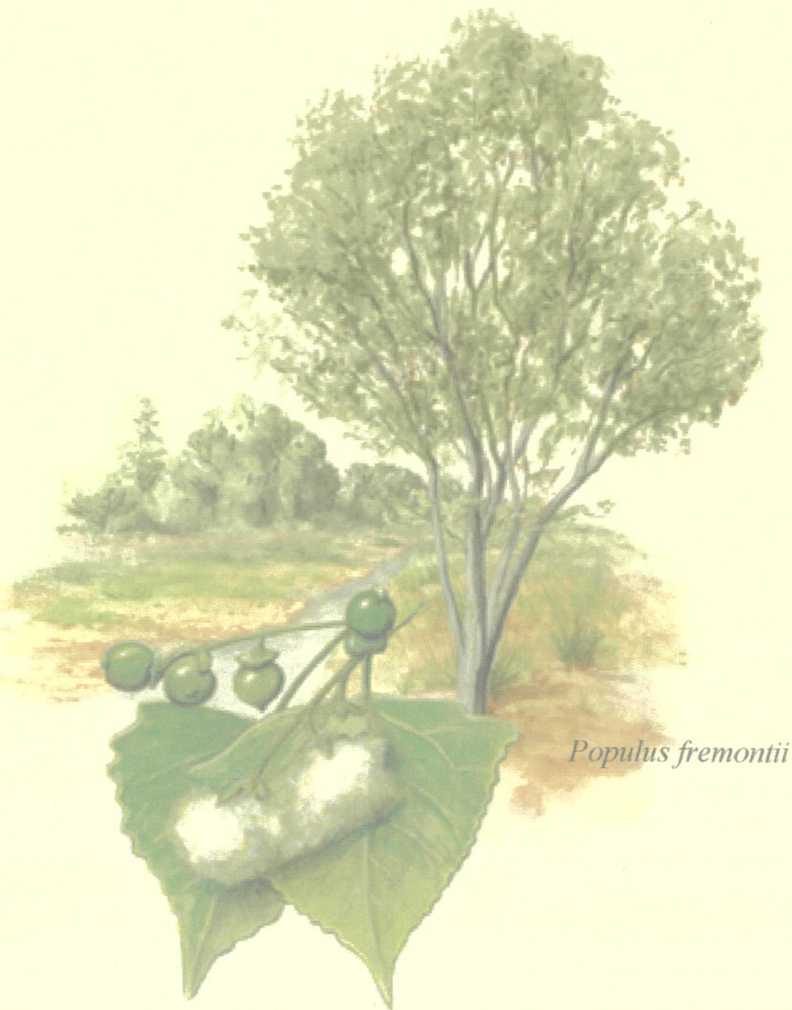
RECLAMATION
Managing Water in the West

Habitat Restoration on the Lower Colorado River: Demonstration Projects 1995-2002



U.S. Department of the Interior
Bureau of Reclamation
Lower Colorado Region

January 2003

Suggested Citing:
Raulston, B.E. 2003. Habitat restoration on the lower Colorado River, demonstration projects: 1995-2002. U.S. Bureau of Reclamation, Lower Colorado Regional Office, Boulder City, NV. 36pp.

To obtain copies of this report contact: U.S. Bureau of Reclamation, MSCP Program Office, LC 8000, PO Box 61470, Boulder City, NV 89006-1470 or call 702-293-8577.

RECLAMATION
Managing Water in the West

Habitat Restoration on the Lower Colorado River: Demonstration Projects 1995-2002

prepared by

Multi-Species Conservation Program Office
Restoration Group
Barbara Raulston

U.S. Department of the Interior
Bureau of Reclamation
Lower Colorado Region

January 2003

ABSTRACT

Habitat restoration on the lower Colorado River over the past 25 years has involved multiple agencies, a variety of techniques, challenges and varying amount of success. Today, challenges still include lack of available water sources, saline soils, unsuitable depths to ground water, the spread of non-native vegetation and high frequency of fire. Because of the extent of restoration needed, cooperation among agencies, including the pooling of resources and personnel, is necessary to accomplish restoration projects. Due to ongoing political, economic, biological factors as well as water allocation considerations, it may now be necessary to accept certain limitations of habitat restoration on the lower Colorado River. Attempts to create native, pristine conditions on such an altered system may be beyond our present capabilities and the majority of restoration sites on the lower Colorado River will need some level of management into perpetuity. However, much can be still be accomplished that will benefit the system ecologically, and the results of four such projects are presented in this report.

INTRODUCTION

The LCR is an extensively managed water conduit, with highly modified flow regimes and extensive channelization. Due to these modifications, it is no longer an ecosystem entirely capable of the natural regeneration of native riparian vegetation which followed historic flood events. Recognizing the intensely political nature of water allocation on the Colorado River, the successful restoration of habitat will be accomplished best by recognizing the limitations inherent in the present-day system and incorporating them into restoration plans.

In the past, restoration of native riparian habitat on the LCR has been hampered by many factors, such as lack of available water sources, saline soils, unsuitable ground water table levels, the spread of non-native vegetation and high frequency of fire. The current condition of soils on the LCR is a cause of many problems encountered. A decrease in the frequency of major flood events, beginning when Hoover Dam was completed in 1935, has caused naturally occurring salts to accumulate in the soils (Briggs 1996). Much of the soil along the LCR is no longer suitable for native woody vegetation because of its high salt content (Busch and Smith 1995, Briggs 1996, USBR 1998). The low tolerance of Fremont cottonwood (*Populus Fremontii*) and Goodding willow (*Salix Gooddingii*) to saline soils is well documented (Shafroth et al. 1995, Briggs 1996, Jackson et al. 1990, Glenn et al. 1998). Depth to groundwater and soil moisture at the surface are important factors for the natural establishment and survival of riparian vegetation (Johnson 1965; Fenner et al. 1984; Asplund and Gooch 1988; Mahoney and Rood 1991; Friedman et al.1995; Scott et al. 1999, 2000; Shafroth et al. 1998, 2000, 2002). Briggs (1992) determined that over eighty-five percent of the restoration projects evaluated in Arizona were unsuccessful due to low water availability or flooding.

Many documents written on the LCR describe historical and current conditions (Grinnell 1914, Mearns 1907, Ohmart et al. 1977, Rosenberg et al. 1991, Periman and Kelly 2000). Briggs (1992) evaluated over twenty-five riparian restoration sites in Arizona and discusses the causes of successes and failures, as well as reasons for riparian habitat losses. Swenson and Mullins (1985) describes and evaluates the use of dormant versus green poles relative to water table depth changes. Additional reports such as Anderson and Ohmart 1976, 1982, 1984a,b; Pinkney 1992; Briggs 1996; Briggs and Cornelius 1997; Taylor and McDaniel 1998; CH2MHill 1999; Jones and Stokes 1999; USBR 1992, 1999 can also be reviewed for a description of current and past restoration on the LCR and elsewhere in the southwestern United States.

The goal of restoration is to provide habitat which can be used successfully by fish and wildlife, and this is not always anthropomorphically "pristine" habitat. There is certainly value in maintaining a diversity of plant life for its own sake, and efforts toward this should always be included in projects. However, in order to make progress towards establishing a significant amount of restored habitat on the LCR, a compromise between purity and practicality, has to occur. This compromise is ultimately based on funding availability. This report can serve as a guide for land managers and those working with and around the various constraints involved in habitat restoration of the LCR ecosystem.

This report explores planting techniques, materials, equipment, personnel needs, irrigation methods, and site preparation used in four habitat restoration projects on the LCR (Figure 1). Data generated from measurements of soil characteristics, tree growth and survival can be found in the Results section, while a general, qualitative description of the restored habitats can be found in the Discussion section of this report. Photographs of each site, before and after restoration are in the Appendix.

STUDY AREA

The lower Colorado River is defined by the Bureau of Reclamation (Reclamation) as that part of the Colorado River from Lees Ferry in the Grand Canyon to the southerly international border with Mexico. Data presented here was collected beginning in 1995 from sites on the LCR. Sites are located at Cibola, Imperial, and Bill Williams River National Wildlife Refuges and on a Bureau of Land Management (BLM) agricultural lease near Yuma, Arizona.

The Bill Williams River in western Arizona flows east to west, beginning at the confluence of the Big Sandy and Santa Maria Rivers above Lake Alamo and ending at Lake Havasu. Alamo Dam, operated by the US Corps of Engineers, is approximately 50 km upstream from the Bill Williams Delta at the confluence of the Colorado River. Below the dam, the Bill Williams River is un-channelized, occasionally floods, and retains some capacity for "natural" regeneration of riparian habitat. Terrain is variable, composed of steep rocky canyons interspersed with broad alluvial valleys.

Both Mojave and Sonoran Deserts are represented in the Lower Colorado River Valley. Temperatures in the summer often reach 35° C and the growing season for riparian woody vegetation is from March - October. Typically, Fremont cottonwood and Goodding willow are not completely deciduous on the LCR. A complete description of the deserts through which the LCR flows can be found in MacMahon and Wagner (1985). Stromberg (1993) describes riparian forests of the Sonoran desert, the processes which created them and those that now threaten them. Busch (1992) analyzes the processes involved in riparian communities on the lower Colorado River specifically.

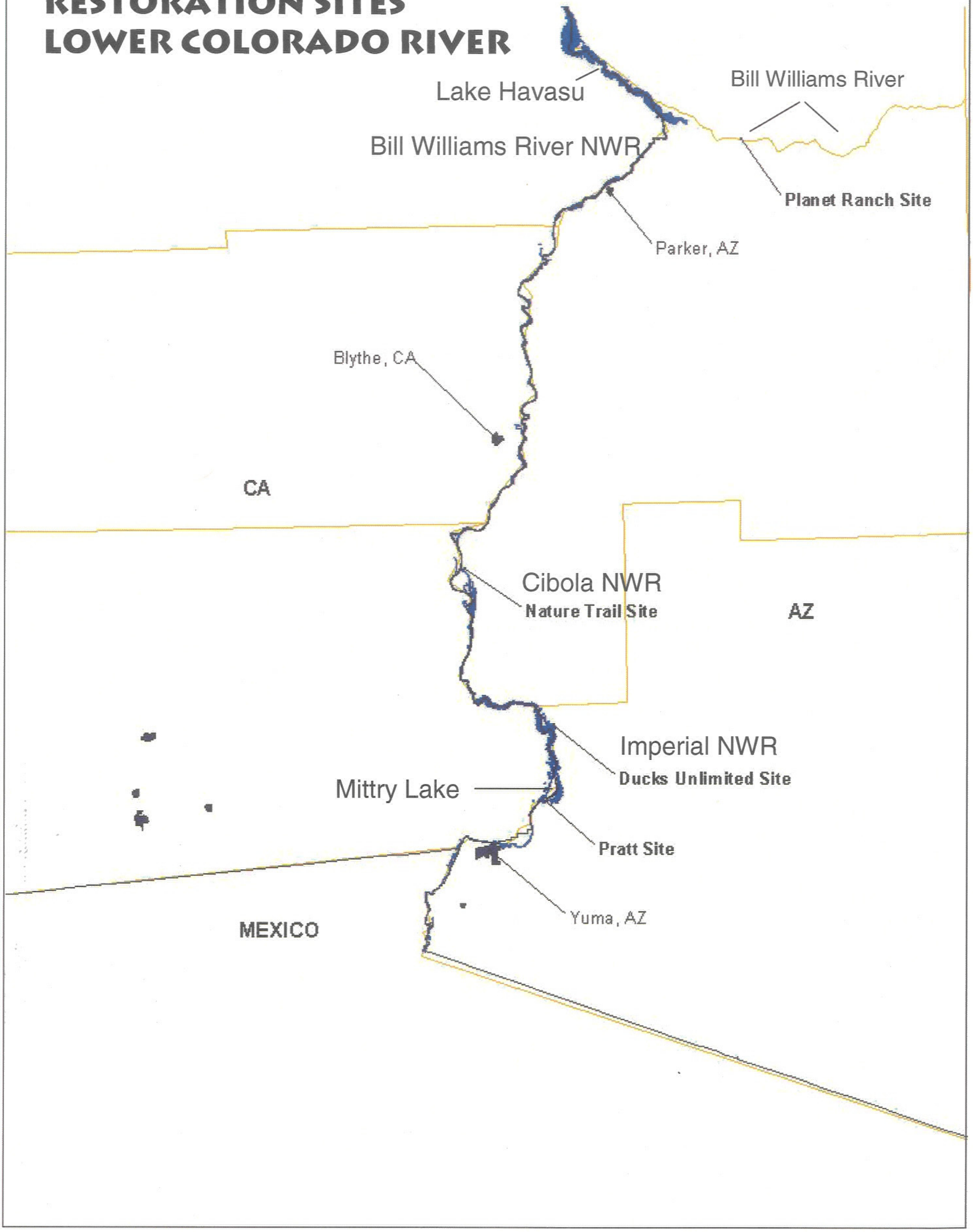
METHODS

COMMON TO ALL SITES

The Planet Ranch and Ducks Unlimited restoration projects were intended to create riparian habitat for a myriad of species. However, the Nature Trail and Pratt restoration projects were intended to create specific habitat for the endangered Southwestern Willow Flycatcher (SWFL) and therefore the "success" of these two sites is based on whether it resulted in habitat similar to that used by this species on the LCR. At present, there is not a strict definition for Southwestern Willow Flycatcher habitat due to the high degree of variation in the habitat used by this species on the LCR. In general, it is characterized by very dense native or non-native vegetation or a mixture of the two, near standing water or with water or moist soil beneath it (McKernan 1997; Sedgwick 2000; Sogge et al. 1997, Sogge 2000; McKernan and Braden 1998, 1999, 2001a,b).

For restoring riparian vegetation, seeds, cut poles, and rooted plant stock are all used on the LCR and elsewhere in the southwestern US. These materials are examined for use under the varying conditions present on the LCR. Equipment and methods used for planting and site preparation are discussed in terms of labor involved, availability, cost and site location. Costs of restoration vary considerably, based largely on the amount of site preparation required. Flood

FIGURE 1.
RESTORATION SITES
LOWER COLORADO RIVER



irrigation and the use of a shallow groundwater table for pole cuttings are discussed. Partners involved in projects are included to demonstrate the frequency and necessity of working with the many entities that have an interest in restoration on the LCR.

All soils were collected with soil augers measuring 16 cm x 10 cm at a minimum of three depths per sample and analyzed at Reclamation's Lower Colorado Regional Laboratory in Boulder City, Nevada (USDA 1996). Sample size refers to individual holes from which soil was collected. Soil salinity is reported as a measure of electro-conductivity (EC) in milli-Siemens per centimeter (mS/cm); texture is reported in percentages of sand, silt and clay per sample. Sand is defined as particles between 0.5- 2 mm, silt is between 0.002-0.05 mm and clay is less than 0.002mm (Kilmer 1982, USDA 1996).

Cuttings or poles for planting were collected from Fremont cottonwood (cottonwood) and Goodding willows (willow) found along the lower Colorado, lower Gila (north of Yuma, AZ) or Bill Williams Rivers (Figure 1). Each pole was trimmed of side branches and placed in water for no more than three days prior to planting. All seeds were collected along the lower Gila River near its confluence with the LCR and directly from the trees, not from the ground, as seeds of these species are only viable for approximately five weeks (Fenner et al. 1984). Rooted stock was purchased from the 'Ahakhav Tribal Preserve Nursery, Colorado River Indian Reservation, Parker, Arizona and Mountain States Nursery, Litchfield Park, Arizona. All purchased plants originated from cuttings or seed taken from the lower Colorado River and lower Gila River, were grown in 3.8 liter plastic pots, and were 0.3 m-0.9 m in height prior to planting.

Foliage cover was calculated by multiplying together perpendicular measurements taken at the widest portion of foliage. Diameter of all trees was measured 1.4 m from the ground using a standard diameter-at-breast height (DBH) tape measure. Measurements were not taken for trees <1.4 m, but height for these trees was recorded. Height was measured with an extendable pole or a clinometer and measured from the ground at the base of the tree to the top of the tallest branch. Trees were examined to determine survival following each growing season. If no green foliage was present and no green color could be seen just under the bark when scraped slightly, the tree was reported as dead. If either was found, the tree continued to be monitored in subsequent years.

PLANET RANCH RESTORATION SITE

The Planet Ranch restoration site is on the border of La Paz and Mohave Counties, Arizona, approximately 16 km upstream on the Bill Williams River from its confluence with the LCR. Although regulated by Alamo Dam approximately 50 km upstream from its delta, the Bill Williams River does flood periodically, allowing natural germination of riparian vegetation to occur along its banks.

Due to flooding of the Bill Williams River in 1993, an alfalfa field on Planet Ranch directly adjacent to the Bill Williams River National Wildlife Refuge (NWR) was completely covered by sand to a depth of 0.6 - 0.9 m. Between that time and the beginning of initial restoration efforts, some saltcedar (*Tamarix sp.*), honey mesquite (*Prosopis glandulosa* var. *torreyana)* and various ground covers and shrub species were established naturally, but for the most part, the area remained relatively bare.

Data on ground water depths had been collected from 1986-1995 from an irrigation well adjacent to the restoration site. Soil samples were collected from eight locations prior to planting. Sampling depths were surface, 0.15 m, 0.6 m and at the water table. The area was planted in January 1995 by personnel from U.S. Fish and Wildlife Service (FWS); Reclamation's Regional Office in Boulder City, Nevada; BLM, Lake Havasu City, Arizona, and local volunteers.

The area was planted with 715 cottonwood and willow (un-rooted) poles cut from trees established on the Bill Williams River following the flood event in 1993 (B. Raulston, pers. obs.). All trees were planted within 1 week of being cut. Using a tractor with an auger attachment, holes approximately 15 cm in diameter were dug to the water table and spaced approximately 6 m apart covering approximately 2.6 ha. (6.5 acres). The entire pole from the apical tip to the base was planted intact with the bottom end placed into the water table. Approximately 1 m of each pole was buried and the hole was then backfilled. The site was never irrigated, trees were intended to survive on ground water alone.

Once planted, 196 trees were randomly selected for monitoring and marked with numbered metal tags. Monitoring occurred following each growing season, however, only DBH and survival were monitored in 1995 and 1996, and no monitoring was conducted in 1997. In 1998, 1999 and 2000, DBH, height, and survival were collected in order to conform with other restoration monitoring on the LCR.

Pratt Restoration Site

The Pratt Restoration Site is located just upstream from Laguna Dam, in Yuma County, Arizona. The 23 hectare area is under a BLM agricultural lease and has been farmed for at least 50 years by the lease holder. This project was a cooperative effort between the leaseholder, Arizona Game and Fish Department, BLM, FWS, Reclamation, the City of Yuma, Arizona and local volunteers.

Prior to planting with cottonwood and willow, a 213 m x 100 m section of the 23 hectare agricultural field was cleared of alfalfa, plowed to a depth of 36 cm and formed into furrows using mechanical farming equipment. Soil samples were taken on 25 March, 1999. Five holes on each half of the field were sampled for a total of 10 sample locations along a transect approximately mid-way down the length of the area to be planted. Samples were taken at the surface, 0.9 m and 1.5 m depths.

Seeds were collected from cottonwood and willow trees along the lower Gila River, in the vicinity of Yuma, Arizona between 23-26 March 1999. One dozen nylon mesh bags measuring 60 cm x 90 cm were filled to capacity with branches containing open seed pods. The bags were stored indoors until 31 March. Beginning at 0700 on 31 March, seeds were scattered over 2 areas measuring 11 m x 213 m and 28 m x 213 m and separated by areas planted with rooted stock. Two additional bags containing both cottonwood and willow seed were collected and dispersed, on 13 and 14 April, and on 26 and 27 April 1999. Throughout seeding, the site was irrigated to keep the surface wet.

All trees planted at the Pratt site (poles and rooted nursery stock) were planted in furrows approximately 2.4 m apart with 1.5 m between trees within the furrows. On 26 March 1999, cottonwood and willow trees were cut for poles along the lower Gila River. All trees were at least 10 cm in diameter, cut into 0.9 - 1.2 m lengths, placed with the bottom end in water, and stored in shade until planted. On 31 March, 46 cottonwood and 47 willow poles were planted at a slight angle (not vertically) with approximately 1/3 of the base buried. Poles were planted at an angle in an attempt to create denser growth at the ground to mid-story level within the canopy than would be obtained from vertically-planted poles.

On 30 March, 1999, 712 Fremont cottonwood trees and 699 Goodding willow trees from rooted nursery stock were planted in rows within two separate areas approximately 24 m x 213 m each. As the furrows were created using a tractor blade, plants were removed from pots and placed into the furrows. The root ball of each plant was then covered by driving a tractor equipped with an angled blade lowered adjacent to the furrow which pushed the soil back into the furrow. Occasionally, a minimal amount of work with hand tools was required to ensure that the entire root ball was buried and that the shoot of the plant was not covered by soil.

Planting of all rooted stock and poles began at 0730 and concluded at 0930, at which time the field was flood irrigated to a depth of approximately 30 cm. The entire field was irrigated every other day until 16 June, when watering was reduced to once per week. The field continued to be irrigated once per week until September. At that time, watering was reduced and thereafter has occurred according to the schedule in Table 1.

TABLE 1. ANNUAL IRRIGATION SCHEDULE, PRATT RESTORATION SITE, YUMA COUNTY, ARIZONA, 1999-2000

Dates	1 Nov - 15 Feb	15 Feb - Apr 15	15 Apr - 31 May	Jun, Jul, Aug	Sep-Oct
Irrigation Frequency	1/mo	2/mo	1/wk	2/wk	2/mo

For rooted stock, every other plant or every third plant, depending on the number of trees present per row, was preselected for measurement. A total of 196 cottonwoods and 200 willows from rooted stock and all poles (46 cottonwoods and 47 willows) planted were measured for DBH, height and foliage area.

In December 1999, cottonwood and willow seedlings in each of the seeded areas were counted by two observers slowly walking down each furrow. The total was determined from the mean of the two counts. Seedlings were randomly selected for measurement using a modified point-quarter method from Elzinga et al. (1998). Points were located along pre-established transects through the seeded areas, with distances between points predetermined based on number of points required to obtain an adequate sample size (Elzinga et al. 1998). The nearest tree in each cardinal direction from the point was measured. In 1999, the majority of seedlings were under 1.4 m, so only height was measured the first year.

By 2000, the high density of native and non-native vegetation established in the seeded areas precluded a total count of all surviving cottonwoods and willows. Instead, transects were randomly established through the areas and the point-quarter method was used to randomly choose 100 trees of each species for measurement. At regular intervals along an established transect, the nearest cottonwood, willow or saltcedar in each of the four cardinal directions was measured (Elzinga et al. 1998).

A small portion of the Pratt restoration site was used to determine if poles cut during August at the height of the growing season would survive as well as those cut in March, when the source trees were just breaking dormancy. Forty poles of each species were cut and planted in August and, like those planted in March, were planted at an angle and irrigated on the same schedule as the rest of the site.

Statistical analysis was performed using Excel, and included ANOVA and t-tests with 95% confidence intervals. Cottonwoods are compared to willows for growth and survival within planting techniques. Data on the growth and survival was analyzed across both species to determine differences in planting techniques. Soil data was analyzed for differences in electro-conductivity and texture.

NATURE TRAIL RESTORATION SITE, CIBOLA NATIONAL WILDLIFE REFUGE

At Cibola NWR, located in Yuma County, Arizona, a portion of a cornfield previously managed for wintering waterfowl was planted with Fremont cottonwood (3.5 ha) and Goodding willow (2.7 ha) during spring of 1999. This site is managed by the FWS and is a cooperative effort with Reclamation to fulfill natural resource missions common to both agencies. Site preparation began in January 1999. A lined irrigation canal was already in place on one side of the field and earthen berms were built around it to control flows during flood irrigation.

Prior to planting, soil samples were taken on 6 January 1999. Soil was collected at five randomly selected sites from three depths, (surface and approximate depths 0.9 to1.5m) and analyzed for texture and EC. The site was cleared of debris, plowed and approximately 15cm diameter holes were drilled 2m apart and 1m deep using a small tractor or bobcat equipped with a 6-8" diameter auger. Holes typically backfilled due to caving in and many of them had to be re-excavated manually with shovels. Between 5-16 April 1999, 10,000 willow and 2,600 cottonwoods were planted from rooted nursery stock on approximately 3.2 ha of land.

Immediately after planting small sections of the site, trees were irrigated using a portable irrigation sprinkler system. When completed, the field was flood irrigated according to the schedule in Table 2. Since 2000, the trees have been irrigated once every four weeks in the winter and once every two weeks during the growing season.

TABLE 2. ANNUAL IRRIGATION SCHEDULE, NATURE TRAIL DEMONSTRATION SITE, IMPERIAL COUNTY, ARIZONA, 1999-

Dates	30 Mar- 22 June 1999	22 June - 21 Oct 1999	22 Oct 1999 - 28 Feb 2000	Mar- Oct 2000
Irrigation Frequency	1/wk	2/mo	1/mo	2/mo

To determine an adequate sample size for monitoring growth, height and DBH were initially measured from a random sample of 50 cottonwoods and 59 willows in August 1999 (Elzinga et al. 1998). Based on this preliminary data, the maximum sample size required was 60 trees, and the minimum was 12 trees. This small sample size reflects the small standard deviation in height and DBH resulting from the similarity in size among trees at the time of planting. To account for an increasing standard deviation as the trees grow, a total of 100 of each species were randomly selected and measured for height and DBH following each growing season.

Ducks Unlimited Restoration Site, Imperial National Wildlife Refuge

This site is located on Imperial NWR, Yuma County, Arizona and managed by the FWS. The project began as a cooperative effort involving the FWS, Reclamation and Ducks Unlimited primarily to restore wetlands for waterfowl and other marsh species, including the Yuma Clapper Rail (*Rallus longirostris yumanensis*). However, this area was known to contain highly saline soils characteristic of many areas on the LCR, and it soon evolved into an experiment to improve soil conditions for native plant restoration.

This site required extensive site preparation, including the excavation of 5 ponds totaling 14 ha of open water for future native fish rearing. The ponds are connected by water control structures and water is pumped into the highest pond from either the LCR or from a nearby well. The lower ponds are filled by gravity. The area around each pond slopes upwards slightly, forming 21 ha of emergent and riparian wetland habitat. The water in the ponds can be raised enough to flood these surrounding areas. The area around each pond was designed for planting with riparian vegetation and irrigating by overfilling the ponds (Figure 2).

In August 1999, after construction of the water control structures, soil samples were collected from 12 randomly selected sites throughout the restoration area at surface, 0.9 m and 1.5 m. In addition, soil samples were collected and analyzed in March 1997 (USBR 1998).

In an attempt to flush salts from the soils, each pond was filled to capacity from the first cell to the last, and then allowed to drain out to the last cell, returning the water to the LCR. Prior to planting, the site was flushed beginning on 31 January 2000 and by 7 February, the site had drained to the level of the adjacent LCR. The areas surrounding each pond were planted in April of 2000 with 4,900 cottonwood and 11,200 willow from rooted nursery stock. A two-seated tree planter (Tree Equipment Design, Inc., New Ringgold, PA), pulled behind a tractor was used to plant the trees. The cycle of filling and draining the ponds continued approximately every 25 days from March - October 2000.

The monitoring plan for this area originally consisted of randomly chosen transects through each cell and selecting trees to measure using the modified point-quarter method from Elzinga et al. (1998). Points were located along pre-established transects through the planted areas, with distances between points predetermined based on number of points required to obtain an adequate sample size (Elzinga et al. 1998). However, by October 2000, it was clear that the mortality of trees at this site was extremely high. Using a Global Positioning Unit, the perimeter of each live and each dead patch of trees was recorded to determine the extent of tree mortality and to analyze any spatial patterns that may exist.

Costs - All Sites

In general, costs reported may be useful for planning restoration projects, but costs can vary from site to site, even when the same planting methods are used. Topography; soil type; depth to groundwater; amount of site preparation needed; irrigation, i.e. pumping costs and delivery methods and location are just a few of the variables that affect cost. Labor (hours) reported can be used to help determine the number of people required for projects. Hourly rates reported are approximately those of a Federal GS-7 Biological Technician and include all fringe benefits.

Some costs reported are not actual costs incurred during the project, but have been modified to better compare them across sites for planning purposes. For example, at some sites, tractors and other equipment were available as in-kind contributions from one of the partners. However, in order for the costs reported here to be useful in future budgets and planning, rental costs are reported as well as the cost of hiring a heavy equipment operator.

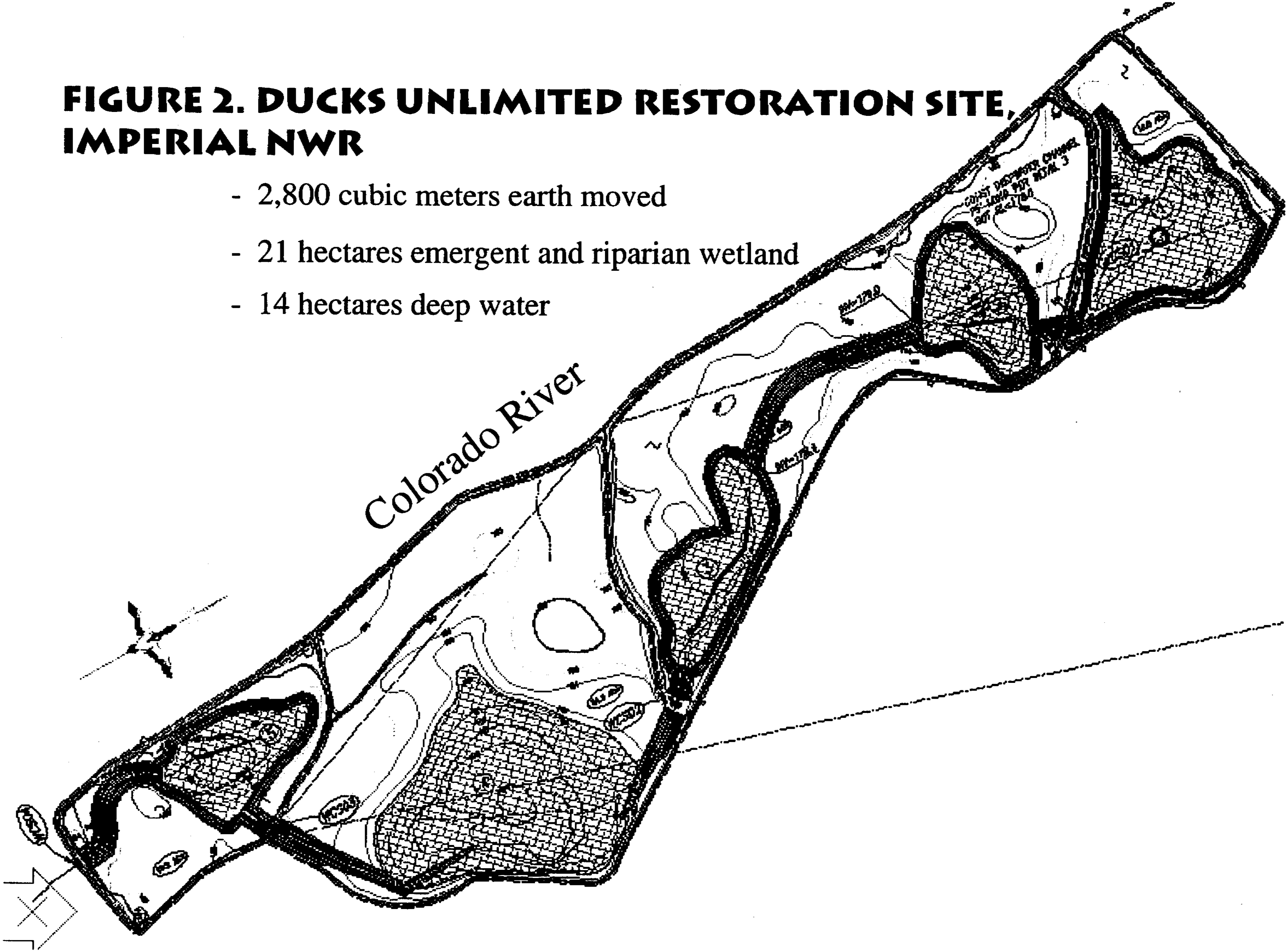
Costs for the Ducks Unlimited site are those directly associated with re-vegetation. Costs associated with the excavation of ponds and installation of water control structures, wells, pumps, fish screens, etc. are not included. An estimate is provided for the cost of clearing the site for planting.

Water, and/or the delivery of it, for irrigation is not included for most sites, due again to the wide variation in costs among sites and the inability to transfer these costs to a general budget for planning purposes. Type and capacity of pumps, fuel or electrical costs, distances from source, pipes, lined vs. unlined channels and types of water control structures are just some of the factors that cause water delivery costs to vary. Since all site preparation and heavy equipment operation for the Pratt restoration site was through a commercial contractor, specific costs are reported.

Soil analysis costs are those incurred per sample by Reclamation's Lower Colorado Regional Laboratory.

FIGURE 2. DUCKS UNLIMITED RESTORATION SITE, IMPERIAL NWR

- 2,800 cubic meters earth moved
- 21 hectares emergent and riparian wetland
- 14 hectares deep water



RESULTS

PLANET RANCH RESTORATION SITE

Electro-conductivities (salinity) for soils at the Planet Ranch are shown in Table 3. Groundwater table depths (Table 4) were collected by Planet Ranch staff from 1986-1995 and ranged from 1.3 m - 3.1m ($\bar{X}$ = 2.1m ± 0.7, N = 10). The soil at this site was classified as sandy in texture (Kilmer 1982).

TABLE 3. MEAN SOIL ELECTRO-CONDUCTIVITIES (SALINITY) IN MS/CM BY DEPTH AT ALL RESTORATION SITES

	Planet Ranch		Pratt	Nature Trail	Ducks Unlimited	
	1995 (N = 8)	1999 (N = 6)	(N = 10)	(N = 5)	Live Areas (N = 12)	Dead Areas (N = 13)
Surface	0.3 ± 0.1	0.9 ± 0.8	2.0 ± 0.3	1.5 ± 0.3	21.1 ± 20.4	42.2 ± 26.8
0.2m	0.3 ± 0.1					
0.3m		0.7 ± 0.4			6.1 ± 4.2	19.6 ± 15.3
0.6m	0.3 ± 0.1					
0.9m		0.7 ± 0.2	2.8 ± 0.9	1.3 ± 0.2	3.7 ± 1.8	12.0 ± 16.0
1.5m			4.3 ± 1.4	1.9 ± 1.1		

Table 4. Mean Water Table Depth, Planet Ranch, La Paz County, Arizona, 1986 -1999.

Year	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1999*
Depth (m)	2.07	2.16	2.32	3.01	3.13	2.59	1.65	1.43	1.29	1.35	>1m

*Soil saturation at 1m was 30%, but actual water table depth was not recorded in 1999

Tree measurement data from March 1995 - November 2000 are provided in Table 5. Cottonwood and willow did not differ significantly in DBH at the time of planting. However, in January 1996, after the second growing season, the difference was significant (t test, $P < 0.05$). In 1998 and 1999, cottonwood and willow differed significantly in DBH and height (t test, $P < 0.05$). Cottonwoods were consistently taller and larger in diameter than willows.

Following planting in March 1995, the Bill Williams River, including the restored area, flooded. In July 1995, the trees were counted to determine how many were lost in the flood. Of the original 715 trees, 695 live trees were counted, 7 poles were dead and 13 were lost in the flood.

TABLE 5. MEAN DBH AND HEIGHT ± SD OF COTTONWOOD (CW) AND WILLOW (W) POLES AT PLANET RANCH SITE, LA PAZ COUNTY, ARIZONA, 1995-2000

	DBH		Height	
Date	CW	W	CW	W
Mar 1995	2.5 ± 0.72 N = 76	2.6 ± 1.2 N = 112		
Oct 1995	2.8 ± 0.79 N = 78	2.9 ± 0.89 N = 117		
Jan 1996	3.2 ± 1.1 N = 55	2.3 ± 1.4 N = 42		
Nov 1998	3.0 ± 2.4 N = 61	1.2 ± 1.3 N = 80	3.0 ± 1.5 N = 69	2.2 ± 0.84 N = 88
Dec 1999	3.3 ± 2.6 N = 57	1.3 ± 1.2 N = 60	3.1 ± 1.6 N = 65	2.3 ± 0.89 N = 72
Nov 2000	3.9 ± 3.2 N = 49	1.4 ± 1.5 N = 46	3.3 ± 1.9 N = 55	2.1 ± 1.0 N = 57

A total of 76% (546/715) trees planted in 1995 were still alive in the fall of 1999. Survival of marked cottonwoods and willows was 63% and 38%, respectively. By fall 2000, the survival of all trees planted in 1995 was 69% (see Discussion section concerning quality of habitat).

PRATT RESTORATION SITE

Salinity of soils at the Pratt site (Table 3) were low enough to support cottonwood and willow and consisted mainly of silt and clay (Table 6). Water table depths throughout the site were greater than 6 feet below the surface. Of the rooted stock and poles, willows were significantly greater than cottonwoods in height, DBH and foliage area the first year following planting (t test, $P < 0.05$) (Table 7). All cottonwoods (rooted stock and poles combined) resulted in an mean height of 2.2m ± 0.8, a DBH of 1.0cm ± 0.5 and foliage cover of 2.2m ± 1.1. All willows (rooted stock and poles combined) averaged 3.6m ± 0.7 in height, 2.1 cm ± 0.7 in DBH and 4.5m ± 1.9 for foliage cover. In contrast, cottonwoods and willows established by seeding were significantly smaller in height than trees planted using the other methods (t test, $P < 0.05$) (Table 7). The difference in height between the two species established by seed was not significant (t test, $P > 0.05$).

For the first year, survival of cottonwoods planted from rooted stock and poles was 89% and 85%, respectively. Survival of willows from rooted stock and poles was 100% and 87%, respectively. After three attempts at seeding, germination was observed on 4 May 1999.

TABLE 6. MEAN SOIL TEXTURES BY DEPTH ± SD AT PRATT, NATURE TRAIL, AND DUCKS UNLIMITED RESTORATION SITES, YUMA COUNTY, ARIZONA

	Surface			0.9m			1.5m		
	Pratt (N = 10)	Nat. Tr (N = 5)	DU (N = 25)	Pratt (N = 10)	Nat. Tr (N = 5)	DU (N = 25)	Pratt (N = 10)	Nat. Tr. (N = 5)	DU (N = 25)
% Sand	2 ± 1	15 ± 14	73 ± 12	9 ± 14	24 ± 25	78 ± 14	7 ± 8	38 ± 31	80 ± 11
% Silt	52 ± 1	60 ± 11	21 ± 10	45 ± 5	58 ± 19	17 ± 11	67 ± 14	49 ± 22	15 ± 9
% Clay	46 ± 1	25 ± 9	7 ± 3	47 ± 13	18 ± 19	5 ± 3	26 ± 18	13 ±10	4 ± 2

TABLE 7. AVERAGE HEIGHT, DBH, AND FOLIAGE AREA ± SD FOR COTTONWOOD (CW), WILLOW (W), AND SALTCEDAR (SC) FROM ROOTED STOCK, POLES, AND SEED AT THE PRATT RESTORATION SITE, 1999 AND 2000

	Rooted Stock		Poles		Seed		
	CW	W	CW	W	CW	W	SC
1999							
Ht (m)	2.3 ± 0.4 (N = 196)	3.4 ± 0.6 (N = 200)	2.1 ± 0.5 (N = 39)	3.7 ± 0.7 (N = 41)	1.4 ± 0.4 (N = 170)	1.3 ± 0.4 (N = 49)	
DBH (cm)	1.1 ± 0.5 (N = 196)	2.1 ± 0.7 (N=200)	0.9 ± 0.4 (N = 37)	2.1 ± 0.7 (N= 41)			
Foliage Cover (m)	1.9 ± 0.7 (N = 196)	3.4 ± 1.3 (N=200)	2.5 ± 1.5 (N = 39)	5.6 ± 2.5 (N = 41)			
2000							
Ht (m)	4.6 ± 1.0 (N = 201)	5.3 ± 0.9 (N = 196)	4.5 ± 0.9 (N = 41)	6.1 ± 1.2 (N = 38)	3.1 ± 0.9 (N = 130)	3.4 ±1.1 (N = 126)	1.6 ± 0.6 (N = 191)
DBH (cm)	4.7 ± 1.4 (N = 201)	4.9 ± 1.3 (N =195)	4.1 ± 1.3 (N = 41)	4.7 ± 1.3 (N = 39)	2.1 ± 1.4 (N = 129)	2.1 ± 1.6 (N = 87)	0.5 ± 0.5 (N = 130)
Foliage Cover (m)							

In December following the first growing season, 1,748 cottonwoods and 506 willow seedlings were counted in the seeded areas of the field.

Following the second growing season (Table 7), willows from rooted stock and poles were significantly greater in height from cottonwoods (t test, $P < 0.05$). The species did not differ in DBH (t test, $P > 0.05$) and foliage area was not measured. Willows were also significantly larger in height than cottonwoods when grown from seed (t test, $P < 0.05$), but showed no difference in DBH (t test, $P > 0.05$). Cottonwoods and willow grown from seed continued to be significantly smaller the second year than trees grown by the other methods (t test, $P < 0.05$). Saltcedar established from windblown seed was significantly smaller both in DBH and height from cottonwood and willow (t test, $P < 0.05$) (Table 7).

Foliage cover for each tree was not measured for the poles and rooted stock the second year, as most of the trees had grown together and formed a closed canopy within rows. Instead, the "gap" still present between rows was measured. Data for rooted stock and poles for cottonwood and willow was combined for a mean distance of 1.6m ± 1.1 (N = 98) between rows.

Survival of cottonwood rooted stock remained 89% after the second year of growth and was 99% for willows. Survival of cottonwood and willow poles was 89% and 83%, respectively. The survival of poles cut and planted in March 1999, when the trees were just breaking dormancy, were compared to poles cut and planted at the beginning of August, at the height of the growing season. Eighty-nine percent (N = 46) of the cottonwood poles cut and planted in March survived two growing seasons. None of the 40 cottonwood poles planted in August 1999 survived through the second growing season. Of the willow trees cut and planted in March, 83% (N = 47) survived for at least 2 years while 29% (N = 40) of those cut and planted in August survived. Combining species, poles planted in March had an average survival rate of 86%, while those planted in August had a survival rate of 14%.

Nature Trail Restoration Site, Cibola National Wildlife Refuge

Mean results of soil conductivity and texture, by depth, are shown in Tables 1 and 4, respectively. In January 1999, water table depths were more than 6 feet below the surface at all sample sites. Trees at the Cibola NWR were monitored for growth in December 1999, following the first growing season (Table 8). DBH of cottonwoods was significantly larger than willows (t test, $P < 0.05$), but no significant difference in height was found between the two species (t test, $P > 0.05$). By November 2000, following the second growing season, differences between the heights and DBHs of the two species were statistically significant (t test, $P < 0.05$). Cottonwoods were larger than willows (Table 8).

TABLE 8. MEAN HEIGHT AND DBH ± SD OF COTTONWOOD (CW) AND WILLOW (W) AT THE NATURE TRAIL SITE, CIBOLA NWR, YUMA COUNTY, ARIZONA, YEARS 1 AND 2

	Year 1		Year 2	
	CW	W	CW	W
Height (m)	2.6 ± 0.5 (N=100)	2.6 ± 0.7 (N=100)	3.9 ± 0.9 (N=100)	3.0 ± 0.8 (N=100)
DBH (cm)	1.4 ± 0.6 (N=100)	1.0 ± 0.6 (N=100)	3.6 ± 1.7 (N=100)	1.9 ± 0.9 (N=100)

DUCKS UNLIMITED RESTORATION SITE

Since the majority of trees planted in April 2000 did not survive through the first growing season, evaluating survival and growth could not be accomplished using the same randomly established transect and quarter-point method used at the Pratt and Nature Trail sites. Instead, the perimeter of each section containing live trees after the first growing season was measured to determine the total area containing live trees. The area of trees surviving was 3.8 ha of the 22.7 ha planted during spring 2000, or 17% of the original planted area survived.

In addition, soil sampling was conducted in June, July, and August of the first growing season. The water table at the majority of sample sites was between 2-3 feet below the surface. The overall soil texture of the site is classified as sand and/or loamy sand, as the percent of sand in each sample was considerably greater than the content of clay or silt (Table 6). There was no significant difference within soil sampling depths in EC between months (t test, $P < 0.05$), therefore the data were pooled within depths and compared between areas where trees survived and where they did not. At all sampling depths, the soil salinity in areas where trees survived was significantly lower than in those areas where trees suffered high mortality
(t test $P < 0.05$) (Table 3).

COSTS

Costs reported in Table 9 include labor involved in site preparation, harvesting seeds and poles, loading and unloading trees from delivery trucks and tree planters, and actual planting. Supplies and equipment include trees purchased from nurseries, rental costs for tractors and other heavy equipment, rental of irrigation sprinklers, purchase of tree planters and soil analysis. Costs per acre associated with three of the sites, Planet Ranch ($2,357), Pratt ($2,329) and Ducks Unlimited ($1,688) were relatively similar, however, costs for planting the Nature Trail site ($7,708) were significantly higher. The major factor determining costs was labor, which is directly related to planting method.

DISCUSSION

Costs

At the Planet Ranch Site, trees were harvested for poles directly adjacent to the site, eliminating access and transportation issues. Poles were cut, stored in water a short distance away

TABLE 9. COSTS FOR HABITAT RESTORATION DEMONSTRATIONS

NOTE: Labor is based on hourly rates, including fringe benefits, of a Federal employee, GS-7/1 Biological Technician.
Heavy equipment rental and costs of operation are based on local commercial prices.

PLANET RANCH Summary	
(pole planting only)	
# Trees	715
Spacing	20'x20'
Acres/hectares	6.5/2.6

Item		Cost	Unit	Quantity	Subtotal	Cost per Acre
Equipment						
	Rental of Tractor with auger	$ 500.00	day	5	$ 2,500.00	
Labor						
	Harvest and Plant Poles	$ 30.00	hr	280	$ 8,400.00	
	Tractor Operator	$ 500.00	day	5	$ 2,500.00	
Soil Analysis (8 sites, 4 samples each site)		$ 60.00	each	32	$ 1,920.00	
Total					**$ 15,320.00**	**$ 2,357.00**

PRATT Summary	
# Planted	92 poles, 1400 potted plants
Spacing	8' x 5'
Acres/hectares	6/2.4

Item		Cost	Unit	Quantity	Subtotal	Cost per Acre
Labor						
	Seed collection and Dispersal	$ 30.00	hr	112	$ 3,360.00	
	Pole Harvesting	$ 30.00	hr	48	$ 1,440.00	
	Planting 92 Poles	$ 30.00	hr	4	$ 120.00	
	Planting 1400 potted plants	$ 30.00	hr	48	$ 1,440.00	
	Site Preparation: Plowing	$ 22.00	ac	6	$ 132.00	
	Discing	$ 8.00	ac	6	$ 48.00	
	Laser Leveling	$ 35.00	ac	6	$ 210.00	
	Furrowing	$ 12.00	ac	3	$ 36.00	
Equipment						
	Small Tractor Rental	$ 11.50	hr	104	$ 1,196.00	
	Large Tractor Rental	$ 21.50	hr	32	$ 688.00	
Supplies						
	Rooted Nursery Stock	$ 2.40	plant	1400	$ 3,360.00	
	Fuel for Tractors	$ 148.00	each	1	$ 148.00	
Soil Analysis (10 sites, 3 samples per site)		$ 60.00	each	30	$ 1,800.00	
Total					**$ 13,978.00**	**$ 2,329.00**

NATURE TRAIL-CIBOLA NWR Summary	
# Planted	12,600 nursery stock
Spacing	6' x 6'
Acres/Hectares	10/4

Item		Cost	Unit	Quantity	Subtotal	Cost per Acre
Labor						
	Loading, unloading trees, planting	$30.00	hr	1273	$ 38,190.00	
	Heavy Equipment Operator (Site Preparation-clearing, plowing, discing, leveling)	$500.00	day	2	$ 1,000.00	
Supplies						
	Trees	$ 2.40	each	12,600	$ 30,240.00	
Equipment						
	Rental -ATV+Trailer for Hauling Plants	$ 550.00	wk	2	$ 1,100.00	
	Rental -Bobcat with Auger, incl. Delivery	$ 265.00	day	10	$ 2,650.00	
	Rain-For-Rent	$ 1,000.00	wk	2	$ 2,000.00	
	Tractor Rental	$500	day	2	$ 1,000.00	
Soil Analysis (5 sites, 3 samples each)		$ 60.00	each	15	$ 900.00	
Total					**$ 77,080.00**	**$ 7,708.00**

Ducks Unlimited-Imperial Summary	
# Trees Planted	16,100
Spacing	10'x10'
Acres/Hectares	50/20

Item		Cost	Unit	Quantity	Subtotal	Cost per Acre
Labor						
	Loading &unloading potted plants, planting	$30.00	hr	420	$ 12,600.00	
	Heavy Equipment Operator (site prep and tractor for pulling tree planter)	$500.00	day	10	$ 5,000.00	
Supplies						
	Trees	$ 2.40	each	16,100	$ 38,640.00	
Equipment						
	ATV +Trailer Rental for Hauling Plants	$ 550.00	wk	1	$ 550.00	
	Tractor Rental	$500	day	5	$ 2,500.00	
	Tree Planter (Purchased)	$3,500	each	1	$ 3,500.00	
***Soil Analysis (120 sites, 3 samples each)**		$ 60.00	each	360	$ 21,600.00	
*Soil sampling increased in order to monitor changes in salinity as the site was repeatedly flushed						
Total					**$ 84,390.00**	**$ 1,688.00**

for a brief time and then planted into holes excavated to the water table using a tractor equipped with an auger.

Since the Pratt site demonstrated three methods of re-vegetation, poles, rooted nursery stock and seeding, labor costs were incurred in seed collecting and pole harvesting. Poles planted at the Pratt site were cut and collected approximately 40 miles away. They had to be cut some distance from vehicles, dragged to and loaded onto trucks, transported, stored in water for a short time, and then loaded and transported again to the planting site. Using a tractor equipped with an angled blade to create furrows for planting rooted stock and poles worked as efficiently as using the tree planters pulled behind tractors.

Restoration at the Nature Trail site (Cibola NWR) cost the most per acre among the four sites. This site was intended to be planted using a tractor equipped with an auger. However, due to the sandy nature of the soil, many of the holes had to be re-excavated by hand with shovels, which increased the time and labor costs considerably. If not for this factor, costs for planting at this site would have been closer to those incurred at Planet Ranch, where a tractor and auger were also used. However, at the Planet Ranch site, soils, although sandy, were also moist just beneath the surface, which kept the holes from collapsing.

The Ducks Unlimited site (Imperial NWR) was planted using a tree planter pulled behind a tractor. This method was extremely efficient and resulted in the lowest planting costs among the four sites.

Qualitative Habitat Descriptions and Factors Contributing to Results

In addition to SWFLs, current studies during the breeding season on the LCR have found many other bird species, previously thought to be native riparian obligates, in the vicinity of water or moist soil in habitat composed of dense mature saltcedar and/or saltcedar mixed with native trees. These species include Yellow-billed Cuckoo (*Coccyzus americanus*), Summer Tanager (*Piranga rubra*) Gilded Flicker (*Colaptes mearnsi*), Brown-crested Flycatcher (*Myiarchus tyrannulus*), Yellow Warbler (*Dendroica petechia*), and Yellow-breasted Chat (*Icterea virens*) (McKernan and Braden 1999, 2001a,b; Halterman 1998, 2000, 2001). The density of trees and under-story vegetation is high at both the Pratt and Nature Trail sites and the areas are kept wet throughout the summer. Year-round avian monitoring began at both sites in 2002.

Areas planted with rooted stock and poles (cut in March) at the Pratt site grew into uniformly tall, dense stands of cottonwood and willow with a nearly closed canopy by the end of the second growing season. The under-story in this area is composed of various grasses and other herbaceous vegetation, both native and non-native, and it is virtually free of saltcedar. Seeded areas at the Pratt site resulted in a mosaic of uneven sized willows and cottonwoods, with the under- and mid-story composed of saltcedar.

The Nature Trail site was dominated throughout the first growing season by an understory of Colorado River hemp (*Sesbania macrocarpa*), a native annual which grows from 0.9-3.0 m in height. After the first year, this species died back and was not observed during subsequent growing seasons. The hemp was interspersed with abundant growth of Johnson grass (*Sorghum halepense*), as well as naturally seeded coyote willow (*Salix exigua*), which is still present.

At the Pratt Site, saltcedar became established in the seeded areas, but not in areas planted with nursery stock or poles. Almost no saltcedar (or any other shade-intolerant shrub or tree species) were found in areas planted in 199 with rooted stock. These trees grew very rapidly, possibly creating a physical barrier to wind-borne saltcedar seeds as well as shading out competing seedlings. Because of inclement weather at the time of the first seeding, it was necessary to re-seed with cottonwood and willow later, in March and April, when more saltcedar seeds were present. It is important to note that within the seeded areas, cottonwood and willow planted from seed exceeded the growth rates of saltcedar established from seed (Table 7).

Based on the results of this study, improved techniques for seeding native vegetation that take advantage of windbreaks, timing of native and non-native seed dispersal and shading effects of cottonwood and willow on non-native vegetation are being considered in current re-vegetation efforts by the Bureau of Reclamation's Lower Colorado River Regional Office. However, a mosaic of saltcedar, other non-natives, and native vegetation is a realistic outcome of future large-scale restoration projects on the LCR.

In December 2000, an additional 2.4 hectares of former agricultural lands at the Pratt site were restored to riparian habitat. Fremont cottonwood, Goodding willow and coyote willow *(Salix exigua)* from rooted stock were planted using the same methods as in 1999 and have shown similar responses in growth and survival. One major difference, however, was the under-story of native *Baccharis* sp. that established naturally after the December planting. *B. sarothroides* and/or *B. salicifolia* (formerly *glutinosa*) both occur in the Yuma area (Kearney and Peebles 1951, Epple 1995) and seed was obviously present in abundance at the time of planting.

Some of the positive results at these two sites can be attributed to agricultural practices which occurred in the years prior to restoration. Flood irrigation of crops on the LCR has replaced the role that flooding once had by preventing the accumulation of salts in soils. Farmers continually battle salt problems in order to grow crops which are not any more salt tolerant than cottonwood and willow. Irrigation infrastructure already present at these sites allowed flood irrigation, which resulted not only in rapid growth of riparian trees, but encouraged under- and mid-story layers to form within the habitat. In addition, although not analyzed extensively as part of this study, soil testing determined that nutrients were higher at the Pratt and Cibola sites than at Planet Ranch. This is likely due to the accumulation of organic materials in the soil through farming at Pratt and providing cover crops for waterfowl, as was the case at the Nature Trail site. The Pratt site is surrounded by agricultural fields on one side and mixed native and non-native riparian vegetation elsewhere. The Bureau of Land Management in Yuma is currently planning additional work adjacent to the site for purposes of fuel reduction for fire prevention, including removal of saltcedar and re-vegetation with native plants.

In contrast to the Pratt and Nature Trail sites where site preparation and irrigation were expected and included in the planning process, the Planet Ranch site was considered ideal for general riparian restoration with no maintenance and minimal site preparation. Soil salinity was at or below 2.0 mS/cm, well within acceptable levels for cottonwood and willow. Soil electro-conductivity tolerances for these species are 2.0 mS/cm, with maximum tolerances around 3.0 mS/cm (Shafroth 1995, Briggs 1996, Jackson et al. 1990, Glenn et al. 1998). Water table depths remained within 1.2 m of the surface, allowing the poles planted to the water table continuous contact with moisture, even during the hot months of summer.

However, very few of the poles grew into trees of the size expected of cottonwood and willow given a stable, shallow water table (Johnson 1965; Fenner et al. 1984; Asplund and Gooch 1988; Mahoney and Rood 1991; Friedman et al.1995; Scott et al. 1999, 2000; Shafroth et al. 2000). Shafroth et al. (2000) suggests that some minor fluctuations in groundwater levels when saplings are becoming established result in trees that root more deeply and have a broad depth distribution of roots. In the case of the Planet Ranch poles, *because* of the stable groundwater depth, subsequent root growth may have been limited to the immediate vicinity of the pole, creating a less healthy root structure overall and resulting in stunted growth.

Another factor suspected of contributing to results at this site is low nutrient levels in the soils. Although soil nutrients from the Planet Ranch site prior to and after planting were not examined, extremely low soil salinity is often correlated with low nutrient levels (pers. comm., Bertin W. Anderson, Re-vegetation and Wildlife Management Center, Inc., Blythe, California). Marler et al. (in press) discusses increased growth and biomass due to effluent application to Fremont cottonwood and Goodding willow.

The trees at Planet Ranch were planted with the spacing of a mature riparian forest following years of competition for sunlight and other resources. In contrast, cottonwood and willows seedlings observed following flooding and natural recruitment in 1993 on the Bill Williams River were established in near solid patches. As they grew and self-thinned, trees still remained directly adjacent to each other, creating a remarkably cool atmosphere within the patch. In many places, some trees within these original patches continue to grow within 2-5 feet of each other after ten years (B. Raulston, pers. obs., December 2002). The microclimate within these patches may provide a necessary function for survival of seedlings and young trees under the harsh desert climate. Without improved seeding techniques, it will be difficult to create such an atmosphere through re-vegetation.

The high mortality of plants at the Imperial NWR site was due to the intolerance of cottonwood and willow to saline soils (Shafroth et al. 1995, Briggs 1996, Jackson et al.1990, Glenn et al. 1998). It was determined from preliminary soil sampling that although salinity was high, the overall sandy texture of the soil would possibly allow flushing of the salts using the water conveyance system. Mechanical difficulties with the pumps allowed for only one flushing of the system prior to planting, however, flushing the site repeatedly over the growing season did not decrease salinity. Leaching salts from soils requires the water table beneath the site to be low enough to provide an adequate distance between it and the soil surface to create a leaching effect, but not so low that moisture is not available for trees to utilize. The shallow groundwater level at this site (less than 1 m) prevented any true leaching of salts to occur. In saline areas, a water table which is too high can be as detrimental as one which is too low. Riparian restoration using cottonwood and willow at the site has been discontinued and it is being managed as cattail and open water habitat, which is still an improvement over pre-existing degraded wetland conditions.

MANAGEMENT RECOMMENDATIONS

Irrigation

Drip irrigation for restoration projects was not explored in these demonstrations because it is not considered practical for the types of large-scale restoration projects the Bureau of Reclamation intends to undertake in the future. If drip irrigation the only method of irrigation available, managers should be aware that weekly maintenance to check emitters and water lines is necessary and essential. Rodents and other wildlife have been known to damage lines, emitters get clogged, and vandalism can occur (pers. comm. Jackie Record, USFWS, Imperial NWR).

The consensus in landscaping literature is to initially place a pattern of emitters around each tree, and then move them away from the base as the tree grows to deliver water beyond the outer edge of the tree's foliage. A cardinal rule for effective watering is to water deeply and less frequently. This encourages deeper, wider root growth, allowing the tree to more effectively utilize nutrients and moisture from its surroundings, and making it less susceptible to blow down by strong winds (Rainbird 2000, Plant and Zimmerman 2002, Microirrigation Forum 2003).

Various sites on the LCR that have been drip irrigated are lacking in ground cover and shrub layers, important components of riparian habitats. Although ground cover and shrubs which establish "naturally" when flood irrigated may not be native, drip irrigation does not seem to produce a complete vegetation profile. Whether trees can be removed from drip irrigation altogether at some point should be considered on a site by site basis. The trees should be monitored following removal of drip irrigation to determine if they are growing and surviving at an acceptable rate. It should be taken into consideration that although drip irrigation is not recommended here to produce quality riparian habitat, the addition of any native tree to the LCR is beneficial to long term restoration as a seed source alone.

Based on the results of these projects, flood irrigation is the best method for providing irrigation, establishing an under- and mid-story, and, in some cases, controlling soil salinity. Although poles and rooted nursery stock are successful means for re-vegetation, seeding may be the most realistic method to restore habitat in the amount needed on the LCR. The Bureau of Reclamation is in the process of testing and expanding the use of seeding in re-vegetation projects on the LCR.

Planting Techniques and Logistics

Passive methods to control the invasion of weeds into a newly planted restoration area were discovered mostly by trial and error during this demonstration process. In order to take advantage of these methods, planning ahead by at least one year or more is essential. Timing of planting, the use of wind blocks composed of more mature trees, and the use of non-invasive cover crops to protect the site until it is planted are discussed.

To counteract the weed problems that accompany flood irrigation, (although sometimes this produces a desirable native under-story, as was the case with *Baccharus* at Pratt in 2000) fast growing native trees such as cottonwood and willow can be planted along the perimeter of a site using rooted stock or poles. Poles should be cut and planted while they are dormant for best results (see Results, Pratt Restoration Site). If adequate irrigation is available, trees should be large enough in one year to provide a windbreak to block some wind-borne seed. At the Pratt and Cibola sites, trees were approximately 2m tall by the end of the first growing season (Tables 7 & 8).

During the intervening year, a cover crop can be planted to protect the site from invasive species establishment. Dates for the beginning of saltcedar seed production and timing of seeding for other vegetation in the immediate vicinity of the restoration site can be determined during this period as well. Removal of the cover crop, collection of seeds and planting with the desired species should be done as early in the spring as possible to take advantage of periods when saltcedar is least likely to be present.

Spreading an even amount of cottonwood and willow seed over wet soil can be problematic. Cottonwood and willow seed is not planted into the soil, but rather lies on the surface adhering to it by means of the cotton-like "fluff" that surrounds the seed itself. Soil surfaces must remain moist until germination. Wet soil, especially soil containing clay, is difficult to work in, and flooding the area afterwards washes all the seed to one end of the field. Experiments with hydro-seeding or hydro-mulching followed by irrigation with sprinklers until the seedlings are established is the next step in the process of determining methods for large scale restoration.

Seeding phenology within the same species can vary depending on location as well as many other factors. Cottonwood and willow seeds are only available for collection for approximately 6 weeks, and the seed viability period varies greatly from a few days to 5 weeks (Fenner et al. 1984). In order to obtain the youngest or newest seeds possible, seeds are collected directly from trees, not the ground and stored in a cool, shaded location in mesh, paper or cloth bags that allow for aeration. Seed should be planted as soon as possible. The viability of seeds kept in the shade was less than 50% three to four weeks after collection (Fenner et al. 1984).

Considerable differences in seed dispersal times between trees on the Bill Williams River and the mainstem of the lower Colorado River are most likely due to the evolutionary importance of seed availability following historical flood events. The LCR historically flooded as a response to snow melt, which occurs later in the spring and early summer; floods on the Bill Williams River are due to heavy winter rainfall and occurred (and still do) in February and March. On the Bill Williams River, seed dispersal for cottonwoods begins early in March and is over by mid-April. Willows in this watershed begin seeding after cottonwoods and are in full seed dispersal by mid-April. In contrast, willows established in the 1950s on Lake Mohave are in full seed dispersal in June and July. For future restoration projects, it should be noted that many of the trees on Cibola, Havasu, Imperial NWRs and other sites on the LCR came from cuttings taken originally from the Bill Williams River NWR. This may explain why trees found on the mainstem of the LCR nevertheless seed at times closer to those found on the Bill Williams River.

The importance of planning ahead in any restoration project can't be overemphasized. If rooted nursery stock is used, trees ordered from commercial nurseries in the amounts needed for large projects must be ordered well in advance. Added time and consideration for fiscal year end dates (October 1) to allow for the purchasing and contracting processes required by Federal agencies should be anticipated. Coordination with other agencies for equipment and labor should begin early to account for other ongoing projects and conflicting uses of irrigation systems that will be needed during and immediately after planting. In addition, if poles are to be used, they should be cut and planted while dormant (ideally no later than March). If planning for cooperative efforts among agencies, the holiday season in November and December should be factored into the planning process to avoid unscheduled delays.

The use of mechanical equipment to plant trees, either a tractor with a blade to create furrows or tree planter attached greatly diminishes the time and labor involved. In some cases, the first step of restoration is to remove saltcedar (only if it is not occupied Willow Flycatcher habitat!) prior to replanting, which requires additional equipment as well as personnel skilled in operating it. The cost of this step increases the overall cost of a project significantly and can be prohibitive. If sufficient water is available, an alternative may be to flood mature saltcedar stands for an extended period, providing suitable habitat for willow flycatchers and other species. Once mortality of saltcedar begins, restoration with native vegetation can take place in a manner that minimizes impacts to occupied Willow Flycatcher habitat, such as replacing small patches of saltcedar at time during the non-breeding season.

Conclusions

Funds required to keep large, restored areas completely free of non-native vegetation are simply not available, but riparian habitat can be created and maintained in spite of non-native weed infestation. Depending on site conditions, it may also be unrealistic to expect riparian vegetation to flourish and become quality habitat without any irrigation. Some irrigation may be required into perpetuity to prevent salt accumulation in the soils, allow plants to develop a proper root system, and as a management tool to attract migratory songbirds.

Knowledge of common farming and landscaping practices dealing with irrigation, soil conditions, etc. should be more readily incorporated into restoration on the LCR. Having an experienced farmer involved in the planting of the Pratt site greatly contributed to its success.

Considerable acres of restored habitat are needed on the lower Colorado River to begin recovering the endangered Southwestern Willow Flycatcher and to benefit other riparian species. Restoration on the lower Colorado River continues to challenge us ecologically, economically, and politically and accepting restored habitat that is not purely native, nor self-sustaining, may be necessary to make significant progress.

Literature Cited

ANDERSON, B. W. AND R. D. OHMART. 1976. Vegetation type maps of the lower Colorado River from Davis Dam to the southerly international boundary. Final Report to U.S. Bureau of Reclamation, Boulder City, Nevada.

ANDERSON, B. W. AND R. D. OHMART. 1982. Revegetation for wildlife enhancement along the lower Colorado River. Report to U. S. Bureau of Reclamation, Boulder City, Nevada.

ANDERSON, B. W. AND R. D. OHMART. 1984a. Lower Colorado River riparian methods of quantifying vegetation communities to prepare type maps- final report. U.S. Bureau of Reclamation, Boulder City, Nevada.

ANDERSON, B. W. AND R. D. OHMART. 1984b. Vegetation management study for the enhancement of wildlife along the lower Colorado River. Submitted to U.S. Bureau of Reclamation, Boulder City, Nevada.

ASPLUND, K.K. AND M. T. GOOCH. 1988. Geomorphology and distributional ecology of Fremont cottonwood (*Populus Fremontii*) in a desert riparian canyon. Desert Plants 9:17-27.

BRIGGS, M. K. 1992. An evaluation of riparian revegetation efforts in Arizona. Thesis submitted to the School of Renewable Natural Resources, University of Arizona, Tucson, Arizona.

BRIGGS, M. K. 1996. Riparian ecosystem recovery in arid lands: Strategies and References. University of Arizona Press. Tucson, Arizona.

BRIGGS, M. K. AND S. CORNELIUS. 1997. Opportunities for ecological improvements along the lower Colorado River and Delta, Final Report. Prepared for Defenders of Wildlife, Washington, D.C. and National Park Service, U.S. - Mexico Affairs Office, Las Cruces, New Mexico by The Sonoran Institute, Tucson, Arizona.

BUSCH, D. E. 1992. Analyses of the structure and function of lower Colorado River riparian plant communities. Dissertation submitted to the Department of Biological Sciences. University of Nevada, Las Vegas, Nevada.

BUSCH, D. E. AND S. D. SMITH. 1995. Mechanisms associated with decline of woody species in riparian ecosystems of the southwestern U.S. Ecological Monographs 65:347-370.

CH2MHILL. 1999. 1997 Vegetation mapping and GIS development. Prepared for U.S. Bureau of Reclamation, Boulder City, Nevada.

ELZINGA, C. L., D. W. SALZER AND J. W. WILLOUGHBY. 1998. Measuring and monitoring plant populations. U.S. Dept of Interior, Bureau of Land Management Technical Reference 1739-1.

EPPLE, A.O. 1995. A Field Guide to the Plants of Arizona. Falcon Press Publishing Co., Inc., Helena, Montana.

FENNER, P., W. W. BRADY AND D. R. PATTON. 1984. Observations on seedlings of Fremont cottonwood. Desert Plants 6:55-58.

FRIEDMAN, J. M., M. L. SCOTT AND W. M. LEWIS, JR. 1995. Restoration of riparian forest using irrigation, artificial disturbance and natural seedfall. Environmental Management 19:547-557.

GLENN, E., R. TANNER, S. MENDEZ, T. KEHRET, D. MOORE, J. GARCIA AND C. VALDES. 1998. Growth rates, salt tolerance, and water use characteristics of native and invasive riparian plants from the delta of the Colorado River, Mexico. Journal of Arid Environments 40:281-294.

GRINNELL, J. 1914. An account of the mammals and birds of the lower Colorado River Valley, with special reference to the distributional problems presented. Zoology 12:51-294.

HALTERMAN, M. D. 1998. Population status, site tenacity, and habitat requirements of the Yellow-billed Cuckoo at the Bill Williams River, Arizona: summer 1998. Submitted to U.S. Bureau of Reclamation, Lower Colorado River Regional Office, Boulder City, Nevada by Kern River Research Center (now Southern Sierra Research Station), Weldon, California.

HALTERMAN, M. D. 2000. Population status of the Yellow-billed Cuckoo at the Bill Williams River, Arizona: summer 1999. Submitted to U.S. Bureau of Reclamation, Lower Colorado River Regional Office, Boulder City, Nevada by Kern River Research Center (now Southern Sierra Research Station), Weldon, California.

HALTERMAN, M. D. 2001. Population status of the Yellow-billed Cuckoo at the Bill Williams River NWR and Alamo Dam, Arizona, and southern Nevada: Summer 2000. Submitted to U. S. Bureau of Reclamation, Lower Colorado River Regional Office, Boulder City, Nevada by Kern River Research Center (now Southern Sierra Research Station), Weldon, California.

JACKSON, J., J. T. BALL AND M. R. ROSE. 1990. Assessment of the salinity tolerance of eight Sonoran desert riparian trees and shrubs. Submitted to U.S. Bureau of Reclamation, Yuma Projects Office, Yuma, Arizona by Biological Sciences Center, Desert Research Institute, University of Nevada System, Reno, Nevada.

JOHNSON, R. L. 1965. Regenerating cottonwood from natural seedfall. Journal of Forestry January:33-36.

JONES AND STOKES ASSOCIATES, INC. 1999. Habitat enhancement concept plan for the Cocopah Tribal Lands and adjacent areas along the Colorado River. Submitted to Cocopah Indian Tribe by Jones and Stokes Associates, Inc., Phoenix, Arizona.

KEARNEY, T.H. AND R. H. PEEBLES. 1951. Arizona Flora. University of California Press, Berkeley, California.

KILMER, V. J. 1982. Handbook of soils and climate in agriculture. CRC Press, Inc. Boca Raton, Florida.

MAHONEY, J. M. AND S. B. ROOD. 1991. A device for studying the influence of declining water table on poplar growth and survival. Tree Physiology 8:305-414.

MACMAHON, J. A. AND F. H. WAGNER. 1985. The Mojave, Sonoran and Chihuahuan Deserts of North America *in* M. Evenari, I. Noy-Meir and D. W. Goodall (editors). Ecosystems of the world, 12A: Hot deserts and arid shrublands. Elsevier Science Publishing Inc. New York, New York.

MARLER, R. J., J. C. STROMBERG AND D. T. PATTEN. In press. Growth response of *Populus fremontii, Salix gooddingii*, and *Tamarix ramosissima* seedlings under different nitrogen and phosphorus concentrations. Journal of Arid Environments.

MCKERNAN, R. L. 1997. Status, distribution, and habitat affinities of the Southwestern Willow Flycatcher along the lower Colorado River, year 1 - 1996. Submitted to Bureau of Reclamation, Boulder City, Nevada by San Bernardino County Community and Cultural Resources Museums Division, Redlands, California.

MCKERNAN, R.L. AND G. BRADEN. 1998. Status, distribution, and habitat affinities of the Southwestern Willow Flycatcher along the lower Colorado River, year 2 -1997. Submitted to Bureau of Reclamation, Boulder City, Nevada by San Bernardino County Community and Cultural Resources Museums Division, Redlands, California.

MCKERNAN, R.L. AND G. BRADEN. 1999. Status, distribution, and habitat affinities of the Southwestern Willow Flycatcher along the Lower Colorado River, year 3 – 1998. Submitted to U.S. Bureau of Reclamation, Boulder City, Nevada by San Bernardino County Community and Cultural Resources Museums Division, Redlands, California.

MCKERNAN, R.L. AND G. BRADEN. 2001a. Status, distribution, and habitat affinities of the Southwestern Willow Flycatcher along the lower Colorado River, year 4 - 1999. Submitted to Bureau of Reclamation, Boulder City, Nevada by San Bernardino County Community and Cultural Resources Museums Division, Redlands, California.

MCKERNAN, R.L. AND G. BRADEN. 2001b. Status, distribution, and habitat affinities of the Southwestern Willow Flycatcher along the lower Colorado River, year 5- 2000. Submitted to Bureau of Reclamation, Boulder City, Nevada by San Bernardino County Community and Cultural Resources Museums Division, Redlands, California.

MEARNS, E. A. 1907. Mammals of the Mexican boundary of the United States: a descriptive catalogue of the species of mammals occurring in that region; with a general summary of natural history, and a list of trees. U.S. Natural History Museum Bulletin No. 56

Microirrigation Forum. Accessed 2 Jan 2002. Drip irrigation of mature trees. <http://www.microirrigationforum.com/new/archives/maturetrees.html>

OHMART, R. D., W. O. DEASON AND C. BURKE. 1977. A riparian case history: the Colorado River. Pp. 35-47 *in* R. R. Johnson and D. A. Jones (editors). Importance, preservation and management of riparian habitat: a symposium. USDA Forest Service Gen. Tech. Rep. RM-43, USDA Rocky Mountain Forest and Range Experimental Station, Ft. Collins, Colorado.

PERIMAN, R. D. AND J. F. KELLY. 2000. The dynamic environmental history of southwest Willow Flycatcher habitat: a survey of changing riparian conditions through time. Pp. 25- 42 *in* D. M. Finch and S. H. Stoleson (editors). Status, ecology, and conservation of the Southwestern Willow Flycatcher. Gen. Tech. Rep. RMRS-GTR-60. USDA Forest Service, Rocky Mountain Research Station, Ogden, Utah

PINKNEY, F.C. 1992. Revegetation and enhancement of riparian communities along the lower Colorado River. Submitted to Bureau of Reclamation, Boulder City, Nevada.

PLANT, J. AND G. ZIMMERMAN. "Protecting Trees", last updated 9 Oct 2002, website homepage TLC for Trees, accessed 2 Jan 2003, <http://www.tlcfortrees.info/protecting_trees.htm>

RAIN BIRD, INC. 2000. Drip Irrigation Made Easy. <http://rainbird.com/pdf/turf/D39266A.pdf> 24 pp.

ROSENBERG, K. V., R. D. OHMART, W.C. HUNTER AND B. W. ANDERSON. 1991. Birds of the lower Colorado River Valley. University of Arizona Press, Tucson, Arizona.

SCOTT, M. L., P. B. SHAFROTH AND G. T. AUBLE. 1999. Responses of riparian cottonwoods to alluvial water table declines. Environmental Management 23:347-358.

SCOTT, M. L., G. C. LINES, AND G. T. AUBLE. 2000. Channel incision and patterns of cottonwood stress and mortality along the Mojave River, California. Journal of Arid Environments 44:399-414.

SEDGWICK, J. A. 2000. Willow flycatcher (*Empidonax traillii*) *in* the Birds of North America, No. 533 (A. Poole and F. Gill, eds.). The Birds of North America, Inc., Philadelphia, Pennsylvania.

SHAFROTH, P. B., J. M. FRIEDMAN, AND L. S. ISCHINGER. 1995. Effects of salinity on establishment of Populus Fremontii (cottonwood) and Tamarix ramosissima (saltcedar) in southwestern United States. Great Basin Naturalist 55: 58-65.

SHAFROTH, P. B., G. T. AUBLE, J. C. STROMBERG AND D. T. PATTEN. 1998. Establishment of woody riparian vegetation in relation to annual patterns of streamflow, Bill Williams River, Arizona. Wetlands 18(4):577-509.

SHAFROTH, P. B., J. C. STROMBERG AND D. T. PATTEN. 2000. Woody riparian vegetation response to different alluvial water table regimes. Western North American Naturalist 60:66-75.

SHAFROTH, P.B., J. C. STROMBERG, AND D. T. PATTEN. 2002. Riparian vegetation response to altered distrubance and stress regimes. Ecol. Appl. 12(1): 107-123.

SOGGE, M. K., R. M. MARSHALL, S. J. SFERRA, AND T. J. TIBBETTS. 1997. A Southwestern Willow Flycatcher natural history summary and survey protocol. National Park Service Tech. Rep. NPS/NAUCPRS/NRTR-97/12.

STROMBERG, J. C. 1993. Fremont cottonwood-goodding willow riparian forests: a review of their ecology, threats, and recovery potential. Journal of the Arizona-Nevada Academy of Science 26:97-110.

SOGGE, M. K. 2000. Breeding season ecology. Pp. 57- 70 *in* D. M. Finch and S. H. Stoleson (editors). Status, ecology, and conservation of the Southwestern Willow Flycatcher. Gen. Tech. Rep. RMRS-GTR-60., USDA Forest Service, Rocky Mountain Research Station. Ogden, Utah.

SWENSON, E. A. 1989. Progress in the understanding of how to reestablish native riparian plants in New Mexico. Pp. 144-150 *in* K. M. Mutz, D. J. Cooper, M. L. Scott, and L. K. Miller (tech. coords). Restoration, creation, and management of wetland and riparian ecosystems in the American West. A symposium of the Rocky Mountain Chapter of the Society of Wetland Scientists, Denver, Colorado.

SWENSON, E. A. AND C. L. MULLINS. 1985. Revegetating riparian trees in southwestern floodplains. Pp.135-138 *in* R. R. Johnson, C. D. Ziebell, D. R. Patton, P. F. Ffolliot and R. H. Hamre (tech. coords). Ecosystems and their management: reconciling conflicting uses. USDA Forest Service Gen. Tech. Rep. RM-120, Fort Collins, Colorado.

TAYLOR, J. P. AND K. C. MCDANIEL. 1998. Restoration of saltcedar (Tamarix sp.) infested floodplains on the Bosque del Apache National Wildlife Refuge. Weed Tech.12:345-352.

U. S. ARMY CORPS OF ENGINEERS. 1999. Alamo Lake, Arizona, Feasibility report and environmental impact study. U.S. Army Corps of Engineers, Planning Division, Water Resources Branch, Los Angeles, California.

U. S. DEPARTMENT OF AGRICULTURE. 1996. Soil survey laboratory methods manual. U.S. Department of Agriculture, soil survey investigations report no. 42, version 3.0. Natural Resource Conservation Service, Lincoln, Nebraska.

U. S. BUREAU OF RECLAMATION. 1992. Vegetation management study, lower Colorado River, Phase 1. U. S. Bureau of Reclamation, Boulder City, Nevada.

U.S. BUREAU OF RECLAMATION. 1998. Soil survey report, lower Colorado River revegetation program, Cibola, Havasu, and Imperial National Wildlife Refuges. U.S. Bureau of Reclamation, Denver Technical Center, Denver, Colorado.

U. S. BUREAU OF RECLAMATION. 1999. Long-term restoration program for the historical Southwestern Willow Flycatcher (*Empidonax traillii extimus*) habitat along the lower Colorado River. U. S. Bureau of Reclamation, Boulder City, Nevada.

Appendix:

Photographs of Restoration Sites

Planet Ranch Restoration Site

March 1995

November 2000

Pratt Restoration Site, March1999

Newly planted trees.

Poles planted at an angle within furrow.

Planting potted plants in furrows created by tractor.

Cottonwood & willow seeds scattered in wet furrows.

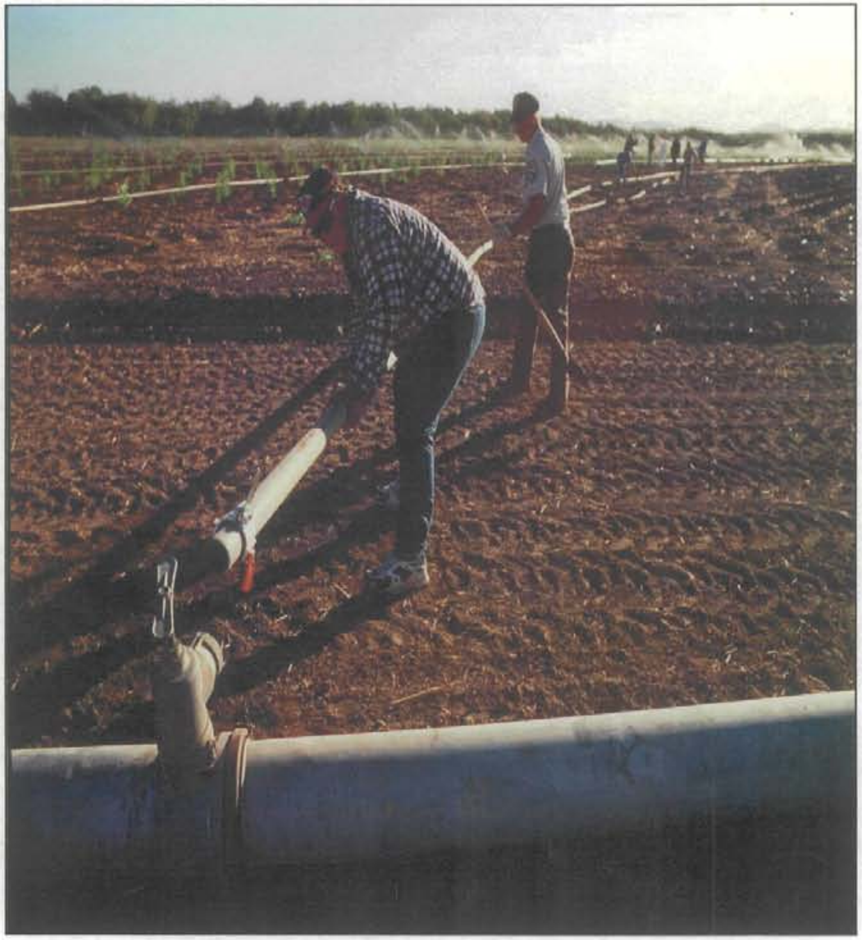
Pratt Restoration Site, Dec 2002

Pratt Restoration Site

Tree Ht 6-8 m, Sep 2002

Nature Trail Restoration Site

Planting rooted nursery stock, Apr 1999.



Sprinkler irrigation pipe installation, Apr 1999.

Nature Trail Restoration Site

Aerial View, July 2000

July 2001

July 2001

July 2001

Ducks Unlimited Restoration Site

(Note: red and yellow markers correspond to same locations on "before" and "after" photos.)

Before

After

Pre-construction:
Shallow, saline water dominated by *Phragmites*.

After construction: Deeper ponds, increased surface area, cattails dominate.