many locations across the valley. Virtually all of these have been cut with a saw or axe; thus it is difficult to establish their cause of death as groundwater withdrawal when the clear alternative is woodcutting. There was a move in the 1950s to cut mesquite because they were phreatophytes capable of "stealing" groundwater with their deep roots, and thus reducing the amount of water available for pumping (R. Edmund, personal communication). On the Gila Indian Reservation, people cut mesquite trees to sell for firewood in Phoenix.

It is highly likely that establishment of the largest mesquites in the valley occurred prior to channelization of the Gila River (Rea 1989) when groundwater was highest. Stromberg et al. (1993) have demonstrated that velvet mesquite leaf area index, vegetation volume, canopy height and basal area are tightly related to water availability. In their study, riparian zones supported trees of 10 m mean height and 28 m^2 / ha basal area. Upland areas lacking access to groundwater supported trees of only 4 m covering 2.5 m^2 / ha in basal area. Leaf water potential, a measure of water stress, dropped as depth to groundwater dropped from 0 to 30 m. This study suggested that groundwater depth of 6 m or less was necessary for the structurally rich stands if velvet mesquite. The largest trees in the valley must have experienced these water depths at one time.

Large trees with well-established tap roots were probably able to persist until even greater declines in the 1940s and 1950s. However, the recruitment of young individuals with taproots large enough to follow the retreating water would have been impossible. Contrary to common beliefs, mesquite trees and other deep-rooted phreatophytes cannot grow their roots through dry soil until they hit groundwater. A large tree with deep taproot has achieved this access to deep water because the groundwater was, at one time, very high and co-extensive with surface moisture. For some prolonged period, the tree's roots were able to grow down through a continuously moist soil. Since then, soil between the groundwater and the surface may have dried up, but the roots remain, soaking up a permanent and (under normal conditions) slowly rising and falling permanent source of moisture. The opportunity for growing such a deep taproot has disappeared, and mesquite trees are currently limited to about 4 m in height.

The cause of death of scattered ironwood (*Olneya tesota*) trees may have been related to groundwater as well. Normally thought of as a hillside plant, ironwood once grew in many locations throughout the floodplain, especially near small washes in the area west of Toltec. Piles of brittle, skeleton-like branches and a few cut stumps remain in this region, along with small pieces of wood that I frequently in abandoned fields in the area. Despite its current distribution in coarse-textured soils, *Olneya* appears to have tolerated, at one time, the slick, "barrens" areas devoid of most other vegetation.

Central Arizona Project Canals

The recent completion of the Central Arizona Project, a network of canals that link virtually all of the Santa Cruz Valley to the Colorado River (Figure 11), has created higher, rather than lower water costs, which must be born by many fewer farmers than when the costs of the project were estimated. As a result, many farmers are on the edge of bankruptcy (Arizona Republic, 31 October 1993). Many of these canals cross vast tracts of abandoned farmland to service the remaining active fields. The canals range from the size of a large irrigation ditch, to a major aqueduct, with a 7 m wide canal and 15 m of cleared and graded dikes on each side. The dangers to wildlife on the main aquiduct were mitigated by ladders and other devices to allow animals to cross the aqueduct unharmed. However, these were not installed in the "feeder" canals which criss-cross the valley (T. Supplee, personal communication; pesonal observations). One land owner told me that when she was growing up, they referred to a certain field near the old Santa Cruz Channel as the "javelina farm" because of all the javelina they would see there. Once the medium-sized CAP canal was installed between the river channel and the field, however, javelina visits ceased (B. Vandenburg, personal communication).

In some places large dikes were built to protect the canals from occasional flooding. This acts as yet another layer of barriers to the flooding regime which characterized this valley's ecosystem (Figure 11). Any restoration of wash systems will have to compensate for these barriers.

A Note on Soils

This study did not address the status of soils in abandoned fields. Soil types differ widely across the valley, and original soil conditions interact with tillage practices, so it is impossible to generalize about the ability of these soils to recover their original structure, nutrients, microbial communities etc. There are three general problems associated with tillage and irrigation: the development of soil surface crusts, the loss or alteration of soil microbial communities, and the presence of pesticide residues.

Soils with low organic matter, high silt content, and high sodium, common throughout the valley, have low aggregate stability and surface crusting. The top few millimeters of these soils have few large pores and high bulk density, limiting water infiltration and seedling emergence. This crust is made worse by flood irrigation, repeated tillage and continuous row crop production, and prevents water infiltration and seedling emergence (Miller and Gifford, 1975). I have observed freshly tilled soils "seal up" shortly after a significant rain, and this phenomenon probably caused the failure of one 10-acre restoration planting (see Part II of final report). The persistence of furrows in fields abandoned over 40 years ago attests to the very dense, hard nature of some of these soils high in silt and clay content.

The role of fungi and bacteria in soil health and functioning is widely acknowledged but poorly understood. Many plant species require a mycorrhizal symbiont for establishment and growth; however, these associations are not known for plants of the desert saltbush community. I tested pairs of adjacent fields, one abandoned and the adjacent area never cultivated, to compare microbial and fungal activity. Fresh soil samples were sent to the Soil Microbial Biomass Service at the Department of Botany and Plant Pathology, Oregon State University. This lab measured the length and biomass of live and dead vesicular-arbuscular mycorrhizae (VAM), the total bacterial number and bacterial biomass, per gram dry weight of soil. The results were ambiguous: old fields and native spots showed equal amounts of variation from site to site both within and between locations (Table 2). Clearly, if differences exist, they are variable at a very small spatial scale, or only occur at certain times of year when soil moisture is adequate. Because the results were so ambiguous (and expensive), no further testing was attempted.

It is likely that agricultural operations seriously modified the living components of the valley's soils. It is also likely that residues of DDT and other long-lived chemical pesticides remain buried in fields used before the ban on DDT. The effect of such residues is not known, but I suspect that their presence limits insect life, including termites, which play a pivotal role in the decomposition of organic matter and affect soil porosity and aeration, infiltration, storage and drainage of water, and growth of plant roots (Woods and Sands 1978; Elkins et al., 1986). Testing for residues of agricultural chemicals is expensive, but should be done before attempting restoration projects, if only to guard against worker exposure. I did not attempt to measure DDT residues in this study.

A RANKED STRATEGY FOR RESTORATION OF THE SANTA CRUZ VALLEY ECOSYSTEM

Ecological Restoration as Part of the Community Planning Process

Because so much farmland has been abandoned, and money for restoration is limited, it is necessary to make decisions about where to devote our attention. Priorities must be set for restoration that make the most sense socially. Only then can biological issues come into play. For instance, it would clearly be foolish to spend time and money restoring land that will be converted to houses, or returned to agricultural production.

Restoration of abandoned farmlands must matter to people. Therefore, we must consult communities that have been affected by abandoned land and find out what they want. Planning is a process that should involve growers, rural residents, land owners (these three are not the same!) and residents of Casa Grande, Eloy, La Palma, Randolf, Coolidge, Red Rock, Picacho, Toltec and Arizona City. The values and assumptions of each interest group should be clearly articulated. Then, a vision of the future of the valley should be developed taking into account all of the various interests and values.

Once a community vision of the valley has been reached, and a level of support for restoration determined, then the following ranking system may be of use, as a tool for planning and as a jumping off point for further discussion.

Consequences of Ecosystem Change for Restoration

Restoration should be based on an understanding of the ecosystem processes and characteristics that formerly shaped the natural communities. If these conditions cannot be reconstructed or compensated for in some way, permanent restoration is unlikely to succeed. The lower Santa Cruz valley is an inland delta that was shaped by the Santa Cruz River and its tributaries. Soils and vegetation were intimately tied to the periodic floods that washed over the valley. The landscape is now greatly modified due Green's Canal, the straightening and channelization of washes, and blockage of waterways by roads and the Central Arizona Project canal system. This has not eliminated flooding, but has greatly changed its characteristics (volume, flow rate, location, time of year).

A key to ecosystem restoration will be reintegration of wash systems so that some natural sheet flooding occurs in selected old fields and native patches. This will also make restoration easier and maybe even less costly, by providing natural irrigation water at irregular intervals. If done properly, restoration of watersheds could actually improve flood control as well, by absorbing excess water.

A second key part of the valley ecosystem was the relatively shallow groundwater which, at least parts of some years, was in contact with surface moisture. Under these conditions, the roots of young mesquite trees were able to reach the groundwater table. Today these conditions no longer exist, and mesquites remain small shrubs instead of becoming large shade trees. It is unlikely that this aspect of the valley can be restored, but it could be simulated in a few areas by using CAP water for irrigation. As irrigation from the Central Arizona Project replaces deep well irrigation, the water table may slowly rise, but it will take centuries to accomplish. The Gila River will continue to influence groundwater depth.

A final ecosystem characteristic we must address is potential for seed dispersal and colonization of old fields. Natural regeneration of many of these old fields is unlikely because they are on average 1291 m from the nearest source of native seed. Only wind-dispersed plants such as burrow-weed (*Isocoma spp.*) and desert broom (*Baccharis sarothroides*) seem to be capable of quickly traversing these distances. Restoration of small patches of native plants (*Atriplex*, *Larrea*, *Prosopis*, annual wildflowers) can counteract this problem by creating long-lived sources of propagules. This will work better where hydrological integrity has been restored, but should also work to some extent without manipulation of wash systems.

Principles of Reserve Design

Several principals of design have been developed for nature preserves in order to maximize the number and diversity of species which can coexist in them (Primack 1993), and these principles are applicable to restoration plans. Large natural areas can more effectively preserve species than small ones. Continuous habitat is more effective than fragmented habitat. A natural area with diverse types of habitat (for example, mesquite bosque, saltbush-wolfberry desert, barren clay flats and creosotebush-bursage desert) is better than one with only one habitat type.

According to this model, restoration should aim to make existing, fragmented habitat large and continuous by restoring abandoned farmland between remnants of never-plowed, native vegetation. Many types of habitats should be restored to maximize species composition.

Another reigning principle of reserve design and management is the exclusive use of native species. In one ecosystem after another, biologists have witnessed the takeover of exotic plants and animals which were at one time introduced for their commercial possibilities or soil-holding potential (e.g., kudzu, multiflora rose, tamarisk, Johnsongrass). Restorationists should use native plants, and the source of seeds should be local wherever possible. There is little evidence that planting a nurse crop of a weedy species will help the establishment of desirable native shrubs and plants (Jackson et al. 1991). In fact, the result may be the opposite--excessive competition with the native species. Usually, it is better and cheaper to start right off with the desired native plants.

Depending on the goals of the community, useful, low water use plants could be incorporated into the restoration. Some useful plants adapted to the region include mesquite (seed pods for cattle feed); jojoba (nuts for oil production); guayule (resin production), California wolfberry (*Lycium californicum*; for landscaping), Fremont's wolfberry (berry production) and desert wildflowers (seed production for other restoration projects). Some species which are normally only found on mountain slopes, such as palo verde and jojoba, appear to do well when planted on the valley floor. Although not part of the original valley flora, these species are native to Arizona, provide excellent wildlife food and cover, and may be better adapted to *current* conditions than some valley species. Thus, restoration may include species which are useful, not only as wildlife habitat, but to seed collectors and landscaping businesses.

A note on the potential for grazing: In my opinion, grazing is not a good option for the valley. The rare areas that supported grass are no longer subirrigated (for example the Sasco flats southeast of Green's Wash may once have been a giant sacaton stand over shallow groundwater, but is now far above the groundwater, due to headcut erosion into the canal and overpumping). Crane's bill (*Erodium cicutarium*) and other ephemeral winter weeds can be used by livestock, but are dependent on good winter rains, which frequently fail. Summer rains are even less dependable. Perennial shrubs such as desert saltbush are eaten reluctantly by sheep and cattle, and do not produce large amounts of forage. Finally, the argument that cattle improve soil and vegetation by "hoof action" has not been established for compacted, dense clay desert soils receiving less than 250 mm of precipitation.

The cost of restoration of abandoned farmlands will be far too great to "pay for" with increased economic return form grazing. The benefits of whole ecosystem restoration for wildlife are less tangible but arguably greater than the purely economic benefits of cattle ranching, because this is a unique ecosystem. Therefore, I recommend that any public money be spent on restoration of the desert lowland ecosystem for the sake of biodiversity, rather than subsidize private enterprise.

Nested Ranking Strategies

The rankings are divided into four alternative strategies, which are in turn prioritized. The best strategy concentrates on restoring the *ecosystem processes* (flooding) at the level of whole watersheds. The second best strategy restores *large blocks of habitat* conecting habitat islands to large natural areas bordering the valley. The third strategy *increases the effective size of existing habitat islands* by restoring around their perimeters. The fourth strategy simply restores land near schools, parks or natural areas, or land that is donated. This is the typical restoration strategy which ignores ecosystem-level processes. This strategy is not necessarily bad, since people tend to congregate around water, and because these projects tend to build support for other more extensive projects later on.

A companion strategy to the three above establishes very small patches natve shrubs and trees at regular intervals in areas that are far from seed sources. While these isolated, species-poor environments are perhaps deserving of the greatest effort to restore them, progress will be slow, and the effect on wildlife habitat may be less noticeable than restoration near habitat islands. By introducing permanent seed sources to these isolated areas, we can at least get the process of natural recolonization started, then come in later if necessary to assist.

The strategies are nested. That is, least-cost Strategy III can be adopted until more money or land become available. Then, the individual natural areas can be connected using restoration, to fulfill Strategy II goals. Note that by linking patches of habitat, we automatically come closer to reintegrating watersheds. Finally, watersheds can be reintegrated to run through land that is already replanted, to restore the ecosystem processes that are the focus of Strategy I.

I. BEST STRATEGY--restore surface hydrology and vegetation for a whole network of washes. Modify flood control ditches so that floodwaters are spread out on abandoned land, slowing the water down and allowing it to sink in. In these areas, change roads and CAP canals so that floodwater is allowed to drain across or under them. This may mean closing selected roads or making more concrete fords to allow drainage. It may also mean sculpting old fields to recreate shallow drainage systems.

— The only abandoned fields which have recovered significantly from farming on their own, have been adjacent to never-tilled natural areas with a wash that cuts into the field. Strategy I will maximize natural restoration of old fields by allowing seeds to spread from natural areas with occasional flooding.

A. Choice of waterway systems

1. **Best.** Choose the stream system that can be most extensively repaired, for the least cost. Maximize waterway length, water capacity, and waterway complexity (number of subchannels). Based on maps of former drainages (Figure 2) and abandoned land (Figure 11) a high priority area would be the south McClellan Wash between Picacho Peak and the Flórence-Casa Grande Canal (Figure 17, region A). Runoff to this system has not been reduced by reorientation of the Santa Cruz, although it may have been obstructed by other things. Much abandoned land exists in its former path, which has been reduced from several small channels to one large one (Figure 10). This wash passes near Eloy and is thus highly visible and would provide recreational opportunities.

2. **Second best.** Choose the stream system with the greatest historical or cultural value (main branch, Santa Cruz near San Francisco Grande) or greatest amount of water available. An example might be the main branch of the Santa Cruz, which winds through San Francisco Grande. However, this is also highly developed area.

3. **Do not** invest in areas that have been permanently been cut off from run-on water due to the CAP canal, Interstate 10, or Green's canal. Decisions should be based on realistic estimate of *current* flow potential, not evidence of past flow. For example, the Toltec area appears to have been a major stream system (Smith 1940) that no longer receives flood waters.

4. **Do not** restore random bits of land without a landscape-scale plan in mind. Even if only small amounts of restoration are feasible due to cost constraints, see where the restoration fits into the bigger picture.

B. Choice of where to begin re-seeding.

1. **Best**--Begin revegetation in the *upper reaches* of the stream system, so plants will seed themselves into other areas downstream.

2. **Second best**--revegetate between natural areas to link them.

3. **Do not** try to re-seed or transplant areas that have recovered similar species composition to nearby desert areas. These areas will recover on their own.

5. **Do not** try to re-seed every square meter of an area. Do small patches or strips that will later become the seed source for natural recolonization.

II. SECOND BEST STRATEGY--Link native (never tilled) stands by restoring abandoned land between them.

A. **Best.** Link large native patches to non-farm areas bordering the farming region, to create an unbroken network or band of reconstructed, restored, and native vegetation connected to large expanses of untilled areas. An example would be restoration of abandoned areas between the Santa Cruz Channel south of Eloy and the southeast edge of the valley (Figure 17, region B). Another high priority project would be to connect native desert patches south of Toltec with the larger expanses of native vegetation north of Interstate 10.

B. **2nd best.** Connect large native patches to one another within the farming region (Figure 17, region C). In this way, the total area available for wildlife would be more than doubled by restoring land between two native areas.

C. Favor restoration between large natural areas over small ones, and favor close connections over far ones. An example would be connecting the small patches of native vegetation chain of native patches along the Florence-Casa Grande canal from Picacho Reservoir to Casa Grande Mountain.

III. Third strategy--Restore areas near native vegetation, where they show no signs of recovery. Expand them using seeds from that or nearby sites. This can later serve as the basis for linking nearby native land.

A. **Best**--choose areas near *large* native patches (Figure 17, region D)

B. **Second best**--choose areas near *small but connected* native patches such as the chain of patches along the Florence-Casa Grande canal (Figure 17, region E)

IV. People-oriented strategy. Restore areas near homes and towns, or where people customarily hunt and walk for recreation. Because most people like the environment around water, this may fit well with Strategy I.

V. Companion strategy for least-cost, long-term ecosystem recovery. In addition to one of the four above strategies, I recommend a program to plant at least one very small (0.5

ha or less) planting of desert saltbush, mesquite, and creosotebush in every quarter section (160 acres) of abandoned farmland that is isolated from other native seed sources Figure 17, region F. Abandoned lands greater than one-half mile from a native seed source should be considered for treatment.

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Table 1. U.S. Agricultural Census data for hectares of "total" cropland and "other" (1954) or "idle" (1987) cropland in Arizona and in Pinal County. "Other" cropland in 1954 was defined as cropland not pastured, harvested, or in cultivated summer fallow. The introduction to the 1954 Census states that since "very little" cropland in the West was idle, this category primarily represents land experiencing total crop failure. "Idle" cropland in 1987 was defined as cropland that was not pastured, grazed, cover cropped or summer fallowed, and did not experience crop failure. Thus, the difference between "other" cropland in 1954 and "idle" cropland in 1987 is a conservative estimate of the change in idle land within farms.

	Hectares		
Year	1954	1987	Change
Arizona			
Total cropland (ha)	653,524	588,366	65,159
Other/idle cropland (ha)	83,301	135,070	51,770
% other or idle	12.7%	23.0%	
Pinal County			
Total cropland (ha)	185,012	137,233	47,779
Other/idle cropland (ha)	22,487	48,575	26,088
% idle	12.1%	35.4%	

Table 2. Total fungal and bacterial biomass, and the fungal: bacteial biomass ratio, in adjacent native desert stands and old fields, for 4 sites in March, 1993. Samples were taken from the first 5 cm of soil, either within 50 cm of the base of a shrub or tree, or more than 2 m from the nearest shrub ("intershrub"). Data are expressed in micrograms per gram dry weight of soil.

Site	Location	microhabitat	fungi (micrograms)	bacteria (micrograms)	ratio f:b
Bon Station	Native	intershrub	9.58	0.57	16.7
	Native	intershrub	32.68	0.34	94.7
	Native	*Larrea*	28.10	0.95	29.5
	Native	*Larrea*	68.19	0.92	73.9
	Field	intershrub	20.88	0.96	21.7
	Field	intershrub	36.57	2.83	12.9
	Field	*Larrea*	48.02	2.80	17.2
	Field	*Larrea*	28.21	2.22	12.7
Montgomery Rd.	Native	*Larrea*	33.38	3.17	10.5
	Native	intershrub	17.86	0.52	34.1
	Field	intershrub	13.98	0.40	35.1
Clayton Rd.	Native	*Lycium*	38.31	0.25	150.8
	Native	intershrub	28.84	1.73	16.7
	Field	intershrub	5.63	0.63	8.9
Houser Rd. West	Native	*Larrea*	18.39	0.57	32.3
	Native	*Lycium*	13.29	1.79	7.4
	Native	intershrub	12.45	0.35	35.8
	Field	*Larrea*	53.01	1.11	47.7
	Field	*Prosopis*	46.97	0.82	57.0
	Field	intershrub	104.36	1.75	59.5

Table 3. Preliminary species list of plants currently found in the lower Santa Cruz Valley, based on graduate field work by P. Comus. A complete and documented list, including voucher specimens, is in preparation; this list should be considered incomplete. An asterisk follows introduced species.

Family, Genus and species	*Introduced
Aizoaceae	
Trianthema portulacastrum L.	
Amaranthaceae	
Amaranthus albus L.	
Amaranthus fimbriatus (Torr.) Benth ex S. Wats.	
Amaranthus palmeri S. Wats.	
Tidestromia lanuginosa (Nutt.) Standl.	
Apiaceae (Umbelliferae)	
Bowlesia incana Ruiz & Paven	
Daucus pusillus Michx.	
Asteraceae	
Ambrosia confertifolia DC.	
Ambrosia dumosa (Gray) Payne	
Anthemis cotula L.	*
Aster sp.	
Baccharis sarothroides Gray	
Centaurea melitensis L.	*
Chaenactis carphoclinia Gray	
Conyza coutleri Gray	
Dyssoidia pentachaeta (D.C.) B.L. Robins	
Erigeron divergens T. & G.	
Eriophyllum lanosum (Gray) Welsh	
Evax multicaulis DC	
Filago arizonica Gray	
Gutierrezia serotina Greene (G. *californica* (DC.) T.&G. sensu K.&P.	
Helianthus annuus L.	
Heterotheca psammophilia Wagenkn. (*H. subaxillaris* (Lam.) Britt & Rusby sensu K.&P.	
Isocoma tenuisecta Greene (*Haplopappus tenuisectus* (Greene) Blake)	
Lactuca serriola L.	*
Malacothrix californica DC var. *glabrata* D.C. Eaton ex Gray	
Matricaria matricarioides (Less.) Porter	
Microseris linearifolia (D.C.) Schultz Bip.	
Sonchus asper (L.) Hill	*
Sonchus oleraceus L.	*
Xanthium spinosum L.	

Family, Genus and species	*Introduced
Boraginaceae	
Amsinkia intermedia Fisch & May	
Amsinkia tessellata Gray	
Cryptantha angustifolia (Torr.) Greene	
Heliotropium curassavicum L.	
Lappula redowskii (Hornem.) Greene	
Pectocarya platycarpa (Munz & Johnst.) Munz & Johnst.	
Plagiobothrys cf. *arizonicus* (Gray) Greene	
Brasicaceae	
Brassica nigra (L.) W.D.J. Koch	*
Brassica tournefortii Guan.	*
Descurainia pinnata (Walt) Britt ssp. *glabra* (Woot & Standl.) Detling	
Lepidium lasiocarpum Nut. ex. T.&G.	*
Lesquerella gordonii (Gray) S. Wats.	
Sisymbrium irio L.	*
Cactaceae	
Cereus giganteus Engelm. (*Carnegiea gigantea* (Engelm.) B.&R.)	
Echinocereus engelmanii (Parry ex Engelm.)	
Ferocactus wislizenii (Engelm.) B. & R.	
Mamillaria microcarpa Engelm.	
Opuntia acanthacarpa Engelm.&Bigel	
Opuntia arbuscola Engelm. (*O. vivipara* Rose)	
Opuntia fulgida Engelm.	
Opuntia leptocaulis D.C.	
Opuntia phaecantha Engelm.	
Opuntia stanlyi Engelm. var. *peeblesiana* L. Benson	
Peniocereus greggii (Engelm.) Britt. & Rose. (*Cereus greggii* Engelm.)	
Caryophyllaceae	
Hernaria cineria D.C.	
Chenopodiaceae	
Atriplex canescens (Pursh) Nutt.	
Atriplex elegans (Moq.) D. Dietr.	
Atriplex lentiformis (Torr.) S. Wats.	
Atriplex linearis S. Wats.	
Atriplex polycarpa (Torr.) S. Wats.	
Chenopodium berlandieri Moq.	
Chenopodium desiccatum A. Nels.	
Chenopodium murale L.	*
Monolepis nuttalliana (Raemer & Schultes)	
Salsola iberica Sennen&Pau (*S. kali* L. var. *tenuifolia* (Tausch.) Aellen)	*
Suaeda torreyana Wats. var. *ramosissima* (Standl.) Munz	
Convolvaceae	
Ipomoea purpurea (L.) Roth	*
Ephedraceae	
Ephedra trifurca Torr.	

Family, Genus and species	*Introduced
Euphorbiaceae	
Euphorbia albomarginata Torr. & Gray	
Euphorbia melanadenia (Torr.) Millsp.	
Euphorbia micromera (Boiss.) Woot. & Standl.	
Euphorbia prostrata (Ait.) Small	
Fabaceae	
Acacia greggii Gray var. *arizonica* Isely (*A. greggii* Gray)	
Astragalus nuttallianus DC	
Melilotus alba Medic.	*
Melilotus indica (L.) All.	*
Olneya tesota Gray	
Prosopis velutina Woot. (*P. juliflora* (Swartz) DC. var. *velutina* (Woot.) Sarg.)	
Geraniaceae	
Erodium cicutarium (L.) L'Her.	*
Hydrophyllaceae	
Nama demissum Gray	
Malvaceae	
Malva parviflora L.	*
Sphaeralcea coulterii (Wats.) Gray	
Sphaeralcea emoryi Torr.	
Martyniaceae	
Proboscidea altheaefolia (Benth.) Decne.	
Proboscidea parviflora (Woot.) Woot. & Standl.	
Nyctaginaceae	
Allionia incarnata L.	
Oxalidaceae	
Oxalis corniculata L.	*
Papaveraceae	
Argemone sp.	
Plantaginaceae	
Plantago insularis East.	
Plantago lanceolata L.	*
Plantago rhodosperma Decne.	
Poaceae	
Aristida adscensionis L.	
Aristida purpurea Nutt.	
Avena fatua L.	*
Bouteloua barbata Lag.	
Bouteloua aristidoides (H.B.K.) Griseb	
Bromus arizonicus Shear (Stebbins)	

Family, Genus and species	*Introduced
Bromus rubens L.	*
Cynodon dactylon (L.) Pers.	*
Hilaria rigida (Thurb.) Benth	
Hordeum vulgare L.	*
Lolium multiflorum Lam.	*
Muhlenbergia microsperma (DC.) Kunth.	
Phalaris carolinensis L.	
Schismus barbatus (L.) Thell	*
Schismus arabicus Nees.	*
Setaria viridis (L.) Beauv.	*
Sorghum halepense (L.) Pers.	*
Scleropogon longisetus Beetle	
Tridens sp.	
Polygonaceae	
Eriogonum deflexum Torr.	
Polygonum aviculare L.	*
Polygonum argyrocoleon Steud.	*
Portulacaceae	
Portulaca oleracea L.	*
Rhamnaceae	
Zizyphys obtusifolia (Hook ex T.&G.) A. Gray	
Scrophulariaceae	
Linaria texana Scheele	
Orthocarpus purpurascens Benth.	
Simaroubaceae	
Castela emoryi (A. Gray) Moran & Felger (*Holocantha emoryi* Gray)	
Solanaceae	
Datura discolor Bernh.	
Datura meteloides D.C.	
Lycium andersonii Gray var. *deserticola* C. L. Hitch	
Lycium californicum Nutt.	
Lycium fremontium Gray	
Nicotiana glauca Graham	*
Physalis acutifolia (Miers) Sandw. (*P. wrightii* Gray)	
Solanum eleagnifolium Cav.	
Tamaricaceae	
Tamarix pentandra Pall.	*
Typhaceae	
Typha latifolia L.	
Zygophyllaceae	
Larrea tridentata (DC) Coville	
Tribulus terrestris L.	*

Table 4. Presence of colonizing shrubs on edge or interior of old fields at least 20 years after abandonment, related to vegetation surrounding the field. Table is based on 3 years of informal observations of species distributions in approximately 50 old fields. Lack of an 'x' indicates that the species was never observed in the field in this location or landscape position. All species have been observed in untilled desert patches in the valley, although not with equal frequency.

		Surrounding vegetation			
		some desert		no desert	
Species	dispersal agents	edge	int.[1]	edge	int.
Atriplex polycarpa (c)	water	x	x		
Atriplex linearis (c)	water	x	x		
Larrea tridentata (c)	water, small mammals	x			
Prosopis velutina (c)	mammals	x	x	x	x
Lycium fremontii (c)	birds	x		x	
Lycium californicum (c)	birds				
Zyziphus obtusifolia (r)	birds	x	x		
Castela emoryi (r)	birds	x	x		
Opuntia spinosior (r)	mammals	x	x		
Ferocactus wislizenii (c)	ants, birds	x	x		
Peniocereus greggii (r)	ants, birds				
Baccharis sarothroides (r)	wind	x	x	x	x
Isocoma tenuisecta (r)	wind	x	x	x	x
Encelia farinosa (c)	wind	x	x	x	x
Tamarix pentandra (r)	wind	x	x	x	x

FIGURE LEGENDS

Figure 1. Map of Pinal County, Arizona showing the Gila River, the approximate path of the Santa Cruz River, and irrigated regions in 1963. Irrigated regions are redrawn from a U.S. Bureau of Reclamation map, "Irrigated areas in Arizona," in cooperation with the University of Arizona Departments of Agricultural Economics and Agricultural Engineering, and represent the limits of the Lower Santa Cruz Valley outside of Indian Reservations.

Figure 2. Map of agricultural regions in the Lower Santa Cruz River Basin, showing location of mapping study.

Figure 3. Remnant desert habitat that have never been cleared or plowed, based on 1983 aerial photography. White areas are either cultivated, abandoned, or developed for residences or industry.

Figure 4. Abandoned farmland and desert habitat in the mapping study. Faint diagonal lines running northwest through the middle of the map are developed strips associated with Interstate 10 and State Road 84.

Figure 5. Study area for quantification of landscape features (size and shape of native and abandoned farm patches).

Figure 6. Area harvested and volume of groundwater pumped in Pinal Co in Pinal County, Arizona, 1905-1992. Agricultural expansion was closely paralleled by increases in groundwater mining. Data for area harvested are from various reports of the Agricultural Crop and Livestock Reporting Service, and pumpage data are from Hammett, 1992.

Figure 7. Total cropland harvested, unharvested, and missing from the Agricultural Census, 1950-1987. The difference between "total cropland" in 1954 and 1987 is an estimate of abandoned farmland. "Cropland not harvested," which refers to idle cropland, has increased as a percentage of total cropland.

– Figure 8. Natural and constructed waterways of the Lower Santa Cruz Valley, circa 1885, based on the Pinal County Soils Map (Poulson et al., 1941). There were no known artificial reservoirs or canals before 1886. a. Southern channel of the Santa Cruz. b. The Santa Cruz Flats, an active alluvial fan north of the Santa Cruz channel without obvious drainageways. Several areas of the valley are referred to as "flats" on modern maps. c. Reemergence of the Santa Cruz River as a distinct channel west of Casa Grande. d. The southern McClellan Wash. e. The northern McClellan Wash. f. Green's Wash. g. North branch of the Santa Cruz.

Figure 9. Natural and constructed waterways of the Lower Santa Cruz Valley, about 1930. Map is based on the map of Poulson et al.(1941) plus recent U.S.G.S. topographic maps for north-south canals running from the Florence-Casa Grande Canals. This system is possibly more extensive than existed in 1930. a. The linked Florence-Casa Grande Canals run from east to west; feeder canals run north to irrigate fields. b. Picacho Reservoir. The canals from the Gila River near Florence do not actually feed the reservoir, but skirt the eastern edge of it. c. The ruins of Green's Reservoir. d. Green's Canal, extending from the junction of the Santa Cruz (west) and Robles (east) washes at Sasco Flats.

Figure 10. Natural and constructed waterways of the Lower Santa Cruz Valley, around 1980. Channelized washes were determined from U.S.G.S. topographic maps. a. Remaining fragment of the northern McClellan's Wash. b. Southern McClellan's Wash. c. Red Rock Wash. d. Convergence of the Green and Santa Rosa Washes. e. Former location of Green's Reservoir, now used for fields. Note the advanced stages of headcutting from Green's Canal to the southeast.

Figure 11. Natural and constructed waterways of the Lower Santa Cruz Valley, 1990. Central Arizona Project canals, carrying water from the Colorado River run west and south from the main aqueduct on the east side of the valley (not shown). Northeast running waterways are accomodated through the use of siphons and culverts. Berms protecting the

larger canals are sometimes as high as 10 meters, especially in low lying areas near the former location of washes..

Figure 12. Size distribution of remaining stands of never-plowed desert, for all patches, and patches 100 hectares and under, 1983.

Figure 13. Change in depth to groundwater between 1940 and 1970 in the study area (U.S.D.A. 1977). Most areas were within 12 to 27 meters of groundwater before pumping began (Smith 1940). Areas of greatest field abandonment do not correspond to areas of most precipitous groundwater decline.

Figure 14. Dispersal of creosotebush into old fields as a function of field age. Dispersal in old fields that have bee out of production for 24-37 years range from 150 to 400 meters. Shrub density follows an exponential decay function ($p<.01$ in all regressions) indicating that density is dispersal limited.

Figure 15. Loss of woodland in Pinal county, from 1949 to 1987. Data are from U.S. Bureau of the Census. In 1949 there were 20,000 hectares of potentially commercially useful woodland on 50 farms. Disappearance of woodland continued to occur at about the same relative rate through 1970.

Figure 16. Land leveling for irrigation is evident in 5 foot (1.5 m) contour intervals (U.S.G.S. 7.5 " topographic map, "Picacho Reservoir," 1981). The large-scale modification of topography for irrigation has serious implications for any future restoration.

Figure 17. Locations in eastern Pinal County illustrating several restoration strategies. A. Strategy I, first priority. Restoration of a watershed, the southern McClellan wash. The current location of the channelized McClellan Wash is also shown. B. Strategy II, first priority. Restoration of land between large tracts of desert habitat and the edges of the agricultural region to expand available native habitat (two locations are shown). C. Strategy II, somewhat lower priority. Restoration of abandoned land between two native desert areas within the farming region. D. Strategy III, first priority. Restoration around a large patch of native desert. This restoration also satisfies the goals of Strategy II, by

connecting two native patches. E. Strategy III, somewhat lower priority. Restoration of small patches of abandoned farmland linking other small patches of native vegetation. F. Companion strategy for all restoration strategies. Installation of small seed source islands on abandoned farmland thatis distant from natural sources of native seed.

These locations only serve to illustrate the main point of each of the strategic alternatives. No decision or plan to restore any abandoned farmland could be done without full participation of valley landowners and residents, and this map in no way endorses these particular sites for restoration work.