OPPORTUNITIES FOR ECOLOGICAL IMPROVEMENT ALONG THE LOWER COLORADO RIVER AND DELTA

FINAL REPORT

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Cover Photograph: Significant parts of the Imperial National Wildlife Refuge have been revegetated with native riparian trees. This and other riparian revegetation efforts can play a critical role in re-introducing native riparian plants along reaches of the Colorado River that have experienced significant ecological decline.

The Sonoran Institute

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Mark K. Briggs[1] and Steve Cornelius[2]

Abstract: The lower Colorado River mainstem and delta have been severely damaged by a variety of human-related activities, including river impoundment, agriculture, water diversions, introduction of exotic plants, and groundwater pumping. In some areas the native wetland habitat that formerly dominated this region has disappeared completely. Nevertheless, there are areas where significant wetland habitat persists as a result of incidental circumstances or purposeful restoration actions. These areas provide important conservation and restoration opportunities. In this investigation, nine restoration efforts along the lower Colorado River from Parker Dam to the delta region were evaluated to learn how lessons from these experiences can benefit future ecological recovery efforts. In addition, investigators assessed the general ecological condition of this reach to identify critical native wetland plant communities and recommend strategies for protecting these areas in the future. It is apparent that wetland ecosystems in both the delta and the mainstem would benefit if effluent waters were allocated to support wetlands, rather than allocated to evaporative basins. Other important strategies for improving the ecological condition of the river should include altering reservoir releases, improving the effectiveness of revegetation efforts, and developing bi-national, collaborative approaches involving local communities and landowners to identify and carry out projects that benefit both them and the ecological condition of the river.

PROJECT OBJECTIVE

The overall goal of this investigation is to identify opportunities and strategies for improving the ecological condition of the lower Colorado River. The focus of this effort is the lower portion of the Colorado River, which includes the mainstem of the river from Parker Dam to the delta as well as the delta itself. This effort has three principal objectives. First, the effectiveness of past recovery* efforts along the lower Colorado River (from Parker Dam to the river's delta) were evaluated so that lessons gained from these experiences can be applied to future ecological recovery activities. Second, the ecological condition of this reach of the lower Colorado River was assessed, with particular focus on identifying areas that contain significant native wetland habitat or

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* Three terms are often used to describe efforts for improving the ecological condition of a damaged area: restoration, rehabilitation, and reallocation (Bradshaw 1988; Aronson et al. 1993). Each term carries with it a specific meaning with regard to the effort's intended endpoint. To avoid confusion, this report will use the generic term "recovery" when the objective of a particular project was not stated or unclear.

show promise for future restoration activities. Third, courses of action are recommended for enhancing damaged areas and maintaining areas of natural significance.

CHANGES ALONG THE LOWER COLORADO RIVER

The Colorado River watershed is a vast system. From its headwaters in the Rocky Mountains to the Sea of Cortez, the Colorado River travels over 2,240 km (1,400 miles) and drains an area of 632,000 square kilometers (244,000 square miles) (this includes 5,200 square kilometers of northern México). Even within the narrow focus of this investigation -Parker Dam to the Sea of Cortez - there are wide variations in land use patterns and physical and biological conditions (Fig. 1). The current hydrologic, physical, and biologic characteristics of this reach and the changes that have taken place in these parameters since the construction of Hoover Dam are fairly well documented (Ohmart et al. 1988, Glenn et al. 1992, Abarca et al. 1993, Glenn et al. 1996) and are reviewed only briefly here.

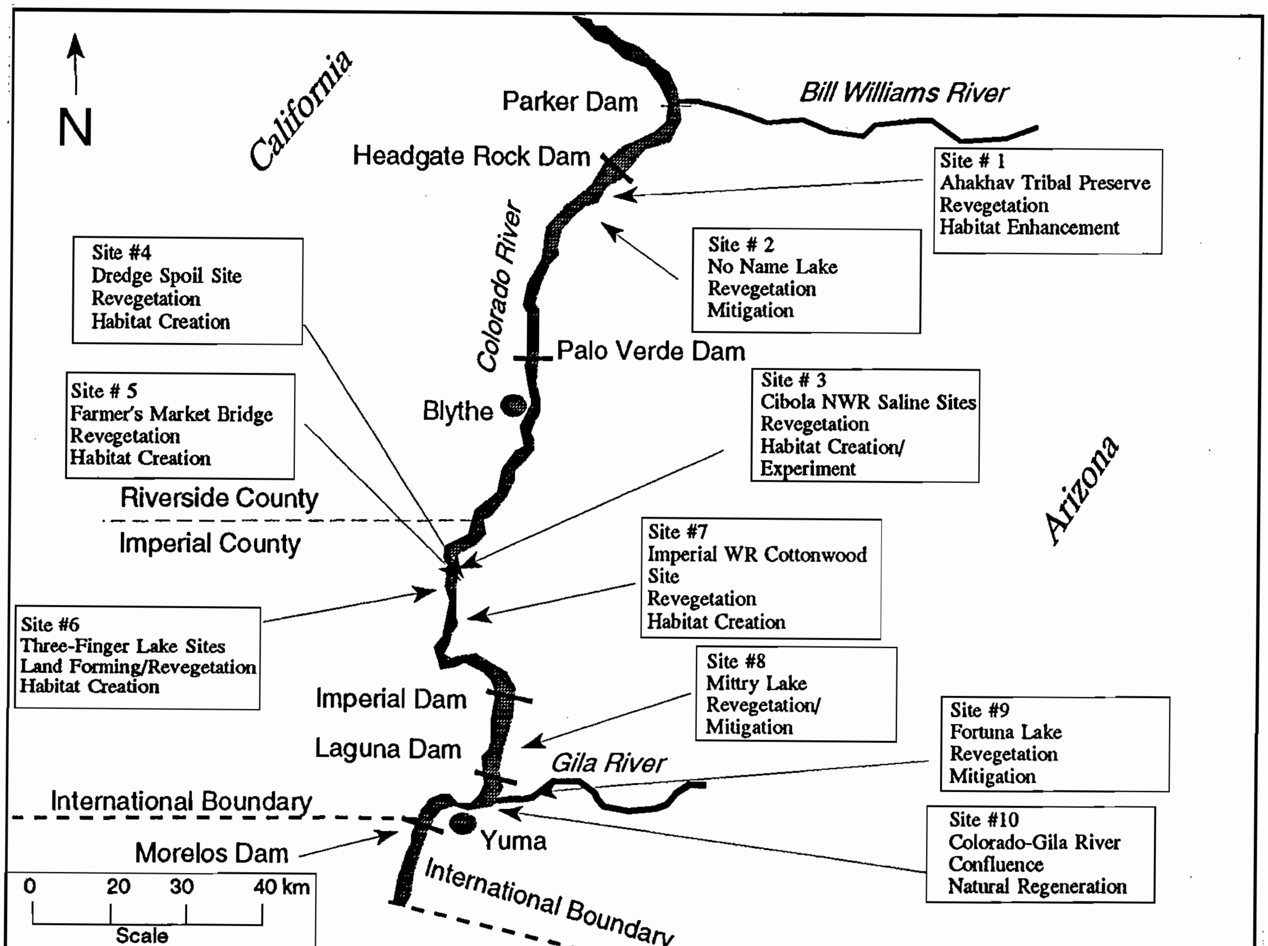

Figure 1. Idealized map of Colorado River mainstem from Parker Dam to the international boundary. Sites included in this investigation are labeled and their approximate location is indicated.

Historic accounts appear to indicate that the lower Colorado River's riparian ecosystems changed little from the time of early Spanish exploration in the 17th century to the 1930s when construction of Hoover Dam was completed (Ohmart et al. 1977). The completion of Hoover Dam in 1935 sparked a wave of major construction and agricultural projects along the river. Today, as the Colorado River flows from Hoover Dam to the delta, it passes through 28 dams, irrigates over 1 million hectares (2.5 million acres) of agricultural land, and serves or supplements water supplies for over 20 million people in the U.S. and México (Colorado River Basin Salinity Control Forum 1990).

The Mainstem

The accumulative weight of river impoundment, river diversions, groundwater pumping, spread of non-native species, agricultural activities, and other human activities has had a devastating effect on the river's riparian ecosystems. In particular, the buffering of annual overflows and altering of natural channel dynamics by river impoundment has compromised habitat for native fishes and limited the creation of sandbars and channel islands, which are critical features for the propagation of many native riparian plants (Ohmart et al. 1977)

The completion of Hoover Dam, and then Glen Canyon Dam in 1963, had dramatic effects on river streamflow. Prior to the dams, the Colorado River was a warm, muddy flow with tremendous seasonal fluctuations. After dam construction, the river became a much clearer flow of cold water that fluctuated relatively little. Such hydrologic changes have adversely effected the river's native population of warm-water fish, such as the razorback, bluehead sucker, flannelmouth, Colorado squawfish, humpback chub, and bonytail chub, while benefiting such non-native fish as the rainbow and cutthroat trout, which are better adapted to the river's artificially created clear, cold waters (Minckley 1991). With the exception of the bluehead sucker and speckled dace, all of the river's native fish are either endangered or under consideration for listing.

The distribution and extent of native wetland plant communities, such as the cottonwood/willow (*Populus fremontii/Salix gooddingii*) riparian forests and the cattail/rush (*Typha* spp./*Juncus* spp.) marshlands, along some reaches of the lower Colorado River appear to have changed significantly. Ohmart et al. (1977) observed, for example, that cottonwood communities along the mainstem have declined from over 2,000 hectaress (5,000 acres) in the 1600s to less than 200 hectaress (500 acres). Saltcedar (*Tamarix* spp.), which was introduced to the western U.S. during the mid-1800's as a soil stabilizer and ornamental plant, now forms homogeneous stands along significant reaches of the lower Colorado River (Ohmart et al. 1977). Indeed, reaches of the lower Colorado River that are not significantly effected by saltcedar are few and far between, even in areas where significant native wetland plant communities persist.

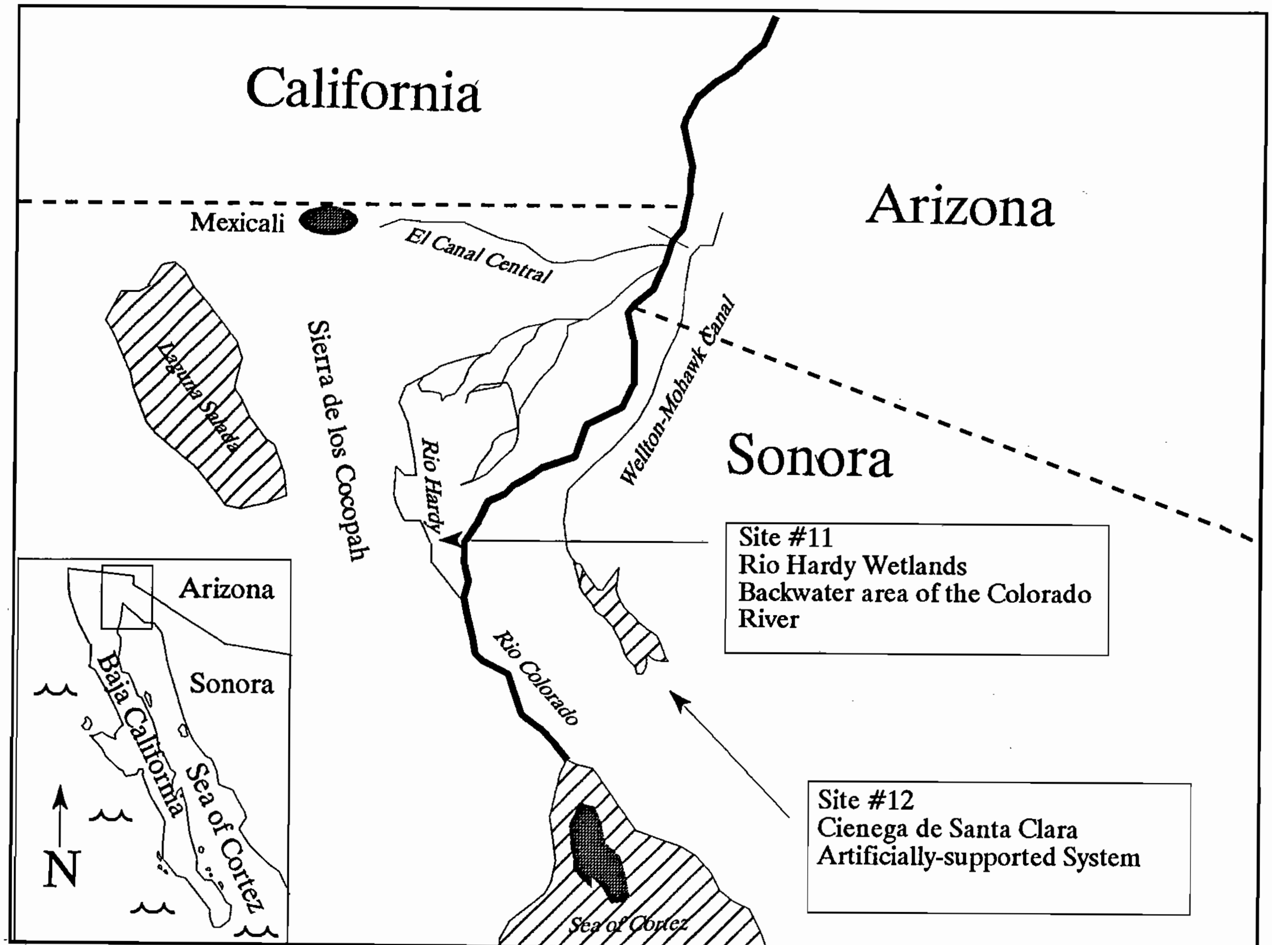

Figure 2. Idealized map of the Colorado River delta and location of sites considered in this study.

METHODS

Background information was collected describing the current ecological condition of the lower Colorado River, the degree to which that condition has changed, and some of the principal reasons behind the ecological changes that have occurred. Maps and aerial photographs were collected and past studies dealing with the river's ecological condition were reviewed. Ecologists, hydrologists, natural resource managers, restorationists, and others with lower Colorado River experience were interviewed to better understand the challenges that will have to be overcome before significant headway can be made in improving the river's ecological condition.

As a preliminary step to performing field work, a group of sites within the study area were chosen for evaluation. Sites were selected in consultation with local experts with regard to their natural significance or the information they may convey to future

Lower Colorado River water is projected to become progressively more saline** due to a variety of human-related activities. The Environmental Protection Agency (EPA) estimated that increased salinity concentrations in the river have been principally caused by out-of-basin exports, irrigation, and reservoir evaporation - accounting for three percent, 37 percent, and 12 percent, respectively, of the increased salinity concentrations that occurred between 1944 and 1988 (Colorado River Basin Salinity Control Forum 1990).

The Delta
Prior to the construction of Glenn Canyon and Hoover Dams, Colorado River water continually reached the delta and the Sea of Cortez, providing nutrients and estuarine habitat for a plethora of marine life. During this time, the silt and water that the river brought to the delta were critical in sustaining dense wetland plant communities that are estimated to have contained 200 to 400 species (Ezcurra et al. 1988 cited in Glenn et al. 1996). The area occupied by the delta prior to dam construction is estimated at over 780,000 hectaress (almost 2 million acres), and included two below sea level depressions, the Salton Sea and the Laguna Salada (Sykes 1937). Tidal marsh, and brackish and riparian ecosystems supported jaguar, beaver, and thousands of migratory and resident waterfowl. In addition, over 20,000 Cocopah people prospered by fishing, hunting, and gathering in the lush delta environment (Alvarez de Williams, 1987).

Today, over 1 million hectares (2.5 million acres) of land in and surrounding the delta has been converted to farmland. As a result of river impoundment and water diversions, river water rarely flows all the way to the Sea of Cortez, altering the natural salinity balance and decreasing the flow of nutrients that supports upper Sea of Cortez fisheries (Glenn et al. 1996). In addition, reduced silt loads due to river impoundment have actually sparked a period of erosion in the delta, rather than accretion (Thompson 1968). Therefore, the area occupied by the delta will probably decrease over time.

Although the 1944 treaty allocates to México 10% of the lower Colorado River's base flow during non-flood years, most of this water is diverted to the Canal Central for agricultural irrigation in the Mexicali and San Luis districts of México (Glenn et al. 1996). As a result, mainstem water reaches delta wetlands only during times of high flow.

The combination of river impoundment and diversions has had a devastating effect on delta wetlands. In areas formerly dominated by *Typha* spp. and riparian forests of cottonwoods or willows, a significant amount of the delta region south of the farmland now consists of dry sand, mud, and salt flats dominated by salt cedar (*Tamarix chinensis*), arrowweed (*Pluchea sericea*), and iodine-bush (*Allenrolfea occidentalis*)

** According to a report developed by the Colorado River Basin Salinity Control Forum (1990), the salinity concentration of Colorado River water below Parker Dam is projected to increase from 640 mg/l in 1990 to over 850 mg/l by 2010.

Freshwater and brackish habitat still remain, but these areas are confined for the most part to agricultural wastewater discharge points, artesian springs, and areas influenced by tidal fluctuations.

Despite the tremendous changes that have occurred in the Colorado River delta, it is important to emphasize that the delta is not beyond recovery. Particularly during the last decade, considerable amounts of Colorado River water, as well as agricultural return flows, have reached the delta, helping to maintain several key intertidal, brackish, and riparian wetlands south of the agricultural fields (Glenn et al. 1992, Payne et al. 1992).

In the delta, as well as the mainstem, significant marsh wetlands still exist. Marshes are a critical component of the lower Colorado River ecosystem and are dominated by soft-stemmed emergent plants such as cattails (*Typha* spp.), bulrushes (*Scirpus acutus*), and phragmites (*Phragmites australis*) and frequently occur next to terrestrial and aquatic habitats. Marsh habitat is critical to a plethora of bird species, including waterbirds such as the western grebe (*Aechmophorus occidentalis*), double-crested cormorant (*Phalacrocorax auritus*), and gadwall (*Anas strepera*); shorebirds such as the killdeer (*Charadrius vociferus*), long-billed curlew (*Numenius americanus*), and sandpipers (*Calidris* spp.); and wading birds such as the green heron (*Butorides striatus*), roseate spoonbill (*Ajaia ajaja*), and the endangered Yuma clapper rail (*Rallus longirostris*).

The principal wetlands in the delta are (1) the Río Hardy wetlands, which are supported by the Río Hardy River and high flow events in the Colorado River; (2) the Cienaga de Santa Clara, sustained by agricultural runoff emanating from the Wellton-Mohawk canal and the Riito drain; and (3) El Doctor wetlands, which are supported by artesian springs (Glenn et al. 1996) [Fig. 2]. A more detailed description of the El Río Hardy wetlands and Ciénaga de Santa Clara is provided in the overview section of this report. In addition, riparian plant communities dominated by *Populus fremontii/Salix gooddingii/Tamarix chinensis* have established in several locations along the main channel of the Colorado River just north of the areas influenced by tidal fluctuations of the Sea of Cortez. These wetlands ecosystems are critical to a variety of wildlife. The Ciénaga de Santa Clara, for example, provides habitat for the endangered desert pupfish (Cyprinodon macularis) and the Yuma clapper rail (*Ralus longirostris yumanensis*) (Abarca et al. 1993). The delta's ecological decline also appears to be intricately related to the decline of two other endangered species: the totoaba fish (*Cynoscion macdonaldi*), which was once common throughout much of the delta (Cisneros and Mata et al. 1995); and the vaquita porpoise (*Phoceona sinus*), which is a harbor porpoise that is heavily dependent on the delta's protected waters and nutrient supply (Moralis and Abril 1994; Peggy Turk Boyer, pers. com., 1997).

recovery efforts. Sites were then visited and field work conducted with personnel who have either studied the area or were involved in the recovery effort.

For each site visited, the following information was gathered:
(1) general background information, including site location, the size of the recovery project, date of project implementation and completion, and project objective;
(2) general ecological condition, including the current composition and structure of the site's plant community, obvious signs of disease or perturbation (e.g., mistletoe infestation, significant population of non-native species, leaves exhibiting symptoms of high salt concentrations), significant changes in ecological condition (e.g., dramatic changes in depth to saturated soils or streamflow characteristics), signs of significant salt accumulation, and obvious signs of erosion;
(3) recovery strategies employed (where appropriate), including information describing the recovery methods, how the strategies were developed, post-project maintenance and monitoring, and evaluation of the effort (how effective the restoration effort was in achieving project objectives and a general description of the present condition of the site; and
(4) lessons learned, describing how the experiences gained from this review can be used to improve the effectiveness of future recovery and conservation efforts along the lower Colorado River.

AN OVERVIEW OF SELECTED RESTORATION EFFORTS AND CRITICAL NATURAL AREAS

In total, 12 sites were evaluated as part of this investigation. Of these, nine are recovery efforts that were completed along the river's mainstem and all but one of these (Three Finger Lake, project #6) used revegetation as the principal recovery strategy. The recovery efforts ranged significantly in size and scope. Some encompassed less than a hectare and involved fewer than a hundred plantings; others encompassed a much larger area and involved thousands of plantings. Three "natural" sites were also included in this effort. These sites were identified as having significant natural value and are not the result of artificial restoration work. Of the three, one is along the mainstem of the river and the other two are located in the delta. A fourth significant natural area - the El Doctor wetlands of the delta- is considered in the recommendation section of the report. Sites are labeled numerically from upstream to downstream.

Site #1
'Ahakhav Tribal Preserve

Location and Size: This 150 acre revegetation site lies within the 1,000 acre 'Ahakhav Tribal Preserve, which is managed by the Colorado River Indian Tribes (CRIT) and lies approximately three kilometers downstream of Headgate Dam.
Objective: To enhance habitat for wildlife and fish, as well as to provide environmental education, outdoor recreation, and cultural opportunities for tribal and community members.

Completion Date: Planting for this part of the 'Ahakhav Tribal Preserve began in 1996 and will be completed during 1998. Recreation, educational, and cultural activties are on-going. Additional riparian recovery efforts are also planned for the immediate future.

Pre-Project Site Conditions: Pre-project vegetation consisted primarily of saltcedar, arrowweed, and honey and screwbean mesquite. Soils are mostly sandy.

Project Strategy: Prior to project implementation, site characteristics were evaluated with regard to soil salinity, soil texture, and depth to saturated soils. Undesirable plants were removed with a bulldozer. Over 10,000 screwbean mesquite, honey mesquite, cottonwood, and Goodding willow seedlings were planted on over 100 acres of land. The site evaluation allowed revegetation practitioners to develop a detailed map of site conditions, allowing them to place plant materials in areas were they would be most likely survive. Mesquites were planted in areas characterized by relatively high soil salinity (electroconductivity levels in excess of 2 dS m^{-1}). Mesquite were placed in the ground as seedlings (as opposed to cuttings or poles). Cottonwood and willow poles were started in a nursery and planted on-site in four liter containers. Once in the ground, all plants were irrigated with a drip irrigation system. Plants will be irrigated until roots are considered to have reached saturated soils.

Results: Ninety percent of all plants have survived to date. A significant portion of these have grown to a height of almost six meters.

Lessons Learned: Although the site was planted only one year ago, growth rates of planted vegetation indicate that mapping site characterisitics, particularly soil salinity and water availability characterisitics, provides data critical to revegetation success. For example, the site evaluation completed as part of this effort allowed relatively salt intolerant plants, such as willow and cottonwoods, to be placed in areas where salt concentrations were within tolerable ranges. Taking advantage of low-lying topographical features, such as secondary channels, was also considered critical to the survival of obligate riparian species such as cottonwoods and willows (Shaffer, Terry, pers. comm. 1997).

Site #2
No Name Lake

Location and Size: The 17 ha (41.5-acres) site is about one river km downstream from Angnes Wilson Bridge and lies adjacent to farmland managed by the Colorado River Indian Reservation.

Objective: To re-establish native riparian plants in an area where the river's riparian habitat has been severely compromised by agricultural activities. This project was also part of a plan to mitigate damages caused by construction activities associated with the Parker II project.

Completion Date: 1987

Pre-Project Site Conditions: Prior to the revegetation effort, the vegetation on the site was arrowweed, with some salt cedar, screwbean mesquite, and willow. The water table depth was estimated to vary from 4 m on the upstream end of the site to about 1.5 m on the downstream end (Pinkney 1992).

Project Strategy: The site was cleared and root-ripped in April 1987. On-site, desirable vegetation was not disturbed. A 38-cm (15-inch) diameter auger was used to disrupt the soil down to the saturated zone. Five days prior to planting, salts were leached by flood irrigating. Approximately 1,380 cottonwoods, 370 willows, 3,560 honey mesquites, 45 palo verdes, 80 California fan palms, and 100 quailbush were planted. Trees and shrubs were in cardboard tubes ten centimeters in diameter and 40 cm long. Nitrogen fertilizer was applied using a liquid injector system. Undesirable vegetation was controlled by applying "Arsenal," and a systemic insecticide "Orthene" was applied to control physllids. One-meter tall-chicken wire baskets were installed around all plants, which were irrigated with a drip system (45 liters each day for the first 30 days; reduced to 3 days a week through September 1987) (Pinkney 1992). Cottonwoods and willows were also planted in an erosional depression located immediately adjacent to the agricultural fields. The depression is roughly 1.5 ha in area and lies approximately two meters below the elevation of surrounding lands.
Results: As of 1990, approximately 53 percent of the total numbers of individuals originally planted had survived (Pinkney 1992). Of this amount, more than 90 percent was honey mesquite and palo verde. The only other plant species with more than 50 percent survival was quailbush. All of these plants occur outside the erosional depression. Of all the cottonwoods and willows that were planted, only those planted in the erosional depression survived. This relatively low elevational area receives periodic runoff from an adjacent agricultural field. Cottonwood and willow in this depression are over 18 m (60 feet) high and appear healthy. As long as the adjacent field is irrigated, this area will have sufficient moisture to support the existing cottonwood and willow. As of 1997, honey mesquite, palo verde, and quailbush have established in scattered locations throughout the south end of the site.
Lessons Learned: The relatively mesic environment of the erosional depression appears to have been crucial to the survival of native, obligate riparian plants. This underscores the importance of both understanding the depth to the saturated zone when revegetating with obligate riparian plants and taking advantage of landscape features that may be characterized by higher water availability.

Site #3
Cibola National Wildlife Refuge Saline Site
Location and Size: The Cibola National Wildlife Refuge is located in La Paz County, Arizona, due west of Cibola, Arizona. The Cibola NWR is located approximately at River Mile 99 on the lower Colorado River in La Paz County, Arizona. The revegetation site is located in the northeast corner of the refuge and consists of eight 6 m * 9 m plots.
Objective: To better understand the feasibility of establishing native plants in highly saline soils.
Completion Date: September 1986
Pre-Project Site Conditions: The site was essentially devoid of woody plants at the time of planting and soils were classified as dense clays. Depth to saturated soils was

estimated at about 1.5 m (roughly four ft) and soil salinity ranged from 6,000 ppm to 60,000 ppm (Pinkney 1992).

Project Strategy: Prior to seeding, all plots were flooded in an attempt to leach out the salts in the soil profile. The plots were seeded and raked in September 1986. Four of the eight plots were seeded with quailbush while the remaining four plots were seeded with equal amounts of screwbean mesquite, honey mesquite, and palo verde. Two of the quailbush plots and two of the mesquite and palo verde plots were fertilized. The plots were flood irrigated three times in 1986 with two to five centimeters of water and once in 1987 with ten to 15 centimeters of water (Pinkney 1992).

Results: Germination rates for all plants was initially high. In 1988, quailbush seedlings were well established (more than 1,000 seedlings germinated), and approximately 1,900 screwbean mesquite, 600 honey mesquite, and 25 palo verde seedlings had also established. However, mortality was high in the following years. All palo verde subsequently died as well as many of the mesquite seedlings. Rabbit damage also occurred and seemed to affect the survival and growth of honey mesquite more than screwbean (Pinkney 1992). Only three to ten mesquite seedlings were found in 1997 in each of the four plots and all were protected with chicken wire baskets.

Lessons Learned: Though difficult, it is possible to revegetate in areas characterized by high soil salinity by using appropriate plant materials and innovative irrigation and planting strategies. However, revegetating areas characterized by high soil salinity should generally be avoided. Evaluating soil chemistry prior to planting allows revegetation experts to place plant materials in areas where they are likely to survive, improving the overall effectiveness of the revegetation effort. Experiences from riparian revegetation efforts along other parts of the Colorado River basin also support this conviction (Anderson 1989).

Site #4

Cibola National Wildlife Refuge Dredge Spoil Site

Location and Size: This site covers 28 hectares (70-acre) and is located about eight km east of Palo Verde, California. It is divided by a levee that parallels the Colorado River. Revegetation work began on the East Dredge Spoil area in 1977 and on the West Dredge Spoil area in 1978.

Objective: To better understand the feasibility of using revegetation to improve the condition of ecologically-damaged reaches of the Colorado River. This was the Bureau of Reclamation's first revegetation experiment.

Completion Date: 1978

Pre-Project Site Conditions: Russian thistle dominated the site prior to project initiation. Soil survey data indicated that soils on the east side of the site are primarily sands with a thin clay layer situated 1 m to 1.5 m (three to five ft) below the surface. In contrast, soils on the west side of the site are primarily loam, but were covered by .5 m to 3 m of dredge spoil material. Depth to the saturated zone of the soil profile varied from 3 m to 4.5 m (Pinkney 1992).

Project Strategy: In total, approximately 2,000 cottonwood, willow, honey mesquite, and blue palo verde trees and shrubs were planted as 1/2 meter-tall rooted cuttings. A

variety of planting techniques were used. Approximately 125 trees of all species were planted in 20 cm diameter holes augered to a depth of 1.5 m. Numerous trees were also planted in holes 30 cm in diameter and 3 m deep as well as holes 5 cm in diameter and 3 m deep. A drip irrigation system was installed that delivered water at a rate of 15 liters per hour to each planted tree or shrub. All trees were watered with 120 liters per day for at least 150 days.
Results: Dredge Spoil plantings were counted in June 1990. At that time, an additional 150 more cottonwoods had established naturally. Natural recruitment of honey mesquite and palo verde is also occurring (Pinkney 1992). Willow numbers continued to decline since the first inventory was completed. In 1997, there appears to be significant differences in survival rates and overall plant health between plantings on the west side of the levee and those on the east side, with establishment rates and plant vigor on the west side of the levee (adjacent to the agricultural fields) appearing much greater. This was also reported by Pinkney (1992).
Lessons Learned: Particularly in arid climates, providing sufficient water to revegetated plant materials is critical for success. At the Dredge Spoil site, plants adjacent to the agricultural fields have established in greater numbers and appear less stressed than those on the opposite side of the levee. Along the lower Colorado River, planting in areas that are likely to receive agricultural runoff may improve the effectiveness of the revegetation effort. Although more research is needed, results of some riparian revegetation efforts indicate that establishing riparian habitat for avian insectivores adjacent to agricultural land can provide benefits for both wildlife and farmers (Anderson 1984).

Site #5
Farmer's Market Bridge
Location and Size: This project consists of two sites located roughly 200 meters from the Colorado River along a levee that runs parallel to the river due west of Cibola, Arizona. The levee can be accessed via Farmer's Market Bridge road. The southern site is roughly .4 hectares (one acre) and the northern site is roughly .8 hectares (two acres).
Objective: To re-establish native riparian trees.
Completion Date: 1986
Pre-Project Site Conditions: Both sites were void of woody plants prior to project initiation. Soils were generally sandy and depth to saturated soils was estimated to vary between 3 m to 6 m (10 and 20 feet) [beneath the surface of the soil] (John Sweat, pers. comm., 1997).
Project Strategy: A total of 65 willow (*Salix gooddingii*), cottonwood (*Populus fremontii*), and screwbean mesquite (*Prosopis pubescens*) were planted at the two locations. Poles and seedlings were used in the revegetation effort. Plantings were irrigated with a drip system for the first two summers.
Results: Survival of planted species was higher in the north site than in the south site, possibly due to higher water availability. Twenty trees survive on the southern site. Of these, only one willow and six cottonwoods were found and all show obvious signs of water stress (stunted growth, canopy die-back, thick and yellow leaves). In

comparison, mesquite appeared much healthier, averaging roughly 5 m in height with spreading, relatively full canopies.
Lessons Learned: Using plant materials that are adapted to current hydrologic conditions is a key ingredient to success. In particular, evaluating depth to saturated zone prior to planting can provide planners with critical information for selecting plant materials adapted to existing site hydrologic conditions.

Site #6
Three-Finger Lake
Location and Size:. The 50 hectare site is located in the Cibola National Wildlife Refuge on the western side of the river due north of Paymaster Landing.
Objective: To restore Three-Finger Lake to its pre-1970 condition.
Completion Date: To be completed during 1998.
Pre-Project Site Conditions: . Depending on Colorado River flow, the size of Three-Finger Lake historically ranged from eight to 60 hectares (150 acres). In 1970, channelization and realignment of the Cibola Division of the river was completed, diverting waters away from Three-Finger Lake and the old river channel. Saltcedar invaded as the lake dried and wildfires eliminated most of the native vegetation. Today, the site was dominated by a dense monotypic stand of saltcedar.
Project Strategy: Beginning in 1994, approximately 50 hectares (127 acres) of the lake site was dredged to an elevation of 65 m (212 ft). In addition, one fish pond was created for rearing native fish. Native riparian vegetation will be planted around the dredged areas.
Results: [the project is scheduled to be completed during 1998]

Site #7
Imperial Refuge Cottonwood and Willow Revegetation Site
Location and Size: This 15 hectare (six-acre) site lies within the Imperial National Wildlife Refuge, which is located near Martinez Lake, Arizona.
Objective: To re-establish Fremont cottonwood and Goodding willow in an area heavily modified by agriculture pressures and overrun by saltcedar.
Completion Date: 1995
Pre-Project Site Conditions Wheat and rye were once cultivated on this site. Since abandoned, the fields were overrun by saltcedar, arrowweed, and other undesirable species.
Project Strategy: Over 600 cottonwood and willow trees were planted in January of 1995. Prior to planting, exotic plants (mainly saltcedar) were cleared from the site with a bulldozer. Soil salinity investigations were performed to guide the development of the planting design and two piezometers were installed to monitor water table fluctuations. Cleared areas were then disked and leveled, and the site was flood irrigated just before the onset of revegetation. An auger was used to drill to saturated soils, which at the time of planting varied between 1 m to 2.5 m below the soil surface. Holes were spaced six meters (20 feet) apart. Poles collected from the Imperial Wildlife

Refuge's nursery were stripped of leaves and branches, and placed in the ground. The average length of the poles used in the revegetation effort was 4 m and the average diameter at breast height (dbh) was 3.0 cm. Following planting, the site was flooded monthly and plants received two liquid fertilizer applications during the growing season. In 1996 and 1997, the frequency with which the planted area was flood irrigated was increased to bi-monthly.
Results:. All of the cottonwoods that were planted have survived to date (see cover photograph). However, by 1997, about 90% of the willows have died. The high mortality rate is believed to be due to localized soil salinity problems.
Lessons Learned: As revegetating with native riparian plants often requires significant irrigation inputs (particularly during the first three summers), having control of the land and the water rights that go with the land is often critical to success. Flood irrigation may help to remove salts from soils to the point tolerated by at least some native riparian plants. In addition, future revegetation efforts of this magnitude may benefit if portions of the site are selectively harvested for plant materials. Such a strategy would create a multiple-age stand of trees whose greater structural complexity may benefit bird and other wildlife species (Steve Hill, pers. comm., 1997).

Site #8

Mittry Lake

Location and Size: The 23-hectares (57-acre) Mittry Lake revegetation site is located on the Arizona side of the Colorado River roughly 24 km north of Yuma. The Mittry Lake Wildlife area borders the revegetation site to the west and the Gila Gravity Main Canal is immediately to the east.
Objective: To enhance habitat for wildlife
Completion Date: April 1986
Pre-Project Conditions: Vegetation found on site prior to project initiation consisted mainly of sparse desertscrub on high elevated areas and mixed riparian vegetation along several of the washes on the site's southern end. Soil types were found to be highly variable, ranging from large rocks to silts and clays. Water table depths were estimated at two to four meters (six to 14 feet) beneath soil surface (Pinkney 1992).
Project Strategy: Six revegetation zones were established on the lake site between March and April 1986. Each of the zones was fenced and tree planting holes were augered to saturated soil (2 m to 4 m deep) using an 38 cm (18-inch) diameter auger. Holes for shrubs were augered 2 m deep using a 19 cm auger. Planting began in March 1986 and was completed in April 1986. All trees and wolfberry shrubs were grown in four liter cans; quailbush plants were grown in small biodegradable containers. All trees and shrubs were irrigated using a drip system and wire baskets were used to protect plants from wildlife damage. Irrigation rates varied with revegetation zone, but all plants generally received water each day for the first 30 days, at a rate of 64 liters per day for trees and 11 liters per day for shrubs (Pinkney 1992).
Results: At the end of the 1988 growing season, only a few cottonwoods were taller than four meters. Of the vegetation planted, willows appeared to have the slowest growth rates, possibly due to water stress and damage from deer browsing. Estimates of water table depths in 1988 indicated that depths were much greater than the two to

four meters initially estimated. The largest of the planted trees were those taking advantage of water leaking from a canal just up hill from the revegetation site. Even though wire baskets were used, rabbits and deer still managed to damage significant numbers of planted vegetation. After the third growing season, honey mesquites not significantly damaged by rabbits were roughly three meters (10 feet) tall. By 1988, some honey mesquites were larger than the planted cottonwoods. Most screwbean mesquites also grew well and were about 1.5 meters tall after two years of growth. Palo verde growth rates were generally slower than that of mesquite. Quailbush grew rapidly and by the third growing season, some were over one meter tall and producing seed. However, rabbit damage to the lower branches outside of the protective baskets was common. Wolfberry (*Lycium* spp.) appeared to be stressed during the early portion of the first growing season but seemed to grow better during the fall months. In heavy textured saline soils, *Lycium torreyi* appeared to be more vigorous than *Lycium andersonii* (Pinkney 1992).
Lessons Learned: Planting riparian trees adjacent to areas where they may receive supplemental water (however artificially) can be the difference between success and failure. Using plants that are adapted to the site's current ecological condition (rather than basing plant material selection solely on what was on site prior to disturbance) can greatly improve revegetation effectiveness. Results also underscore the need for further research describing the salt and water tolerances of non-agricultural plant species.

Site #9
Fortuna Fish Pond
Location and Size: This 3.2-hectare (eight-acre) revegetation site surrounds the Fortuna Fish Pond, is located about 16 km east of Yuma, Arizona at the confluence of the Gila River and Fortuna Wash.
Objective: To mitigation for impacts from the construction of the Yuma desalinization plant.
Completion Date: Spring of 1985
Pre-Project Site Conditions: Saltcedar (*Tamarix chinensis*), arrowweed (*Pluchea sericea*), and creosote bush (*Larrea tridentata*) were the dominant woody species found on the site prior to project initiation. Soil survey indicated generally sandy soils with a 15 cm thick clay layer found approximately 1.2 meters beneath the soil surface on the western portion of the site. Depth to saturated soils was estimated to be less than three meters (10 feet). However, soil moisture readings indicated that there was a significant difference in water availability above and below the clay layer (25 percent and 3 percent, respectively) (Pinkney 1992).
Project Strategy: Approximately 300 cottonwood, willow, and mesquite seedlings (grown in four-liter containers) were planted in pre-augered holes around the periphery of Fortuna Pond during the spring of 1985. In November 1986, approximately 100 cottonwood and willow cuttings and poles were also planted. The cuttings were planted in saturated soils around the edge of the pond; no holes were augered for the cuttings. The poles were 2.5 to three meters long and were planted in 5

cm-diameter holes augered to about one meter deep. Most of the plants were protected initially with one-meter tall chicken wire baskets. In 1986, 1.5-meter tall, welded wire baskets were placed around some plants to protect against beaver damage (Pinkney 1992). Plants were irrigated each day in 1985 from planting to September. Afterwards, irrigation was cut off until May 1986 when the trees began to appear stressed. Daily watering at the same rate began and continued to September 1986. After September, the rate was decreased to roughly ten liters per day.

Results: Two years following the completion of the revegetation work, approximately 30 percent of the trees had died. In 1988, more than 70 percent of the cottonwoods and willows along the edge of the pond were over three meters tall; some of the trees along the outlet channel and the edge of the pond were six meters tall or more. By 1997, many of the trees were over 10 m (35 ft) tall and appeared to be growing vigorously.

Lessons Learned: Results underscore the need to clarify project objectives. In this case, it is difficult to evaluate whether revegetation results actually mitigated for disturbances caused by the construction of the de-salinization plant. Without additional detail put into developing the objective further, such a determination is difficult if not impossible to answer.

Site #10

Colorado River-Gila River Confluence

Location and Size: This is a naturally vegetated site at the confluence of the Colorado and Gila Rivers, just downstream from Prison Hill in Yuma, Arizona. The site is situated along four kilometers of the West Main Colorado River canal and encompasses over 80 hectares (200 acres).

Ecological Characteristics: Most of the vegetation here appears to have come up following the high magnitude flows of 1993 and 1994, although large cottonwood trees along the southern portion of the site probably came up following the floods of 1983. Further work is required to develop a detailed description of this site's current ecological characteristics and the degree that is has changed since 1983. Nevertheless, it is apparent that significant natural regeneration took place and contains an extensive riparian forest that consists of such native species as Fremont cottonwood, Goodding Willow, mesquite, seep willow (*Baccharis glutinosa*), and cattail.

*Conservation Challenges**** : Taking advantage of nature's efficacy by allocating waters to wetland plant communities that develop following large flow events could be an effective way of maintaining significant wetland habitat along the river. As is the case throughout much of the lower Colorado River, however, acquiring water of sufficient quantity and quality for maintaining such critical native wetland habitat is one of the critical conservation challenges.

Recommendation: Additional areas that contain significant desirable riparian habitat need to be identified for possible protection. Even if such areas cannot be protected, there may be some strategies (e.g., reducing vehicular traffic, changing livestock management) that could go a long way in increasing the value of habitat to wildlife.

*** The categories "Conservation Challenges" and "Recommendation" are used for sites where no artificial revegetation or recovery work was preformed.

Site #11
Río Hardy Wetlands
Location and Size: The Río Hardy wetlands are in the Colorado River delta on one of the western most branches of the river (Fig. 2).
Ecological Characteristics: Flow into the Río Hardy comes principally from agricultural runoff and geothermal wells discharged into the channel (Payne et al. 1992). A potential third source is backflow from the mainstem of the Colorado River during times of high flow. The Río Hardy wetlands are dominated by halophytic plants such as iodine-bush (*Allenrolfea occidentalis*), quail-brush (*Atriplex lentiformis*), and *Salicornia verginica.* Ground cover includes saltgrass and alkali weed; and less salt-tolerant plants such as arrowweed (*Pluchea sericea*) and desert broom (*Baccharis emoryi*).
Conservation Challenges: The vegetation of this area has changed significantly since the turn of the century. As described by McDougal (1904), this area was dominated to the north by a riparian forest of cottonwoods (*Populus fremontii*) and willow (*Salix gooddingii*) with an extensive tidal-influenced plain of saltgrass (*Distichlis spicata*) at its southern end. In between there were scattered mesquite trees (*Prosopis* spp.) and saltbushes (Atriplex spp.). Today, the riparian forest is no longer present and the wetland is dominated for the most part by halophytic plants (Glenn et al. 1996). From at least 1977 to 1983 the Río Hardy wetlands were maintained by ponded waters behind a natural dam (Glenn, pers. comm. 1997). The destruction of the dam during high flow events of 1983 has caused the wetlands to drain and generally decline (Payne et al. 1992), although large flows during 1992 and 1993 caused the wetland area to increase from a low of 1,175 hectares in 1988 to 24,000 hectares in 1993 (Glenn et al. 1996).
Recommendation: The earthen dam that was destroyed by the floods of 1983 needs to be re-constructed. Such a strategy is relatively simple and inexpensive, yet could significantly increase the current area occupied by the Río Hardy wetlands (Payne et al. 1992). Indeed, the Cocopah people have already initiated construction of a replacement dam close to where the original dam was located (Edward Glenn, pers. comm., 1997).

Site #12
Ciénaga de Santa Clara
Location and Size: The cienaga is located on the eastern side of the delta and covers roughly 20,000 hectares, with 4,500 hectares thickly vegetated (Fig. 3).
Ecological Characteristics: In total there are 22 wetland plants in and along the periphery of the cienaga. The main portion of the cienaga is dominated by *T. domengensis* and at least eight other hydrophytes (Glenn et al. 1996). It is supported principally by agricultural runoff from the Wellton-Mohawk canal, with lesser inputs from the Riito Drain.
Conservation Challenges: The principal conservation challenge facing the cienaga is the possibility that the Wellton-Mohawk canal will be turned off. The Wellton-Mohawk canal was planned as a temporary answer for agricultural wastewater deposition until the de-salinization plant went on line. Although the Santa Clara system is also

supported by waters emanating from the Riito Drain, flow in the Wellton-Mohawk can is much greater and therefore more crucial. If this source of water is indeed turned off, a significant portion of the cienaga will be compromised. In addition, the cienaga faces challenges from the invasion of exotic plants and increasing high levels of salinity. *Recommendation:* The U.S. Department of the Interior needs to make a long-term commitment to providing Wellton-Mohawk waters to the cienaga. There should also be consideration to directing more "wastewater" (flood water, effluent, and agricultural runoff) into the delta. For example, wastewaters that currently flow from Mexicali Valley to the Salton Sea and Laguna Salada could instead be directed to the delta.

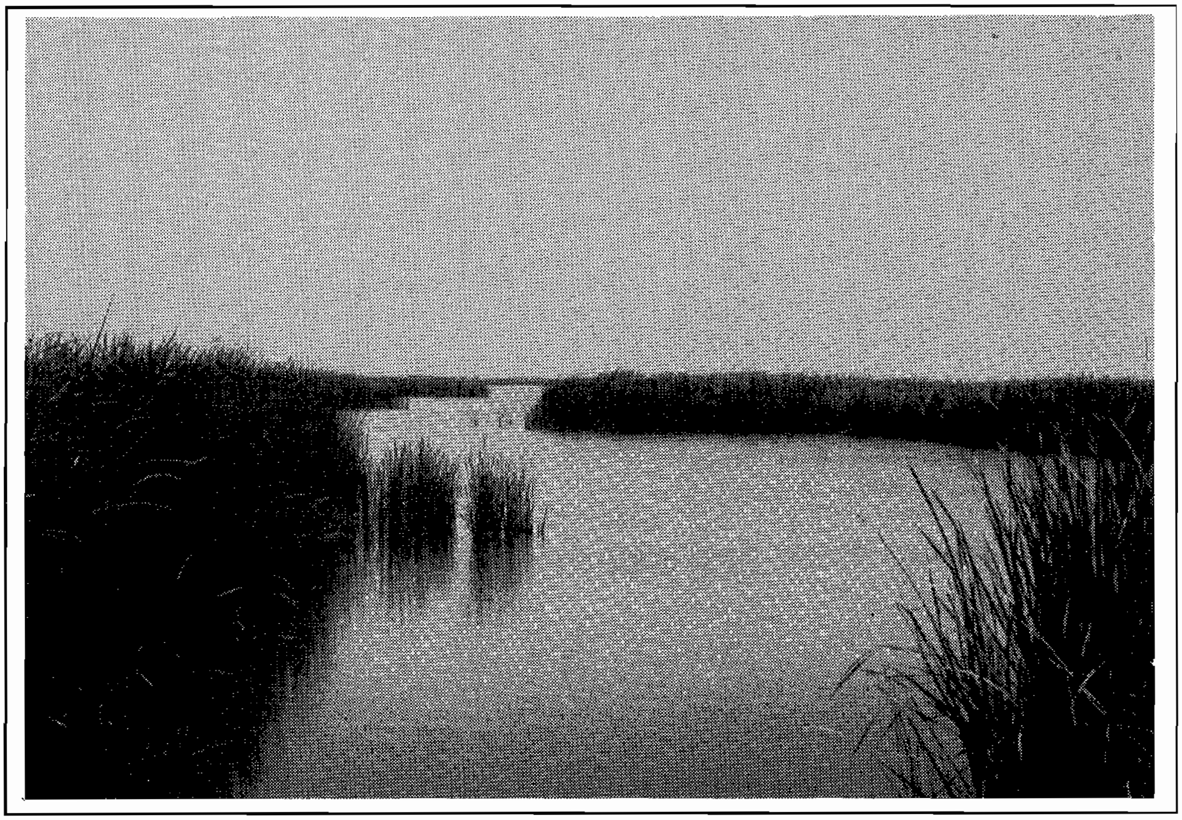

Figure 3. The Ciénaga de Santa Clara covers nearly 20,000 ha and provides critical habitat for a variety of wildlife species, including several species that are listed as endangered.

OBSERVATIONS AND RECOMMENDATIONS

The ecological condition of the lower Colorado River has deteriorated significantly over the last 65 years. The cottonwood-willow forests that once dominated the mainstem and the delta have been reduced to isolated stands and individual trees. The immense marshlands of the delta region are only shadows of their former selves, with significant portions being tenuously maintained via a system of agricultural runoff canals. From an ecological standpoint, the loss of these wetland ecosystems is probably one of the major environmental issues facing both the U.S. and México today.

River impoundment, the diversion of river waters for farms and cities, and agricultural activities are the principal causes for the dramatic decline of the river's ecological condition. The challenges to bringing the river back to some healthy state are monumental, requiring comprehensive solutions that address the underlying causes of ecologic decline. Providing water specifically for ecological improvement, altering dam releases to promote natural regeneration, conserving water throughout the river's watershed, and addressing water allocation issues are just some of the regional challenges that will need to be addressed before significant headway can be made in improving the river's overall ecological condition.

Since the lower Colorado River is rapidly approaching the point where every drop of river water is spoken for, it will be necessary to "find" the water to meet the environmental needs of the basin. Given, given the current socio-political and economic landscape of the Colorado River, however, it is likely that years of negotiation may be required before some of these long-term strategies can be implemented. In the meantime, it is reasonable to look for less politically charged strategies that can bring immediate, though more local, benefits to the river's ecological condition. Such strategies include improving the effectiveness of recovery efforts, maintaining existing critical natural areas, and purchasing marginal agricultural land to re-establish native wetland ecosystems.

The recommendations or strategies that are presented below run the gamut between policy recommendations (strategies that would require some kind of policy change before they could be implemented) and restoration/protection recommendations (strategies that focus on improving the effectiveness of wetland restoration and protection efforts). As some of restoration and protection recommendations (e.g., improving the effectiveness of riparian revegetation efforts) do not require major changes in the socio-political landscape, they could potentially be implemented on a much tighter time frame than recommendations which are purely policy orientated. However, other restoration and protection recommendations (e.g., augmenting agricultural return flows to the Río Hardy wetlands) would require a change in policy before they could be carried out.

1. Improve the Effectiveness of Colorado River Recovery Efforts

Evaluating the results of past recovery efforts along the Colorado River provides a wealth of information regarding how to improve the effectiveness of similar efforts. Some of the principal lessons drawn from these past recovery experiences are described below. They are general in nature and focus more on planting strategies that can be applied on a regional basis than site specific planting techniques or issues.

Develop project objectives that are clear and specific.
One of the threads that often runs through restoration efforts of all sizes and shapes is the lack of attention paid to developing clear and concise project objectives. Ill-defined project objectives can create cracks in the very foundation of the project, often reducing its overall effectiveness. The personnel that become involved in the restoration effort, the strategies that are ultimately employed, the time frame for project completion, the project budget, and evaluation of the effectiveness of the effort all hinge on the objective of the project (Briggs 1996).

The objectives of the recovery efforts evaluated in this investigation varied considerably. Some projects, like the No Name Lake revegetation effort, were done to mitigate for disturbances in other areas. Other efforts, like the Mittry Lake revegetation effort, were completed to enhance habitat for wildlife.

Developing project objectives with greater detail would significantly benefit future recovery efforts. The objective of the Mittry Lake revegetation effort (to improve habitat for wildlife), for example, would be much improved by a description of the wildlife species that the created habitat was designed to benefit. Such a explicit objective would allow project managers to see a clear endpoint and develop recovery strategies that are geared toward establishing a relatively specific type of environment.

Depending on the detail required, project objectives could then go as far as describing the plant density, diversity, and vertical complexity that needs to be created before a project is deemed successful. Such detail will greatly aid in determining project success and the need for future efforts.

Consider using recovery strategies other than revegetation
The Bureau of Reclamation, Bureau of Land Management, Fish and Wildlife Service, and others have used revegetation strategies extensively along the lower Colorado River to re-establish native riparian plants. Despite some notable revegetation successes, it is obvious that the results of these artificial-planting efforts pale in comparison to nature's own regenerative capabilities. Comparing the natural regeneration that was experienced at the confluence of the Colorado and Gila Rivers following the 1983 and 1993 floods to the results of artificial revegetation efforts underscores the need to create opportunities for more cost-effective and significant impacts through natural regeneration strategies. Such comparisons may be unfair, but they nevertheless highlight the need to evaluate the recovery strategies that are being implemented along the lower Colorado River to determine whether the money that is being spent is having the desired effects.

Revegetation is often limited in its effectiveness because it often does not address the causes of ecological deterioration (Briggs 1996). Essentially, the goal of revegetation is to replace lost plants. If the root causes for the loss are not adequately addressed or are not well understood, it is very likely that artificially-planted materials will meet the same demise as those that they are trying to replace. Most successful revegetation efforts are implemented in concert with strategies that address the reasons behind the ecological damage that has occurred (Briggs 1996).

The question that needs to be answered is whether the money, time, and energy that is being spent on revegetation can be better directed on implementing other types of recovery or maintenance strategies? To answer this important question, it is imperative that river managers assess a range of recovery options and attempt to tie specific strategies to the unique characteristics of specific reaches of the river.

Base recovery strategies on a thorough evaluation of site ecological conditions
Generally, successful recovery efforts are based on a sound understanding of the site's current ecological condition. Depth to saturated soils, soil salinity concentrations, presence of exotic plants, and intensity of use by recreationists and livestock are just some of the factors that need to be evaluated to develop a sound site recovery plan (Briggs 1996). Such information is also critical for developing realistic project objectives.

Use plant materials that are adapted to current site ecologic conditions
Revegetation planners often attempt to re-establish plants that were present prior to disturbance even though they may no longer be adapted to the site's current hydrologic condition. Depth to the saturated soils in some areas along the lower Colorado River has increased significantly, making it difficult to establish many obligate riparian species as cottonwoods and willows. This has often led to low establishment rates of planted vegetation.

The Farmer's Market Bridge (site #5) revegetation site, underscores this point nicely. As the depth to saturated soils at this site are significant, all of the cottonwoods and willows that were planted either died or suffer from water stress, while the majority of the mesquite that were planted have survived and appear healthy (Fig. 4). In similar situations in the future, using species such as mesquite, quail bush, or saltbush that are native to the region yet are better able to survive in the changed hydrologic environment (or more saline conditions) will probably significantly increase the effectiveness of the revegetation effort.

Take advantage of agricultural return flows or runoff
Results experienced at Dredge Spoil Site (Site #4) and No Name Lake (Site #2) demonstrate the validity of planting vegetation in areas that are likely to experience significant agricultural runoff. Both sites receive runoff from adjacent agricultural fields during the hot, dry summer months. This seems to have had a remarkable effect on survival and growth rates of planted trees. At the Dredge Spoils site, for example, the riparian vegetation planted on the levee side immediately adjacent to the

agricultural fields appear much healthier and seem to have experienced greater growth rates those on the opposite side of the levee.

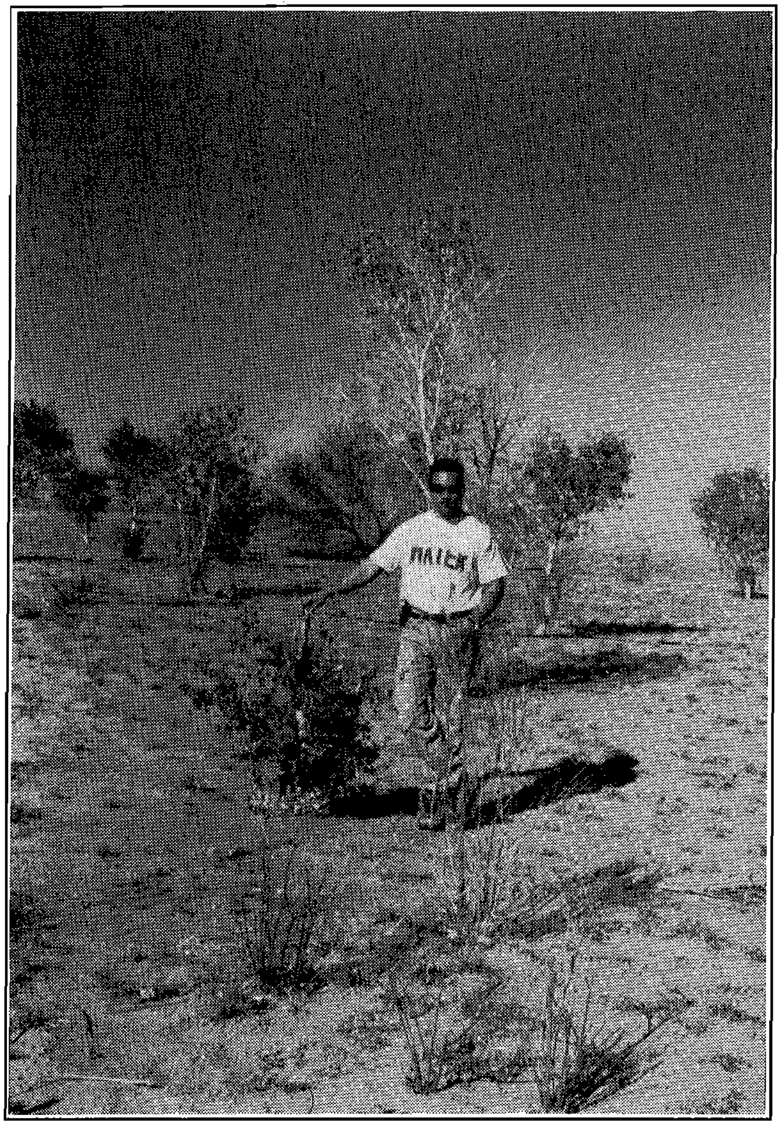

Figure 4. Eleven-year old-cottonwoods planted at the Farmer's Market Bridge revegetation site show obvious signs of water stress.

Future revegetation efforts should take advantage of similar opportunities. Moreover, it has been noted that establishing native, riparian plants immediately adjacent to farmland can provide useful habitat for a variety of avian species, helping to compensate for avian habitat loss in other areas (Anderson et al. 1988).

Take advantage of sites that are inherently more mesic

Old river meanders and other low elevation topographic features can be characterized by relatively high water availability. Such areas can offer ideal conditions for the re-establishment of native, obligate riparian plants and should be considered for future revegetation efforts. At the No Name Lake site (site #1), the only obligate riparian trees to establish and grow were those planted in the relatively low elevation of the lake's depression.

Develop recovery projects with a long-term outlook

All too often recovery efforts fail simply because there was no technical expertise or funding available following project completion. By its very nature, restoration has a long-term time frame. Success is therefore measured over a protracted time period, requiring a institutional capacities and a political will that need to persist well beyond the completion of the recovery effort. At the very least, the design of the recovery effort needs to include funding and personnel for maintaining irrigation systems and fences, controlling exotic plants, replacing lost plant materials, and monitoring results for three years following project completion (monitoring should continue over a longer time frame).

2. Identify and Protect Existing Wetland Ecosystems

In both the delta and the lower reaches of the Colorado River there remains significant areas occupied by native, wetland habitat. The cottonwood-willow riparian forest at the confluence of the Gila and Colorado Rivers, the Cienaga de Santa Clara, and the marshlands of the Río Hardy are examples. Whether these areas were created naturally or artificially, with intent or completely by accident, their protection should be a clear short-term priority for lower Colorado River conservation efforts. Additional existing natural areas should be identified and plans to maintain or enhance their ecological condition should be developed.

The Ciénaga de Santa Clara

The Ciénaga de Santa Clara exemplifies this priority. The cienaga is maintained for the most part by drainage flow from Arizona's Wellton-Mohawk canal. Since the canal's completion in 1978, the cienaga has grown from 200 hectares (estimated in 1973) to about 20,000 hectares (Glenn et al. 1996). As noted above, this cienaga offers habitat for many wildlife species, including probably the largest populations of the endangered Yuma clapper rails (Eddleman 1989; Abarca et al. 1993) and Sonoran desert pupfish (Hendrickson and Verela 1989; Abarca et al. 1993). If the Yuma desalting plant begins operation and the Wellton-Mohawk waters are diverted to irrigation districts in Mexacali, the largest remaining wetland in the region will be significantly compromised (Glenn et al. 1996; Zengel et al. 1995). Conservation efforts need to focus on ways to maintain flow into the Cienaga. If the desalting plant does go on line, other sources of water need to be found to make up for that lost to plant operations. Such alternative waters could be found by allocating Colorado River water for ecosystem maintenance or diverting agricultural return flows from México southward.

Río Hardy Wetlands

The Río Hardy wetlands have experienced growth and decline over the past 50 years. During the period of 1947 to 1983, the wetlands of the Río Hardy were maintained by water impounded behind an natural bar that existed roughly 35 km from the mouth of the Colorado River (Payne et al. 1992). However, the bar was destroyed by the high flows of 1983 and the resulting drainage reduced the size of the wetlands from 63,000 ha in 1983 to 1,175 ha in 1988. High flows during 1992, however, have increased the wetlands to 24,000 ha, but this increase is likely temporary if some type of impoundment structure is not re-created (Glenn et al. 1996).

Conservation/recovery efforts in the near future should focus on augmenting agricultural return flows to the Río Hardy wetlands and preventing waters from escaping once they reach the wetlands. Ducks Unlimited engineers have recommended repairing the natural dam that was destroyed by the flooding of 1983 (Payne et al. 1992). This strategy would probably reduce drainage from the Río Hardy wetlands and help to restore at least a portion of the former wetland area. Conducting a feasibility study of this and similar strategies to maximize the environmental use of waters entering these wetland areas should be a priority.

The Colorado-Gila River Confluence
The cottonwood-willow riparian forest at the confluence of the Colorado and Gila Rivers is a product of natural riparian regeneration following the high flows of 1983 and 1993. The expanse of this area demonstrates the often dramatic resiliency of these wetland systems. Such natural regeneration also represents an important restoration/conservation opportunity. As in this case, nature has done the majority of the ecological improvement work. Flooding has re-worked alluvial sediments to create ideal seedbed conditions for riparian plants; and nearby riparian plants have disseminated seed.

Future priorities should include identifying similar natural areas throughout the basin and developing plans for their protection. As is the issue throughout the lower Colorado River, "finding" the water required to maintain these areas is the key challenge. In addition, other issues, such as vehicular traffic, development pressures, water pollution, etc., may need to be addressed if the Gila-Colorado River riparian ecosystem and other similar areas are to remain viable in the future.

3. Appropriate Water Resources for Restoration
Restoration cannot happen unless water is allocated specifically for that purpose. Unfortunately, the 1922 Colorado River Compact does not dedicate waters to maintain healthy wetland/aquatic ecosystems. The same is true for international treaties between the U.S. and México which contain no language on environmental considerations. Yet, it is highly likely that all of the legally allocated water will be used for human consumptive uses in the near future by the seven basin states and México. Simply put, water management and planning does not consider aquatic ecosystems. The fact that Colorado River water is almost completely exhausted before it reaches the delta underscores this point. It is therefore critical to change traditional water policies that currently focus solely on human consumptive needs so that they reflect a more sustainable management of the river's waters.

Morrison et al. (1996) pointed out that one of the major obstacles in the way of gaining water allocation for restoration is the lack of scientific information that quantifies the amount of water needed for some degree of wetland restoration. Essentially, restoration allocations will probably not be made until there is a better understanding of the benefits that the water is likely to bring.

4. Expand Revegetation Efforts in the National Wildlife Refuges
Some of the most extensive (at least in terms of the area covered) riparian revegetation efforts along the lower Colorado River have been experienced in the Imperial and Cibola National Wildlife Refuges. In general, such protected areas offer great potential for revegetation because the land and the water is under the direct control of the

managers and they therefore may be able to better manipulate recovery strategies to fit site specific conditions At the Imperial Wildlife Reserve, for example, revegetation efforts have established cottonwoods, mesquites, willows, and other species on hundreds of acres of land. Moreover, the refuge has have been able to do this without infringing upon the water rights of others. In addition, there is room to accomplish more as less than half of Imperial's 27 million cubic meters (22,000 acre-ft) consumptive use allocation is being used (Ellis, pers. comm., 1997). In a sense, riparian revegetation has become a farming operation where cottonwoods and willows are the crop of choice instead of alfalfa (John Swett, pers. comm., 1997). Yet, such efforts can create significant riparian habitat in areas where such habitat has just about disappeared." Providing funds to expand such efforts in these and other protected areas could significantly increase the amount of native riparian habitat found along the lower Colorado River.

5. Develop a Concerted Binational Effort for Restoring the Delta

Since México has legal entitlements to less than 10 percent of the river's annual flow, it is unfair and unrealistic to assume that México should take sole responsibility for restoring the delta. A binational effort that provides the framework for a variety of cooperative cross-border ventures is critical for the future of the delta (Morrison et al. 1996). Given the disproportionate Colorado River allocations between the two countries, water and restoration assistance should be provided to México from the U.S. In addition, it should be noted that U.S. interests will probably benefit from the recreational qualities that a restored delta will bring. Birding, camping, kayaking, and other non-consumptive uses could expand tremendously in a restored delta region, bringing significant economic benefits to local communities and to tourism interests in both México and the U.S.

6. Develop and Implement Community-Based Conservation Approaches

Over 23 million people have a direct stake in the current and future use of lower Colorado River water (Morrison et al. 1996). The great majority of these users live far from the river and are interested in it principally as a water source. Through state and federal channels, their voices can be heard regarding a variety of river-related issues (e.g., allocation, water quality, etc.). Riverside communities have an even larger stake in the river's health by virtue of the real and potential economic, social, and environmental values it provides. They may not have, however, the appropriate opportunity for input into decisions that affect their lives even more directly than those living afar. Bringing communities together and providing a forum to discuss common problems and identify concrete ways they can engage each other and the water and land managers, in focused action can be mutually beneficial to both the river and neighboring towns and communities. Gatherings of local stake holders from both sides of the border to discuss the sustainable use of Colorado River water has been initiated and will continue to expand (Nagel, pers. comm., 1997).

A regional economic study by the Sonoran Institute in 1996 identified nature-based tourism as a priority option for building a firmer sustainable business environment and local economic opportunity in the Sonoran Desert borderlands, including the lower Colorado River and delta region. A steering committee has formed and is in the process of developing a business plan for a regionally based Ecotourism Association. This initiative seeks to sensitize local communities to the opportunities and obligations associated with designing and carrying out a campaign to highlight the natural and cultural attractions of the region. Prime destinations for community-based and environmentally beneficial tourism exist along much of the lower Colorado River. This opportunity has been developed most extensively in the Reserva de la Biosfera Alto Golfo y Delta del Rio Colorado where Conservation International-Mexico and SEMARNAP/INE have collaborated in promoting the Cienaga Santa Clara as a destination and carrying out nature guide training for the neighboring Ejido Luis Johnson (Fig. 5). Other opportunities may exist in association with the Imperial, Cibola and Bill Williams National Wildlife Refuges, and the Rio Hardy in Baja California. The goal of this and other community-based resource management efforts (such as sustainable consumptive use of wild species) is to create appreciation for the spiritual, cultural, and economic benefits provided by adjacent natural areas, and design incentives for residents to become actively engaged in their conservation. This approach generally is accomplished by providing opportunities for neighboring communities and land owners to participate meaningfully in decision-making processes that concern the land and water they are fortunate to live next to, and by structuring management policies so that financial benefits are accrued by communities that accept a resource conservation obligation.

7. Create Zones of Protection

Providing increased levels of protection can help to maintain critical wetland areas in the long-term. The Cienega de Santa Clara is part of the much larger Reserva de la Biosfera Alto Gulfo de California y Delta del Río Colorado. This protected area was established by the Mexican Government in 1993 to conserve the ecosystems of the Sonoran Desert, upper Gulf and the delta, and to provide and protect fishing and tourism activities. This international reserve is recognized by UNESCO and offers significant protection to core ecosystems. Future Colorado River conservation efforts need to focus on protecting additional native wetland habitats. Even just curbing human activities in areas identied as having significant natural habitat could generate significant gains for wildlife. For example, unrestricted vehicular traffic can significantly reduce the use of marshland and open water areas by waterfowl (Anderson and Ohmart 1988). Closing off or reducing traffic to such critical marshland areas is one way to improve the utility of available habitat to wild species.

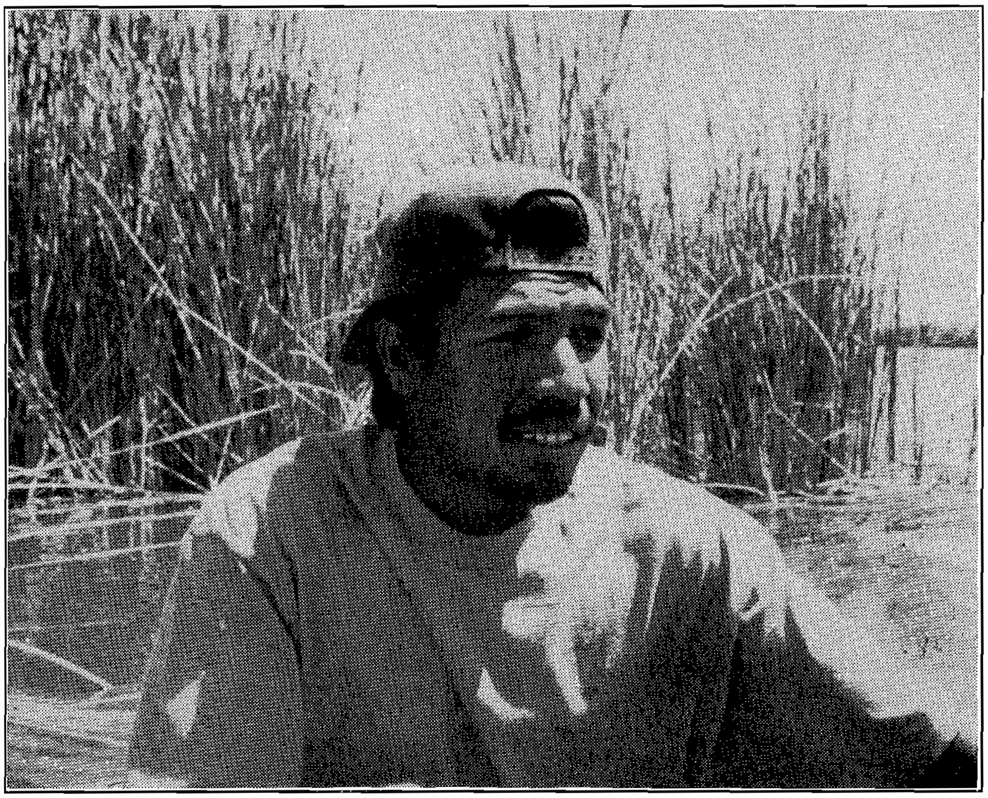

Figure 5. As part of a management course conducted by the Reserva de la Biosfera Alto Golfo y Delta del Rio Colorado, members of the Ejido Johnson were trained as Ciénaga de Santa Clara guides. Such programs can strengthen links between local communities and the conservation of critical wetland ecosystems.

8. Modify Reservoir Operations and Water Use Practices

Altering dam releases to enhance or maintain the Colorado River's wetland habitat needs to be a future priority. The successful completion of the 1996 test flow or "flood" from Glen Canyon Dam to restore river beaches may set the stage for further manipulations of dam releases for environmental purposes. If such artificially-produced floods can remove sand and silt out of reservoir storage to downstream sites, a variety of objectives could be accomplished. Depositional bars can be created to enhance natural propagation of native riparian plant species and backwater breeding areas for many native fish can also be created immediately downstream of newly-formed depositional bars.

Performing such releases for environmental purposes may be more likely than before as flood water management along the lower Colorado River in the last decade is changing because Lake Powell behind Glenn Canyon Dam has filled to near capacity. This means that flood flows will probably pass through Glen Canyon Dam much more frequently, significantly increasing the amount of water brought into the lower reaches of the river and the delta (Payne et al. 1992; Glenn et al. 1996). If this scenario is accurate, a variety of restoration/conservation opportunities may exist that were not possible before.

9. Resolve Other Water-Related Issues

Along the lower Colorado River and in the delta there seem to be numerous areas that are ecologically damaged due, at least in part, to water-related issues that are not directly associated with reservoir management and water allocation. These "other" water-related issues include addressing groundwater over-pumping, water pollution, and improving water conservation measures (Morrison et al. 1996). In comparison to altering dam releases or allocating water for environmental purposes, tackling some of these issues may be an effective way of realizing short-term ecological improvements. Implementing water conservation measures to reduce groundwater pumping in areas such as Mexicali, Blythe, and Yuma could reduce drawdown of nearby wetlands.

10. Use Wastewaters More Effectively

The river has approached the point of full utilization where essentially every drop of water that passes through is spoken for. Therefore, obtaining significant amounts of water specifically for wetland enhancement will become increasingly difficult. On the other hand, the amount of wastewater - agricultural drainage and municipal effluent - is growing significantly. Although this water cannot be used for human use, it is well-suited for maintaining wetland vegetation (Glenn et al. 1997). Already a significant amount of the brackish wetlands in the delta are almost completely sustained by "unusable" agricultural runoff. A priority of future wetland conservation efforts should be to develop strategies for using wastewaters more effectively. Indeed, at a meeting between the heads of water management agencies of the U.S. and México, scientists, agricultural, municipal, and environmental representatives suggest that the improved management of wastewaters could reestablish up to 40,500 hectares (100,000 acres) of wetland habitat in the delta (Glenn et al. 1997).

Although the volume of municipal sewage effluent produced each year is much smaller than that produced from agriculture runoff, it is likely to increase with expanding urbanization. Depending on the quality of the effluent, some may also be suitable for maintaining wetlands. Moreover, certain wetland areas could be developed specifically to help clean municipal wastewaters, thus providing the dual benefit of wetland habitat creation and contaminated water filtration. Of course, safe guards would have to be developed so that wetlands do not become inexpensive disposal zones for raw sewage.

Conclusion

Due to a variety of human-related impacts, much of the lower Colorado River native wetland ecosystem is damaged or has disappeared completely. Only remnants remain of the magnificent riparian cottonwood-willow forests that once graced significant reaches of the lower Colorado River. In the delta, the majority of the remaining marshlands are maintained via tenuous associations with agricultural runoff canals. As ecological conditions along the lower Colorado River deteriorated, so to has the well-being of the people and wildlife that depend on the river for their survival. During the height of their dominion, the population of the Cocopah, the original river people, exceeded 20,000. Today, scattered communities consisting of a few hundred individuals remain, located for the most part on the backwaters of the Río Hardy, and near San Luis and Summerton, Arizona. Wildlife species such as the totoaba (a fish species cherished by the Cocopah), the vaquita porpoise, desert pupfish, and the Yuma clapper rail, all of which once thrived in the delta's ecosystem, are listed as endangered under the U.S. Endangered Species Act.

From an ecological and conservation perspective, the situation along the lower Colorado River has reached a critical juncture. To make significant progress in repairing the ecological condition of the river, it is imperative to address difficult and politically-charged bi-national policy issues such as groundwater drawdown, water allocation, and dam releases. Of these, altering dam releases may provide the greatest opportunity for broad ecological recovery of native wetland ecosystems. A significant reason for the ecological decline of these ecosystems is river impoundment; manipulating dam releases to mimic natural flow patterns would directly address this problem and probably promote natural regeneration of native wetland plant species as long as sufficient natural seed sources remain.

Some of these strategies may require years of negotiations and planning, however, before they can be implemented. This underscores the need to look for creative solutions that can be carried out more rapidly. Strategies such as using wastewaters for environmental purposes; developing plans to protect critical refugees of native species (e.g., cottonwood/willow forest at the confluence of the Colorado and Gila Rivers); improving the effectiveness of wetland revegetation techniques, increasing areas protected by state and/or federal agreements; and using community-based conservation approaches would have dramatic, albeit local, effects on enhancing or maintaining the ecological condition of the lower Colorado River.

Of these approaches, immediate attention should be given to using agricultural runoff and municipal effluent for environmental purposes. Currently, some of these so-called wastewaters drain north and are squandered in the closed Salton Sea basin. Working with the communities that line the Colorado River should be another top priority. Such community-based conservation approaches could have the dual benefit of bringing ecological relief to the river and economic and/or health benefits to riverside residents . As they directly involve riverside peoples, community-based approaches also have long-term staying power - a critical element in the success of any conservation/restoration effort.

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