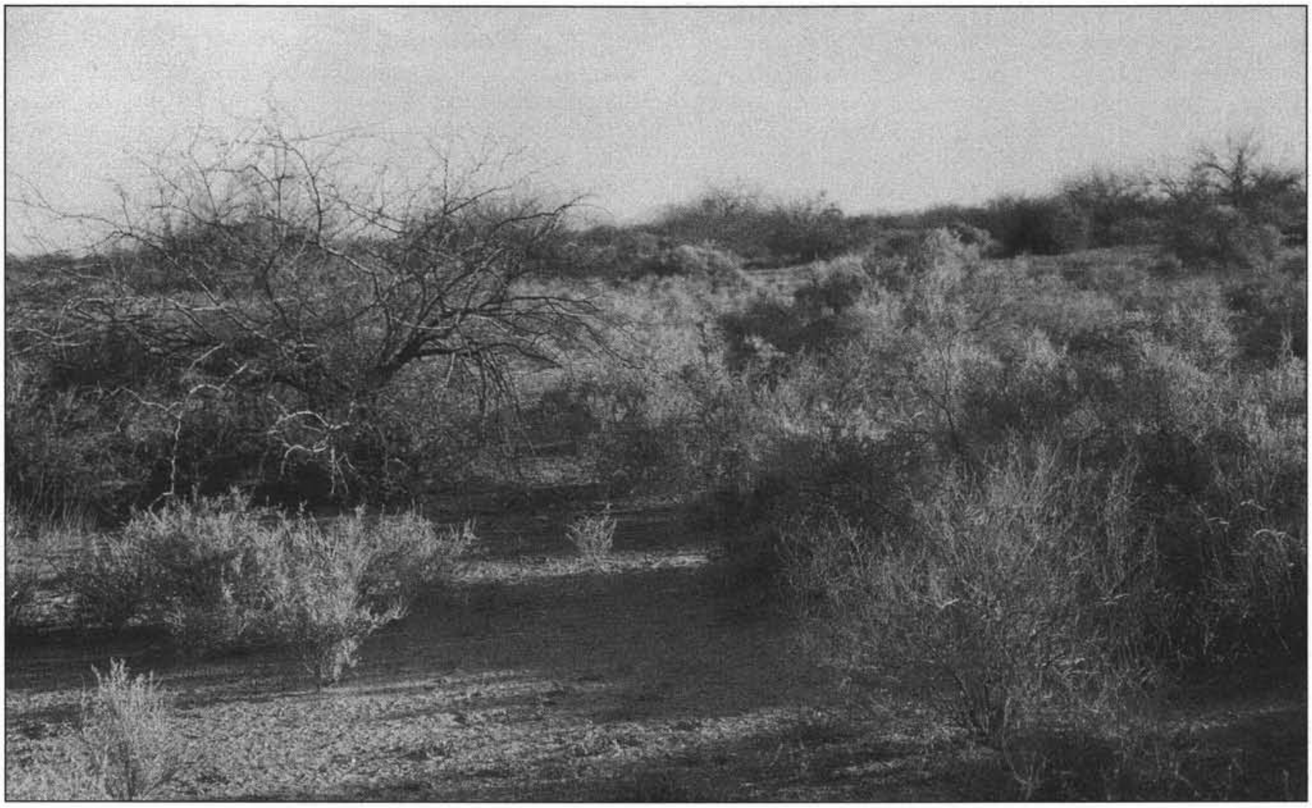


The model—desert saltbrush community near Fire Lake, Arizona

Photos courtesy of Laura Jackson

Desert Restoration

Revegetation Trials on Abandoned Farmland in the Sonoran Desert Lowlands

Preliminary work on abandoned agricultural sites suggests a "lazy but patient" approach may be best.

By Laura L. Jackson[1], Joseph R. McAuliffe[1], and Bruce A. Roundy[2]

The stretch of interstate highway between Arizona's two big cities, Tucson and Phoenix, is probably the most traveled and the least liked in the state. The highway follows paper-flat valleys once devoted to growing cotton, pecans and melons. However, agriculture began to contract after the early 1950s, and now 25 to 50 percent of all the agricultural land that the highway traverses— 2,200 square kilometers (850 square miles) in the Santa Cruz and Gila river valleys—has been abandoned (L. J., unpublished data). Much of it is dominated by the short-lived shrub burrowweed (*Isocoma tenuisecta*); some fields abandoned as long as 35 years ago have no plants growing on them at all.

There is little interest in restoring the lowland desertscrub native to this part of the Sonoran Desert. As in the cornbelt, native vegetation remains here only in small, "postage stamp" remnants. But if Iowas's cornfields were abandoned, prairie enthusiasts would surely swarm the area in a restoration effort of historic proportions. Lowland desertscrub, on the other hand, is uncharismatic and little known. Biologists in Arizona have traditionally headed for the mountains and riparian areas, ignoring the farming areas in favor of a more pristine, "natural" landscape. The first study of lowland deserts in Arizona was done by two plant physiologists from the U.S. Bureau of Plant Industry; not surprisingly they evaluated the soils and vegetation for their agronomic potential (Shantz and Piemeisel, 1924). Since then only one study of the lowland desert vegetation has been done (Karpiscak, 1980).

If this were a road cut, a mine spoil, or a wetland, laws would require restoration. But it is assumed that these agricultural lands will "go back to nature" on their own, and of course there is some basis for this assumption. In the forests of the eastern United States, when land is released from agriculture it is usually colonized rapidly by annual and perennial herbs, which are then gradually

[1]Desert Botanical Garden, 1201 N. Galvin Parkway, Phoenix, AZ 85008, (602)941-1225
[2]Department of Renewable Natural Resources, 323 BioScience East, University of Arizona, Tucson, AZ 85719, (602)621-7259

replaced by longer-lived native species (see for example Oosting, 1942; Horn, 1974, 1976; Tilman, 1986).

It is not clear, however, that the same thing will happen in drier climates. Reichhardt (1982) found very limited establishment of native perennial grasses in fields last cultivated 40 years earlier in eastern Colorado, where rainfall averages only 30 cm/year. If anything, the prognosis is even more doubtful in agricultural regions of the Sonoran Desert in Arizona, where rainfall is less than 25 cm/year. Karpiscak (1980) 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 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. Only a few fields that happen to be adjacent to undisturbed vegetation are recovering rapidly.

In 1989 the Desert Botanical Garden in Phoenix, Arizona received a grant from the Jesse Smith Noyes Foundation to study restoration of abandoned farm land in Arizona's lowland deserts. The motivations were twofold: first, abandoned farmlands were shockingly barren reminders of ecological failure; second, the Desert Botanical Garden is devoted to the conservation not only of rare species in deserts, but of whole desert ecosystems, and the Sonoran saltbush desertscrub ecosystem is considered rare as a result of agricultural and urban development (Turner, 1974). If former farm land adjacent to existing remnants of native vegetation could be partially restored to functioning saltbush desertscrub, it would be possible to expand the area of this unique desert ecosystem considerably. Environmental benefits would include better groundwater recharge and less flood damage to county roads, reduction of dust and an increase in wildlife habitat. Rural people, who now live in an industrial farming landscape interrupted only by the desolation of the derelict farmland, would benefit from expansion and enhancement of wild areas.

Sonoran saltbush desertscrub has no recognized value to society in the form of "ecosystem function," as do wetlands; nor is it prized as habitat for endangered species. Furthermore, the lowland deserts are too low in productivity to support a livestock industry, before or after farming. As a consequence, although the extent of the damage due to agriculture is much greater than that due to strip mines, and the disturbance is nearly as profound, clearing and abandonment of these areas are not regulated.

At the scale of the individual field, the problems of restoring Sonoran saltbush desertscrub have much in common with restoration projects in other arid areas (see, for example, Bainbridge and Virginia, 1990). We were primarily concerned with determining the historic species composition for a given site, acquiring seeds of those species, introducing them to the site, and providing them with extra water for establishment. We anticipated that seedlings would need a prolonged period of moist conditions in order to grow big enough to withstand the rainless period between April and July. The preliminary results of this study, carried out on a 2.5-ha site near Toltec, Arizona, are presented below.

Such techniques, of course, are useful only on a modest scale. Even if substantial funding could be found, and active restoration made feasible on a scale of hundreds of hectares, that would represent only 0.01 to 0.001 percent of all the abandoned land in just one river valley. Landscape-scale restoration typically depends heavily on natural succession. We wanted to know which types of land could recover on their own, and which truly required assistance. We knew that both soil type, which determines water availability, and distance to remnant stands of native vegetation were certain to be important. Some of these issues are being addressed in an ongoing study of the landscape pattern of field abandonment in the Santa Cruz Valley of Arizona to determine the relationship between the rate at which shrubs invade old fields and their soils, topography and distance from seed sources.

On another level, we had to recognize that recovery of this valley to a pre-disturbance condition, whether by natural recovery or active restoration, may be impossible. Tillage mixed formerly distinct soil horizons, changing the dynamics of water infiltration and availabilty, thus reducing the already miniscule chances for seedlings to become established. The leveling of hundreds of contiguous square kilometers has transformed the valley from a network of dendritic ephemeral streams into a cartesian grid sytem of roads and ditches. The Santa Cruz River has been diverted and channelized to prevent it from flooding the valley. As a result, it no longer recharges the shallow water tables that some plants depended upon. Critical to any restoration plan for this area was an accurate assessment not only of its historical plant and animal communities, but also of its current potential to support them.

To our knowledge, restoration of desert farmland in the United States has been attempted in only two other studies. In 1985 workers at the USDA-SCS Plant Materials Center in Tucson seeded a small test plot in a completely barren old field near Red Rock, Arizona (Munda *et al.*, 1986). They created water catchments by establishing berms on the contour, and seeded fourwing saltbush (*Atriplex canescens*), desert saltbush and wolfberry (*Lycium* spp.). In spring 1991, large shrubs of these species were still growing there, indicating that this method can work, at least under certain conditions. More recently, Thacker and Cox (in press) and Cox and Madrigal (1988) have developed methods for reseeding fields with South African grasses such as buffelgrass (*Cenchrus ciliaris*) and Klein grass (*Panicum coloratum*) before the land is retired, using irrigation only in the first year to establish seedlings. This was done on recently retired cotton fields, and cost $250-500 per hectare.

Thirty-four years of making the desert bloom: a landscape history

Our study area is the one square mile (259 ha) of Section 33, T7S R7E, Pinal Co., Arizona (lat. 32°45", long. 111° 37"). We chose it because it contains fields that were abandoned at different times and that have recovered to different degrees, making it broadly representative of the Eloy area of the Santa Cruz floodplain. Historical aerial photos taken between 1936 and 1979 (Fig. 1 a-f) in combination with an intimate knowledge of the soils and vegetation of this square mile today, have allowed us to piece together its history.

The earliest agricultural developments using groundwater rather than surface water were in or near ephemeral rivers or "washes," where the groundwater was within reach of the early wood-fired steam pumps. The Santa Cruz Wash was actually a broad (2.5-km), continuously shifting belt of overland flow rather than a channel (Fig. 1a; Smith, 1940). Our study site lies adjacent to and partly within this belt, visible in Fig. 1a as a dark streak across the extreme southwestern corner of the section. According to a description by G. E. P. Smith (1940), the northwest-flowing wash was dry most of the time, but flooded periodically, recharging the groundwater so that vegetable farmers in the late 1930s were able to pump from depths of only 22 m. Current groundwater pumping in the vicinity is from depths in excess of 400 m. We have found fragments of ironwood (*Olneya teosota*) and a large (1 m diameter) trunk of blue palo verde (*Cercidium floridum*) on the study site, suggesting greater water availability in the past.

Farming operations were small in the late 1930's, but already showed signs of the industrial scale they would later attain. A third of the owners had less than 20 ha each, often in specialty crops, but 41 percent of the land was held in parcels greater than 174 ha, and 43 percent of the owners lived outside the county, leasing it out to tenant farmers (Greisinger and Barr, 1941). On our study area only about 32 ha had been cleared by 1936 (Figure 1a) and no pumping was reported until 1938 (Smith, 1940).

Fields abandoned before the early 1950s had some advantages in recovery compared to fields abandoned during the 1960s or later. Farmers commonly did not use cement to line irrigation ditches prior to the 1950s, so water seeped out and was available to trees and shrubs growing along ditch banks. "Tailwater"—the water left over at the end of the row—was allowed to run off the field. (Attesting to the amount of water used by ditchside vegetation are the skeletons of huge cottonwood trees still standing next to irrigation ditches today. Live cottonwoods were a common sight until farmers began using aerially-applied herbicides to defoliate cotton before picking, in the process killing the trees.) Furthermore, these relatively small and often isolated farms were more likely to have been bordered by native desert vegetation than were larger farms that were abandoned more recently. This meant that there were ample sources of seeds for reinvasion of native vegetation, both from nearby undeveloped desert, and from the relatively lush vegetation living on "wasted" irrigation water. In addition imperfect leveling of older fields meant that some microtopography was still in place to provide safe sites for new seedlings.

In part of our study area, a 24-ha (80-acre) field bordered on two sides by native vegetation and irrigated from unlined ditches running northeast, was apparently cleared, cultivated and then abandoned between 1938 and 1949 (Fig. 1b and c, west 1/2 of southwest quarter section). A ditch (note the denser vegetation) running southeast to northwest probably was installed to channel runoff from the Santa Cruz wash for irrigation, further underscoring the past importance of flooding in the region. Recovery has been rapid here, and mesquite (*Prosopis velutina*), desert saltbush, creosotebush, wolfberry and globemallow (*Sphaeralcia* spp.)—all native to the area—are now abundant. Indeed, without an aerial photo revealing the parallel marks of a disk or plow, we could not have determined that the area was ever cultivated.

There was a boom in cotton production in the early 1950's, followed by a sharp decline in 1954 due to new production limits and a crash in cotton prices (Shapiro, 1989). Accordingly, the maximum amount of land on our section was cultivated between 1949 (174 ha) and 1954 (178 ha) (Fig. 1 b, c). By 1964 only 72 ha were still in cultivation, and by 1970 farming had ceased altogether (Fig. 1 d, e). The passage of the Arizona Groundwater Management Act in 1980 sealed the fate of the study site and many nearby farms, since it stipulated that land not irrigated between 1970 and 1975 could no longer be irrigated. Our site, and many farms like it, would never be irrigated again. Acording to aerial photos taken in 1983, half of the 56 square miles in the area has been farmed and abandoned. The pumps are gone, many roads are in disrepair, and the irrigation ditches have silted in. Thus, any attempt to revegetate this area would have to be carried out without additional irrigation water.

During the late 1970's the region underwent a revolution of sorts that affected the fate of much of the abandoned farmland. In response to the persistent rumor that a regional airport would be built halfway between Phoenix and Tucson, speculators snapped up cheap, abandoned farm land (including our site) along the highway and the railroad it parallels. So far, no airport has materialized and the land is still in limbo. As a consequence, the land owners (often limited partnerships and real estate companies) have no reason to care about the condition of the land they own. There is no motivation to restore "worthless" land.

Restoration experiment

Although the social and economic feasibility of restoring abandoned farmland remains an issue, we wanted to find out whether it is ecologically feasible to establish perennial shrubs on a typical abandoned field that showed no signs of recovery. We chose two barren (less than 0.1 percent cover) areas within the 259 ha study site described above, and planted seeds of the native species found growing in nearby desertscrub. By concentrating rainfall with simple water catchments, enhancing water infiltration through tillage and modifying the environment around the seed and seedling, we hoped temporarily to ameliorate the adverse conditions preventing natural seedling establishment.

We tested the effectiveness of straw mulch, annual grasses and weeds as a cover for establishment of desert saltbush, creosotebush, mesquite and wolfberry, the main native perennials now found on an adjacent undisturbed site. Restorationists often use straw mulch in revegetation work to conserve soil moisture and to improve soil structure (Kay, 1987), but straw is expensive to purchase and haul. Weeds and annual grasses might act as a living mulch, but might also compete too much with the shrub seedlings. To sort out these factors and their interactions, we designed a factorial experiment including various combinations of straw mulch and living mulches of weeds or annual grasses on a series of plots seeded with desert saltbush, creosotebush, mesquite and wolfberry.

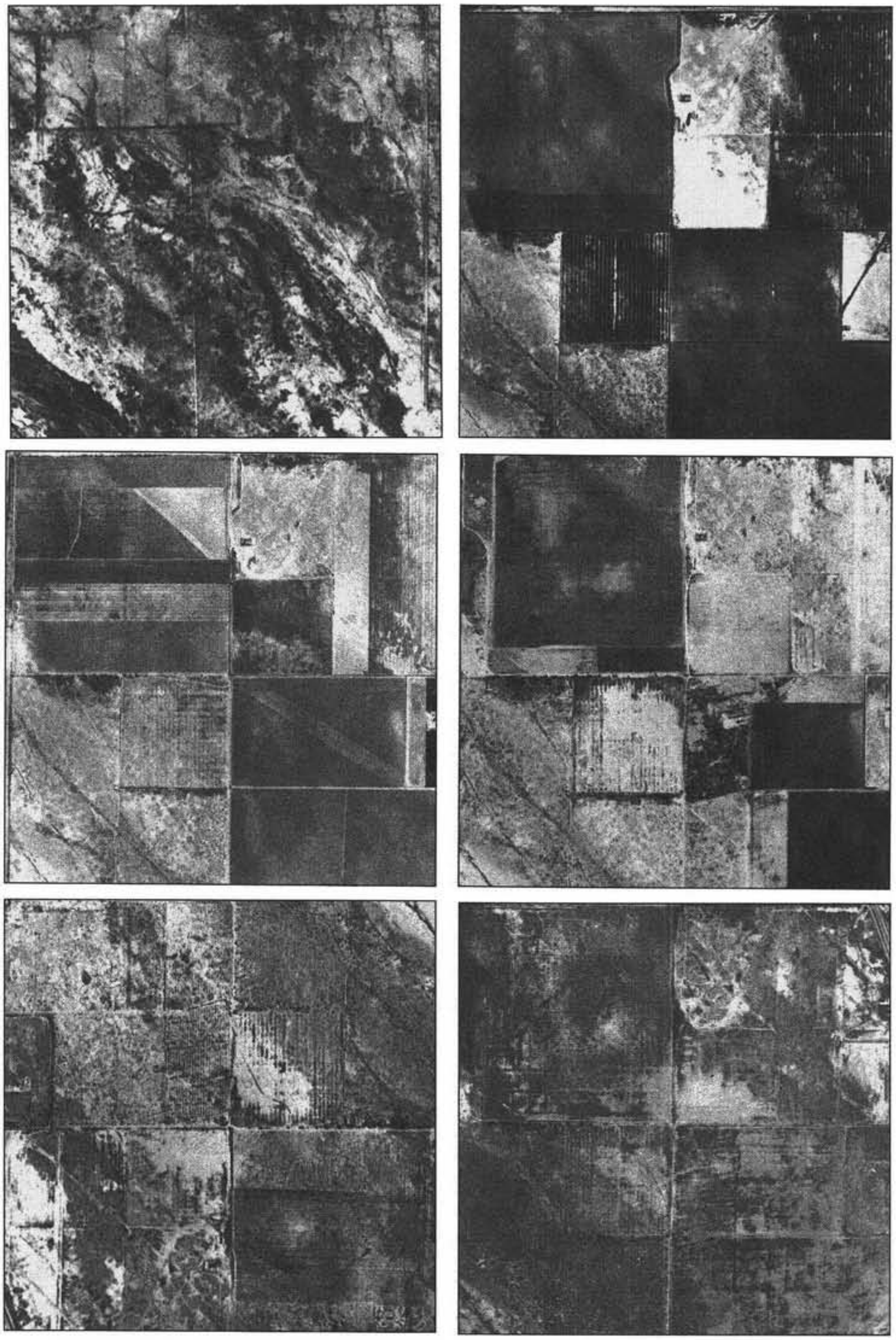


Figure 1: Aerial photos of the study area, a square mile (2.56 square km) in Pinal Co., Arizona, near the town of Toltec. Photos were available (left to right, top to bottom) for a) 1936; b) 1949; c) 1954; d) 1964; e) 1970 and f) 1979. North is toward the top of the page in all photos. Rectangles in 1 f indicate the approximate positions of experimental sites 1 and 2.

Climate, vegetation and soils

Average annual rainfall at our site is 215 mm (8.5 inches), about 40 percent of which falls in locally heavy summer thunderstorms during July, August and September, and the balance in gentle, winter rains. The mean maximum July temperature is 40.5°C (105°F), with a record maximum of 47.2°C (117°F; Sellers and Hill, 1974; data is for Eloy, AZ).

For the study we chose two 1.3 ha barren (less than 0.01 percent perennial plant cover) areas 0.7 km apart (Fig. 1 f). Site 1 was abandoned between 1954 and 1960; site 2 between 1949 and 1954. Representatives of the original dominant vegetation, including creosotebush, desert saltbush , linear-leaved saltbush (*A. canescens* var. *linearis*), mesquite, wolfberry and globemallow were growing on land that had last been cropped before 1949 (Fig. 1b, w 1/2 of sw 1/4), within 1 km of site 1 and 300 m of site 2. These were the perennial species used in the seed mix.

All of the seed for the study was donated by local native seed companies or collected by Desert Botanical Garden volunteers. Summer rains were better than average in 1990, producing good crops of seed from warm-season ephemerals such as six-weeks grama (*Bouteloua barbata*) and three-awn grama (*B. aristidoides*). The grass seed was collected, in some cases, by sweeping the seeds off the desert floor with brooms and dustpans before it could be taken by harvester ants.

We examined soil profiles at the experimental sites from two 1.8 m deep trenches excavated with a backhoe. The top two centimeters consisted of a very fine sandy clay loam with platey structure. From approximately 2-60 cm the profile consisted of sandy clay loam with a subangular blocky structure. Below 60-65 cm the profile contained a weakly cemented carbonate horizon (caliche) extending to the bottom of the pit. We also examined soil profiles in areas nearby where natural revegetation had occurred after a brief period of cultivation. Interestingly, the upper 3-30 cm of these profiles contained coarser-textured horizons (sandy loams). Rainwater can infiltrate sandy loams more quickly than the relatively impermeable sandy clays found in the barren sites. Since water availability in the soil clearly limits vegetation here, and since availability is reduced on impermeable soils, we suspect that our experimental sites have remained nearly free of vegetation due to their finer-textured, less permeable soils.

Sodium concentrations, as measured by electrical conductivity were low (0.7 to 1.4 mmhos/cm) at the surface and 5-10 cm depths, and medium (2.1 mmhos/cm) at a depth of 15-25 cm.

Water catchments and experimental treatments

Because summer rains are less predictable than winter rains and are accompanied by high-evaporation conditions, we planted during the winter rainy season in early January,1991. To increase the amount of water available to our plantings, we used rainwater running off the barren, impermeable soil surface to supplement our experimental plots where its flow was arrested by low berms arranged on the contour (Fig. 2). First we surveyed at each site to determine the direction of slope, which was less than 1 percent. Then, using a border disk commonly used for making cotton rows, we created two rows of nine parallel berms separated by water catchment areas 15 m wide. Each berm was 30 m long and 40 cm high. We used a stiff-tined "ripper" to create a 2.4 m wide seed bed (the actual experimental plot) on the uphill side of each berm. The ripper disturbed the soil to a depth of 10-15 cm and left large (5-10 cm diameter) clods on the surface.

At each site, the seed bed next to each berm was broadcast-seeded with a mixture of perennial shrubs. Only the lower sixteen of the available eighteen plots at each site were included in the experiment. The two plots on the high end of each site caught water from a much larger runoff area and thus would have produced spurious results. Half of each plot was designated at random and seeded with Mediterranean grass (*Schismus barbata*), six-

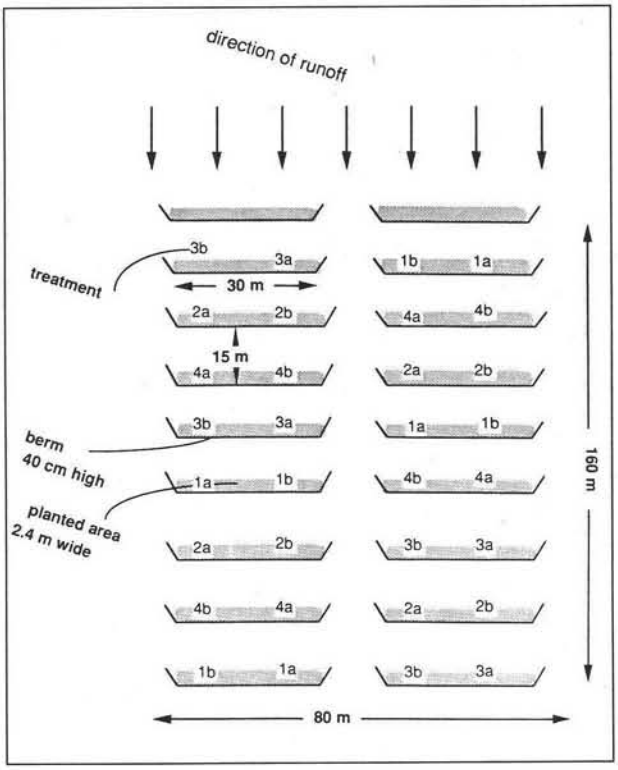


Figure 2: Layout of berms, plots and treatments on site 1. Abbreviations: 1) mulched, weeded; 2) mulched, not weeded; 3) not mulched, weeded; 4) not mulched, not weeded; a) annuals planted; b) annuals not planted.

weeks grama, three-awn grama, and Indian wheat (*Plantago insularis*), all common ephemerals of the lowland deserts. Mediterranean grass, the only exotic species, was planted because it is completely naturalized to the area and was the only available cool-season grass.

Each combination of mulch and weeding treatments (four in all) was randomly assigned to four replicate berms at each site. Half of all berms received wheat straw mulch at the rate of 900 kg/ha (two tons/acre). On site 1, seeded and mulched January 3, 1991, we ran over the straw with a tractor-drawn "crimper," a series of weighted, blunt disks which push the straw into deep impressions in the soil. At this rate of straw application, straw covered about 50 percent of the soil surface. On site 2, seeded and mulched January 16, the straw was not crimped.

Plots randomly assigned to the weeding treatment were hand-weeded as soon as weeds began to appear in February, and again in March, April and May. The principal weed in plots mulched with wheat straw was wheat, which germinated immediately and headed out in March. All plots had uneven weed infestations, principally of narrow leaf goosefoot (*Chenopodium desiccatum*), filaree (*Erodium cicutarium*), and London rocket (*Sisymbrium imbrio*). Russian thistle or tumbleweed (*Salsola kali*) did not reach great size or number until early May.

We did not see any evidence of seed herbivory on either site, probably because the sites were so barren that few animals ventured into the area. Rabbits ate some of the wheat in the mulched, unweeded plots, but we observed no nibbling on the shrub seedlings.

Environmental measurements

In order to measure the effects of mulching and tillage on temperature and water availability, we installed five gypsum moisture blocks one m apart at two depths, one and 15 cm, in three locations: in a mulched, weeded plot ("mulched"); in an adjacent unmulched, unweeded plot, ("cultivated") and between two plots in unmanipulated soil ("bare") at site 1. Thermocouples were also installed to measure the temperature of the soil at a depth of 1 cm at each location. Thermocouples and gypsum blocks were attached to a computerized data logger which took readings every minute, converted these to hourly averages, and stored the data electronically. Continuous data were available from March 13, when the equipment was installed, through April 23, 1991.

Seedling counts

To monitor the success of seedlings, we established eight permanent, 0.25 m^2 circular quadrats at regular intervals along the 30 m long plots. We identified and counted seedlings within each quadrat in March, April and May, 1991. In May, we also estimated the percent cover of desert saltbush and all other seedlings combined. We measured seedling heights for the three largest seedlings in each quadrat in May, when most growth had probably ceased due to exhaustion of soil moisture (no rain fell after March 28th).

Data analysis

The resulting data were analyzed on the basis of a randomized complete block, split-plot experimental design. We averaged the data from the four quadrats within each split plot, and used these means in analysis of variance. The effects of whole-plot treatments and their interactions (mulch, weeding, and mulch plus weeding) were tested using the appropriate whole plot error term (Sokal and Rohlf, 1981).

Results

Rainfall

The water catchments worked well. Rain falling in the pavement-like bare areas between the plots flowed into the tilled plot in front of each berm. Our tillage in the seeded plot had broken up the surface crust, allowing water to soak in more easily, and the berm next to each plot prevented any water from flowing off the plot. Following a 30 mm rain on March 28th there was standing water in the tilled area, while the bare areas between plots were already dry. The low permeability of these soils makes it necessary to hold water on them for a long time to ensure water infiltration (Poulson *et al.*, 1941). For the same reason, untilled areas between the plots made excellent drainage areas.

The timing and amount of rainfall proved to be a major factor influencing the outcome of the experiments. We worked the ground at site 1 and site 2 on January 3, 1991, and planted site 1 the same day. Sixty-eight mm of rain had fallen since December 15, leaving a moist and friable seed bed. On January 4-6 the area received 24 mm of rain (data are for Coolidge, AZ; Arizona Climate Summary,

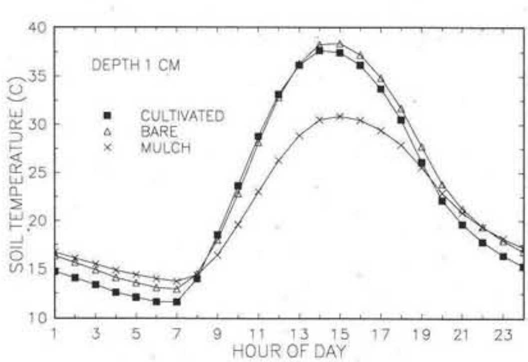


Figure 3: Soil temperature at 1 cm in a dry soil, April 8, 1991. Mulched soil had lower daytime temperatures at 1 cm depth than cultivated and bare soil.

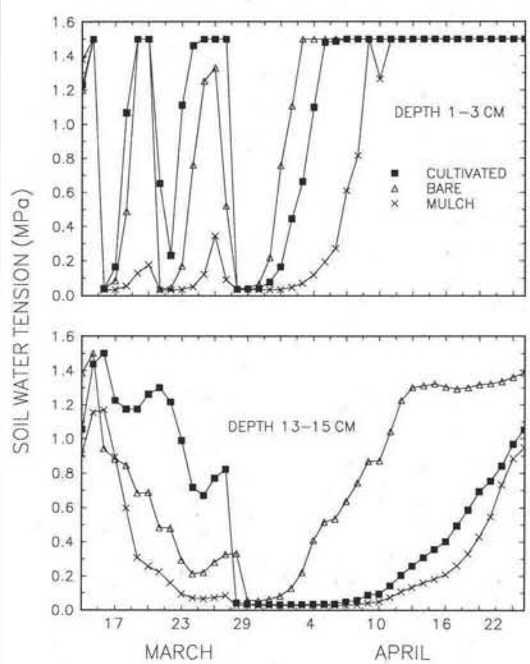
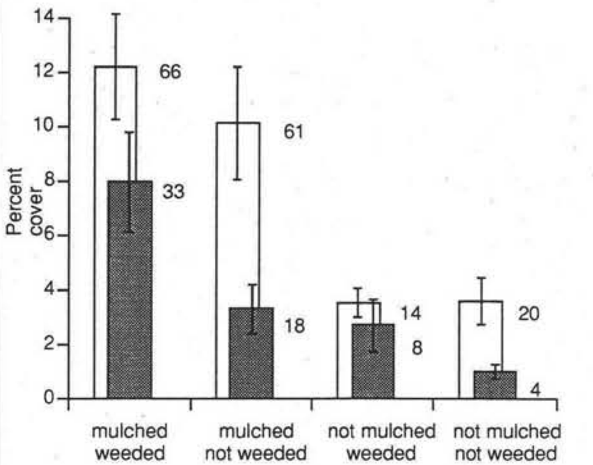


Figure 4: Soil water tension (megapascals) at 6 am at 1-3 cm (top) and 13-15 cm (bottom) depths. Both cultivation and mulching delayed increases in water tension following rain, prolonging periods of high moisture ability.



Results of Analysis of Variance

(white)	percent cover of all species	Mulching	p* = .0004	significant
		Weeding	p = .53	no effect
		Annuals	p = .62	no effect
(solid)	percent cover of desert saltbush	Mulching	p = .015	significant
		Weeding	p = .033	significant
		Annuals	p = .534	no effect

* p stands for the probability that two means are *not* different. In general, a value of p that is less than .05 is considered a "significant difference."

Figure 5: Mean percent cover (bars) and number of plants per square meter (numbers) for desert saltbush (solid bars) and all other species combined (white bars). Error lines on each bar represent one standard error above and below the mean. Mulching greatly increased seedling establishment both for desert saltbush and for other species combined. Weed control also increased establishment of desert saltbush.

1991). This soaking rain immediately after planting proved to be ideal for seedling establishment at site 1. We were not able to plant site 2 until January 16, by which time the soil had dried out. No significant rain fell again until 15-20 March (24 mm measured on the site); desert saltbush and Indian wheat seedlings emerged at site 2 shortly thereafter, but much later and in lower numbers than at site 1. For this reason our discussion of the results will be confined to site 1.

Soil temperature and moisture

The effects of mulch on soil temperature and moisture retention are intuitively obvious, but rarely measured (Evans and Young, 1970, 1972). On a typical sunny day in a dry soil (April 8, 1991), surface temperatures in untreated and unmulched soils approached 39°C (102°F) at midday, but were never greater than 31°C (88°F) in the mulched plots (Fig. 3).

Emerging seedlings are very sensitive to moisture in the top 2 cm of soil. In the untreated ("bare") and unmulched ("cultivated") plots, rain on March 16 (12 mm), March 21, (12 mm) and March 27 (30 mm) wetted the surface to field capacity, but the soil dried out 1-4 days after each rain (Fig. 4). In the mulched plots, moisture in the top 2 cm stayed high (that is, water tension was low) over the entire 21-day period. We expected mulch to increase and prolong soil moisture near the surface, but to have little effect on soil moisture in lower layers. However, this was not the case. At 13-15 cm depth, mulched soils accumulated moisture faster than merely cultivated and untreated soils, and held onto it longer (Fig. 4).

Seedling Establishment

Desert saltbush, and to a lesser extent, linear-leaved saltbush and Mediterranean grass, emerged almost immediately after the rain on January 4. Warm weather after the March rains triggered germination of mesquite in several plots. Creosotebush and perhaps wolfberry, as well as six-weeks grass and three-awn grass are more likely to germinate during the monsoon rains in the summer; we will continue to collect data through another rainy season to verify this. No species other than desert saltbush emerged in sufficient numbers on site 1 to allow us to analyze for treatment differences, so we will present results only for this species and the aggregate of all other species will be presented.

We had to look very closely to find the 3 mm long, purplish-brown cotyledons of desert saltbush, and this gave us the opportunity to observe the kind of microhabitat that favored germination and growth. In unmulched plots, most seedlings emerged from cracks in the soil behind and underneath soil clods and in the low depressions formed by tilling. In mulched plots we found seedlings on both ridges and valleys, underneath straw that cast less than 100 percent shade. Overall, seeds of desert saltbush germinated and survived best in the mulched, weeded plots (Fig. 5). Although the total percent cover of desert saltbush after three months of growth (4-8 percent) was not impressive, the number of saltbush seedlings in *all* treatments (4 to 33, Fig. 5) was substantially higher than it would be in mature stands. Annual grasses did not come up in sufficient quantity to have any effect on either weed suppression or desert saltbush establishment.

It is likely that only the most vigorous plants will survive spring and fall droughts. By May, the majority of saltbush seedlings in all plots were less than 5 cm high and unbranched, but some of the largest seedlings in the mulched plots had reached 30 cm and were woody and highly branched. On the other hand, mulching had a (barely) significant effect on average seedling height. In plots that were mulched and weeded, on the other hand, the mean height of the tallest seedlings was 13.6 cm compared to only 9.6 cm in unmulched, weeded plots.

It was our hope that by getting any sort of plants established, even weeds, we would eventually improve the chances for natural recovery by increasing soil organic matter and water holding capacity. Therefore, we also wanted to know how the various treatments affected total plant cover, including all perennials and annuals. For all species combined, mulch still had a significant effect on total plant cover, but weeding did not. These results suggest that, if the goal is to maximize plant cover at minimum cost, weeding is not necessary but mulch is.

Discussion

Active restoration of farm lands is clearly not warranted if native vegetation will gradually recover on its own. It is critical to know whether a) the site was barren before agriculture, due to natural soil conditions, and b) enough time has elapsed to allow for vegetation recovery. We chose sites that were almost completely devoid of perennial vegetation, despite proximity to seed sources and considerable time since abandonment (37-42 years for site 2, 28-37 years for site 1). Since there was no evidence of any shrub recruitment on these sites, it is unlikely that waiting an additional 40 years would solve the problem. Aerial photos showed vegetation on the sites before farming, so this was not a natural "slick spot" where plant growth has always been impossible. On our sites, it is likely that initial soil properties (a platey, vesicular surface crust providing poor infiltration), changes in the hydrology of the region due to pumping and water diversion, and the destruction of soil structure and mixing of soil horizons due to tillage have combined to make natural plant establishment all but impossible.

Even in undisturbed deserts, seedling establishment occurs only infrequently, when there is unusually plentiful rainfall. Not only is moisture necessary for immediate germination and growth, but seedlings must grow large enough to tolerate the drier, normal conditions (Went, 1948; Jordan and Nobel, 1979, 1981; West *et al.*, 1979). These conditions pose a barrier to establishment, and it is the restorationist's job to get over this barrier. It is likely that any restoration in deserts relying on direct seeding and rainfall will fail in most years. Water catchment systems and mulching will increase the chances for seedling establishment. In a good rain year we were able to establish desert saltbush and linear-leaved saltbush on both mulched and unmulched plots—at least at one site. Plantings made at site 2, just two weeks later, which were not immediately followed by rain, were significantly less successful (a maximum of 20 saltbush seedlings/m^2 in mulched plots at site 2, compared with 33 /m^2 at site 1), and this is reason to be humble. It is likely that in a poorer rain year, we would have gotten no seedlings at all on our unmulched plots.

We will not know for several years whether our plantings this year are ultimately successful. During especially dry or even normal rainfall years, the dense stands of saltbush in the mulched plots may fare worse than the sparser stands on unmulched plots. Species diversity is low in all plots; it is not clear whether seeds of warm-season germinators such as creosotebush will come up this summer, or whether they should be replanted. Our berms covered 2.6 ha, but the actual seeded area was only 0.23 ha. It is unlikely that areas between the seeded strips will revegetate easily, because the soil surface crust is so hard. We have seen signs of the activities of burrowing animals (ground squirrels, coyotes, badgers) elsewhere in the study area; perhaps they will eventually be attracted to our plantings, break up the surface crust and facilitate subsequent plant establishment.

Predictions and Recommendations

We predict that restoration in desert old fields will be best accomplished by building water catchments, mulching with coarse, woody debris that is slow to break down, and then planting a fraction of the restoration area repeatedly until a good rainfall year occurs. Depending on the life of the seeds in the soil, an area might need to be reseeded every third year or so. Seeding, mulching and catchment techniques would all need to be tailored to such a long-term approach.

This "lazy but patient" method requires a long term commitment, but is not capital-intensive. The cost of seeds would be high but would be spread out over the waiting period and offset by the savings in irrigation. This approach mimics the process of natural succession, but enhances it by promoting greater water infiltration and also by ensuring that when good rainfall does occur, seeds are there to take advantage of it. This may not occur naturally if stands of native plants do not exist nearby, or may occur only infrequently when good seed crop years are followed by good rain years.

In contrast, the "hard-working but impatient" approach is capital-intensive at the beginning of the project (transplanting, watering and controlling weeds). It is more immediately satisfying, is more easily written into a contract, and can create impressive results, but may ultimately prove wasteful. Where soil erosion is not an imminent danger (as it is not on these flat lands) there is usually little reason to be impatient about establishing a vegetative cover.

A great deal of research is necessary to learn about the establishment requirements of desert shrubs of the lowland Sonoran Desert. Their biology is not well known because they are of little value as rangeland. We will continue to study the effects of soil and mulch manipulations on the soil microenvironment as perceived by the seed and seedling. These studies will teach us not only about restoration, but about the basic ecology of the lowland desert ecosystem.

Water Farms—Opportunities for Restoration

A final wave of farm abandonment is likely to occur during the next 10-20 years due to the practice of "water farming." Many environmentalists have argued that we could eliminate the need for ecologically destructive and politically unpopular dam projects by "retiring" irrigated farm land from agricultural production and pumping the former irrigation water to fast-growing southwestern cities. Agriculture, they point out, uses 85-95 percent of the water in southwestern states, but constitutes only two percent of the personal income; in economic terms agriculture would not be missed. (Reisner and Bates, 1990).

The idea of water farms was not widely implemented in Arizona until groundwater law changed in 1980, and the Central Arizona Project canal system was completed in the mid-'80's. Since then, about 40,000 ha of active farm land have been purchased by cities, mining companies, and other water users. Similar purchases have begun to occur in Colorado, Nevada and California as well. This trend will create monotonous, weedy fields requiring years, if not centuries, to recover.

Water farming per se will have no direct effect on the ability or inability of farm land to recover, since the mined groundwater is too deep to be accessible to even the deepest-rooted plants. Moreover, unlike previous waves of abandonment, this one may be accompanied by the political and economic incentive to restore some of the lost desertscrub habitat. The practice of water farming itself is politically controversial, and for this reason there may be an incentive to give something back to affected rural communities. Municipalities that buy water farms are senstive to the criticism that their fields of weeds are ugly, and that they have caused the land to "dry up and blow away." The City of Tucson, which bought and retired 8,900 ha of farms in the late 1970s, was successfully sued because tumbleweeds from the abandoned fields tumbled onto a neighboring farmer's property, spreading seeds and making it difficult to pick cotton (Thacker and Cox, in press). As a result, the city now must mow to keep down the weeds. Other water farm owners are anxious to avoid bad press and lawsuits.

Reflecting these concerns, the City of Mesa, Arizona has offered to donate the use of five farms ranging in size from eight to 32 hectares to the Desert Botanical Garden for restoration experiments. (Mesa owns 4,700 ha of active farm land that will be retired from agriculture during the next ten years). In addition to the land, they have offered to provide us with one acre-foot of water per acre for two years. (An acre-foot is the amount of water necessary to cover an acre with a foot of water— that is, 22,610 gallons or 81,400 liters. An average cotton crop requires in excess of 3.5 acre-feet.) Our experiments will compare the patient and impatient approaches to restoring this farmland. The Arizona Department of Fish and Game has expressed interest in supporting this work because it would enhance habitat for both game and non-game species.

It is likely that agriculture in the Southwest, heavily dependent on both water and energy, will continue to shrink. It is important that farmers and those who plan to retire farm land for water rights know that most of their "retired" farm land will not "go back to desert" within a few decades; that restoration, though expensive, has tangible benefits such as creation of wildlife habitat and expansion of a rare and unique ecosystem; and that methods of large-scale restoration and assisted natural regeneration are being developed.

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Literature Cited

Arizona Climate Summary. 1991. Laboratory of Climatology, Arizona State University, Tempe, Arizona. Vol. 17, No. 7-12.

Bainbridge, D.A. and R. A. Virginia. 1990. Restoration in the Sonoran Desert of California. *Restoration and Management Notes* 8 (1):3-13.

Costello, D. F. 1944. Natural revegetation of abandoned plowed land in the mixed prairie association of northeastern Colorado. *Ecology* 25:312-326.

Cox, J. R. and R. M. Madrigal. 1988. Establishing perennial grasses on abandoned farmland in southeastern Arizona. *Applied Agricultural Research* 3:36-43.

Evans, R. A. and J. A. Young. 1970. Plant litter and establishment of alien weed species in rangeland communities. *Weed Science* 18:154-162.

Evans, R. A. and J. A. Young. 1972. Microsite requirements of establishment of annual rangeland weeds. *Weed Science* 20:350-356.

Greisinger, P. and G. W. Barr. 1940. Agricultural land ownership and operating tenures in Casa Grande Valley. University of Arizona Agricultural Experiment Station Bulletin Number 175, Tucson, Arizona.

Horn, H. S. 1974. The ecology of secondary succession. *Annual Review of Ecology and Systematics* 5: 25-37.

Horn, H. S. 1976. Succession. R. M. May (Editor) *Theoretical ecology: principles and applications.* Oxford: Blackwell Scientific, 1976:187-204.

Jordan, P. W. and P. S. Nobel. 1979. Infrequent establishment of seedlings of *Agave deserti* (Agavaceae) in the northwestern Sonoran desert. *American Journal of Botany* 66: 1079-1084.

Jordan, P. W. and P. S. Nobel. 1981. Seedling establishment of *Ferocactus acanthodes* in relation to drought. *Ecology* 62:901-906.

Kay, B. L. 1987. Modifications of seedbeds with natural and artificial mulches. G.W. Frasier and R. A. Evans, editors, Proceedings of symposium, seed and seedbed ecology of rangeland plants. Tucson, AZ: 21-23 April 1987: 221-224.

Karpiscak, M. M. 1980. Secondary succession of abandoned field vegetation in southern Arizona. Ph. D. dissertation, University of Arizona, Tucson, 219 pp.

Kay, B. L. 1987. Mulches for erosion control and plant establishment on disturbed sites. Schaller, F. W. and Sutton, P. eds. *Reclamation of drastically disturbed lands.* American Society of Agronomy, Madison, Wisconsin: American Society of Agronomy; 1987:476-483.

Munda, B. 1986. United States Department of Agriculture Soil Conservation Service-Plant Materials Center, Tucson. Personal communication.

Oosting, H. J. 1942. An ecological analysis of the plant communities of Piedmont, North Carolina. *American Midland Naturalist* 28:1-126.

Poulson, E. N., R. Wildermuth, and W. G. Harper. 1941. Soil survey: the Casa Grande area, Arizona. United States Department of Agriculture, Bureau of Plant Industry, Series 1936, Number 7, United States Government Printing Office, Washington, District of Columbia, USA.

Reichhardt, K. L. 1982. Succession of abandoned fields on the shortgrass prairie, northeastern Colorado. *Southwestern Naturalist* 27:299-304.

Reisner, M. and S. Bates. 1990. *Overtapped oasis: reform or revolution for western water.* Washington, D.C., Island Press.

Sellers, W. D., and R. H. Hill, editors. 1974. *Arizona Climate, 1931-1972.* Tucson: The University of Arizona Press.

Shantz, H. L. and Piemeisel, R. L. 1924. Indicator significance of the natural vegetation of the southwestern desert region. *Journal of Agricultural Research* 28:721-801.

Shapiro, E. A. 1989. Cotton in Arizona: a historical geography. Master's Thesis, The University of Arizona, Tucson, Arizona, USA.

Smith, G.. E. P. 1940. The groundwater supply of the Eloy district in Pinal County, Arizona. University of Arizona Agricultural Experiment Station Technical Bulletin Number 87, Tucson, Arizona USA.

Thacker, G. L. and J. Cox. In press. How to establish a permanent vegetation cover on farmland. Pima County Cooperative Extension, The University of Arizona, Tucson, Arizona.

Tilman, D. 1986. Nitrogen-limited growth in plants from different successional stages. *Ecology* 67: 555-563.

Turner, R. M. 1974 . Map showing vegetation in the Phoenix area, Arizona. Map I-845-I. Miscellaneous Investigations Series 1:250,000. United States Geological Survey, Reston, Virginia, USA.

Turner, R. M and D. E. Brown. 1982. Tropical-subtropical desertlands. Brown, D.E. Editor. Biotic communities of the American Southwest—United States and Mexico. *Desert Plants* 4:180-222.

Weaver, J. E. and F. W. Albertson. 1956. *Grasslands of the Great Plains.* Lincoln, Nebraska: Johnsen Publishing Co.

Went, F. W. 1948. Ecology of desert plants. I. Observations on germination in the Joshua Tree National Monument, California. *Ecology* 29: 242-253.

West, N. E., K. H. Rhea, and R. O Harniss. 1979. Plant demographic studies in sagebrush grass communities of southeastern Idaho. *Ecology* 60: 376-388.

Wetland Restoration in the Mitigation Context

The two aren't necessarily the same thing, but mitigation can provide opportunities to do real restoration.

By John W. Munro

The regulatory structure that surrounds and permeates the wetland mitigation process is so bulky, so bureaucratic, and so loosely enforced that much of the land-altering work undertaken to mitigate the loss of wetlands falls considerably short of real restoration. In my view this is unfortunate because, despite its limitations, mitigation policy does provide real opportunities to do wetland restoration, and in some instances even to make a net contribution to wetland conservation. The purpose of this article is to suggest improvements in mitigation regulations that would address these shortcomings, and to provide guidelines for carrying out restoration work in the mitigation context.

At the outset it is only fair to acknowledge that the policy and practice of requiring some sort of mitigation to compensate for damage done to existing wetlands has already benefitted the discipline of restoration enormously. It has provided opportunities for projects that, even when they are not restoration projects in the strict sense, have provided invaluable experience with a variety of wetland types throughout the U.S. This in turn has led to improved techniques, sharing of information and ideas and, not least, the spread of the idea that it is actually possible to create reasonable facsimiles of at least some kinds of wetlands.

The question of whether or not wetlands that are constructed by humans ever actually "work," or provide satisfactory substitutes for their natural counterparts has been debated long and hard within the regulatory setting. Permit applicants and many environmental consultants want to prove that wetland mitigation is reasonable and fully compensatory. On the other hand preservationists want to prove that restored wetlands are a very poor substitute for the real thing.

The question itself is a bit ambiguous since each of us—the accountant, the developer, the farmer, the government biologist, and the wetland ecologist—will have a different opinion of what a wetland should do in order to pass the "Does it work?" test. In Asia, rice farmers have been making their wetlands "work" for many centuries. And many "working" wetlands have been created almost by accident as a result of highway and other construction projects.

John Munro is an ecological consultant specializing in wetland ecology, wetland design, and the wetland regulatory process at Munro Ecological Services, Inc., Harleysville, PA 19438 (215) 287-0671.