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RIPARIAN ECOSYSTEM CREATION AND RESTORATION: A LITERATURE SUMMARY

by

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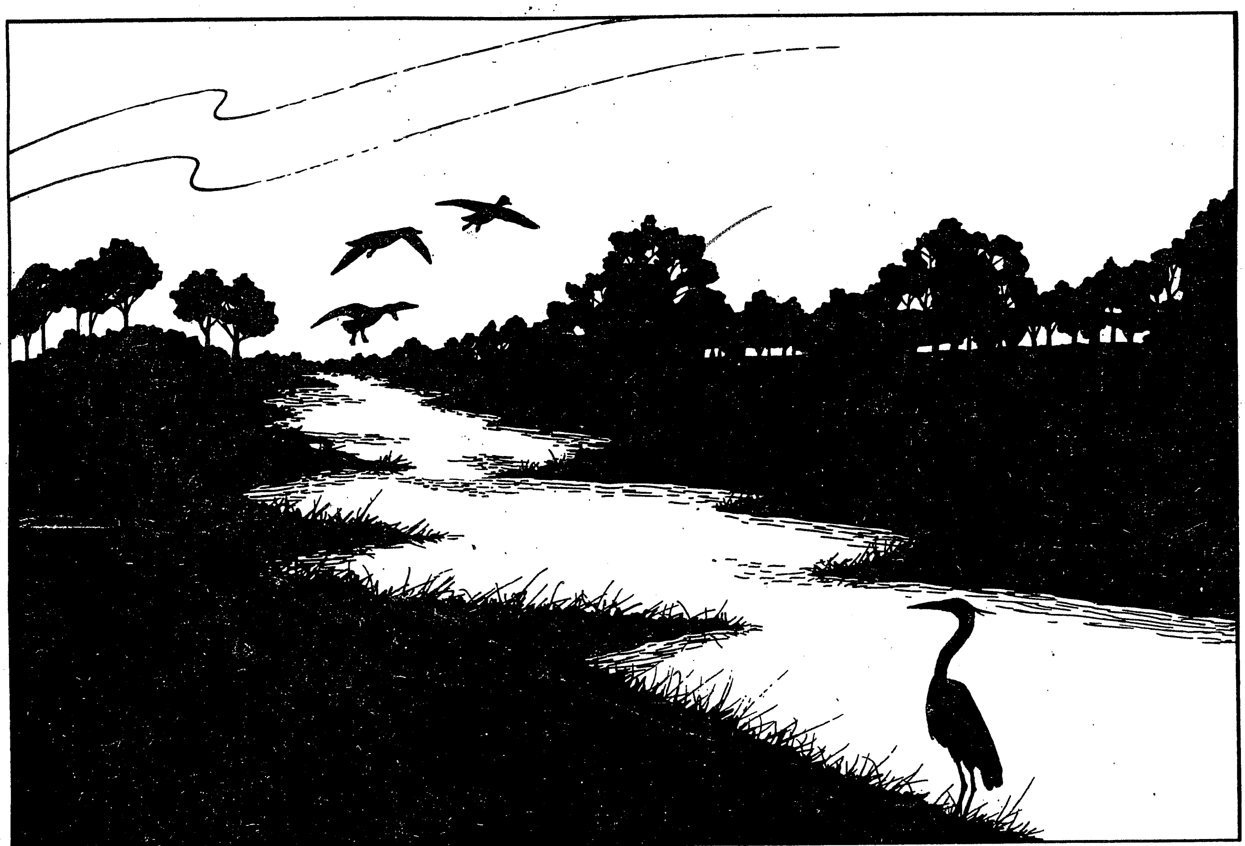

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PREFACE

Riparian ecosystem literature summarized in this report was obtained from the Wetland Creation/Restoration (WCR) Data Base, developed in 1988 by the U.S. Fish and Wildlife Service, National Ecology Research Center. The WCR Data Base is a highly indexed, keyworded bibliography of 1,000 articles pertaining to creation or restoration of various wetland types. The data base provides an overview of information available, and a comparison of amount of information published, on various types of wetland creation/restoration projects and techniques useful for developing or evaluating these efforts.

The WCR Data Base was updated in early 1989 with an additional 86 articles. Literature concerning riparian ecosystems from these articles also is included in the literature summary.

The 1988 version of the WCR Data Base is available on floppy disks. Information concerning the data base can be obtained from:

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INTRODUCTION

Riparian ecosystems generally compose a minor proportion of surrounding areas, but typically are more structurally diverse and more productive in plant and animal biomass than adjacent upland areas. Riparian areas supply food, cover, and water (especially important in the arid West) for a large diversity of animals, and serve as migration routes and forest connectors between habitats for a variety of wildlife, particularly ungulates and birds.

Because riparian ecosystems often are relatively small areas and occur in conjunction with waterways, they are vulnerable to severe alteration. Riparian ecosystems throughout the U.S. have been heavily impacted by man's activities. Riparian ecosystem creation and restoration have been used as mitigation for project impacts from highway, bridge, and pipeline construction; water development; flood control channel modifications; industrial and residential development; agriculture; irrigation; livestock grazing; mining; and accidental habitat loss.

Creation of a riparian ecosystem in a more mesic upland area (e.g., grassland or cropland) adjacent to a river requires appropriate water supply and grading the topography to suitable elevations to support plantings of riparian vegetation. Restoration involves returning the ecosystem to predisturbance conditions and typically implies revegetation. Removing exotic vegetation or restoring water supplies to predisturbance level also may be involved. Enhancement of riparian ecosystems commonly refers to improving existing conditions to increase habitat value, usually by increasing plant or community diversity to increase value for wildlife. Managing a riparian ecosystem typically involves enhancement techniques. However, creation and restoration projects often involve use of techniques considered more management-oriented (e.g., fencing to prevent cattle grazing until planted vegetation of a created or restored wetland is established).

Protection of an existing riparian ecosystem from impact should be of utmost importance during planning and construction phases of development projects. If loss or damage is unavoidable, wetland creation or restoration can be used as mitigation. Compared to other wetland types (e.g., coastal wetlands), projects and techniques involving creation or restoration of riparian ecosystems are not well documented. For example, only 8% of the records in the WCR Data Base contained information on riparian ecosystems, whereas 31% of the records contained information on coastal emergent or forested ecosystems. To provide a source of currently available literature, riparian information from 92 records (primarily published papers or reports) in the U.S. Fish and Wildlife Service's (FWS) Wetland Creation/Restoration (WCR) Data Base (Schneller-McDonald et al. 1988) was used to develop a literature summary of creation and restoration of riparian ecosystems.

The summary provides an overview of the status of riparian ecosystems in the U.S., a discussion of several riparian functions, and a review of some techniques used for planning, implementing, monitoring, and measuring project success of creation/restoration efforts. Case studies of various creation or restoration projects are used to demonstrate these techniques and to report some results of their use. Several well-documented case studies are discussed in detail to illustrate more extensive efforts to plan, implement, or monitor riparian ecosystem creation/restoration projects.

For the purpose of this report, riparian ecosystems are defined as landscapes adjacent to drainageways of floodplains that exhibit vegetation, soil, and hydrologic mosaics along topographic and moisture gradients that are distinct from the predominant landscape surface types. Major plant communities are described under palustrine system in Cowardin et al. (1979).

Literature from the WCR Data Base was used to provide a summary of riparian ecosystem creation/restoration literature. Thus, information concerning natural systems is not included unless discussed in these articles. This focus allows the reader to compare relative information available on riparian ecosystem creation/restoration efforts. However, this focus also results in limited information in some sections of the report (e.g., Status of Riparian Ecosystems in the U.S.).

Individuals involved in riparian ecosystem creation/restoration efforts are encouraged to thoroughly examine available literature on natural and altered systems. Brinson et al. (1981) provide a comprehensive review and synthesis of the ecology and status of riparian ecosystems. Over 500 articles are cited in their 124-page report. Chapters include the following topics: status of riparian ecosystems in the U.S., ecological functions and properties of riparian ecosystems (e.g., geomorphology, primary productivity, nutrient cycling, hydrology), importance of riparian ecosystems to fish and wildlife, and considerations in valuation (ecologic and economic) of riparian ecosystems. Brinson et al. (1981) also discuss management of riparian ecosystems. Riparian ecosystem management literature was not included in the WCR Data Base, unless the article also discussed creation or restoration.

LITERATURE FOCUS

The 92 records of the WCR Data Base containing information on riparian ecosystem creation/restoration were published from 1960 to 1988; 74% were from the 1980's. Records include information from 27 States and Canada, with California represented in the largest number (24 records). One third of the records concerned Region 1 (West Coast to Idaho and Nevada) of the FWS Regions (USFWS.REGION, Table 1). Region 7 (Alaska) was represented in only two records.

Riparian ecosystem creation/restoration techniques are the topic of the largest percentage of the records (46%, STUDY.TYPE, Table 1), followed by case studies, overviews, comparative studies of several cases or a comparison with a control or undisturbed riparian ecosystem, and articles discussing riparian ecosystem creation/restoration programs or plans.

Table 1. Percentage of the 92 riparian ecosystem creation/restoration records in the WCR Data Base containing keywords. Records may contain multiple keywords in each field. (See text for further description of fields.)

Field	Keyword	Percent
USFWS.REGION	1 (West Coast to Idaho)	35.9
	4 (Southeast)	25.0
	2 (Southcentral)	20.7
	6 (Great Plains to Utah)	20.7
	3 (Midwest)	17.4
	5 (Northeast)	6.5
	MANY (applicable to all regions)	5.4
	7 (Alaska)	2.2
STUDY.TYPE	TECHNIQUE	45.7
	CASE	40.2
	OVERVIEW	33.7
	COMPARATIVE	29.9
	PROGRAM (or plan)	20.7
OBJECTIVE	GENERAL	54.3
	HABITAT (fish or wildlife)	35.9
	HYDRO (includes flood control)	20.6
	EXPERIMENT (lab or field)	16.3
	EROSION	13.0
	INCIDENTAL	12.0
	WQUALITY (water quality)	8.7
ACTION	PLANT	54.3
	LFORM (landforming)	47.8
	SEED	32.6
	STABIL (bank stabilizing)	28.3
	HYDRO (altering flow)	28.3
	SOIL (treating or adding)	25.0
	SPOIL (using spoil materials)	17.4
	CONTAM (contaminated soil/water)	15.2
	FERT (fertilizing)	15.2
	CUT (mowing or clearing)	12.0
	STOCK (stocking fish or beavers)	8.7
	FIRE (burning)	2.2
	BIOCIDE (herbicides/pesticides)	2.2

(Continued)

Table 1. (Concluded)

Field	Keyword	Percent
WET.TYPE	PO-FO (palustrine forested)	69.6
	PO-SS (palustrine scrub-shrub)	64.1
	R (river subsystem not stated)	47.8
	PO-EM, R-EM2 (emergent)	46.7
	R2 (lower perennial river)	34.8
	UB, US, SB (unvegetated surfaces)	21.7
	R3 (upper perennial river)	14.1
	R4 (intermittent stream)	10.9
	PO-AB, R-AB, (aquatic beds)	8.7
	R1 (tidal river)	4.3
RESPONSE	VEGETATION	66.3
	HYDRO (hydrologic flow)	23.9
	SUCCESS	22.8
	ECON (economics, costs)	21.7
	FISH	21.7
	NGBIRDS (nongame birds)	16.3
	WQUAL (water quality)	15.2
	SOIL (soil properties)	15.2
	WFOWL (waterfowl)	14.1
	INVERT (aquatic invertebrates)	14.1
	MAMMALS	14.1
	CHEM (soil or water chemistry)	13.0
	SHOREB (shorebirds)	12.0
	REPT (reptiles)	6.5
	AMPHIB (amphibians)	4.3
	HUSE (human use, recreation)	3.3

Providing fish and wildlife habitat was the objective of 36% of the records, followed by improving hydrologic flow, erosion control, and water quality (OBJECTIVE, Table 1). Experimental studies compose 16% of the records. A "GENERAL" code was given to about half the records, indicating that the objective of riparian creation or restoration was not stated or was a general effort to mitigate for an impact, such as highway or reservoir construction. Twelve percent of the records were coded "INCIDENTAL" and included information such as natural riparian succession.

Principal techniques discussed in the records are planting, landforming, and seeding (ACTION, Table 1); bank stabilizing, altering hydrologic flow, treating soil, fertilizing, and mowing or clearing were used less often. Stocking (fish or beaver), burning vegetation, and using herbicides or pesticides were mentioned in less than 10% of the records. Seventeen percent of the records discuss spoil materials, and 15% deal with contaminated water or soil (including mining, agricultural, and wastewater).

Wetland vegetation classes (WET.TYPE, Table 1) discussed in the records included palustrine forested (PO-FO), scrub-shrub (PO-SS), emergent (PO-EM), and aquatic beds (PO-AB), and riverine nonpersistent emergent (R-EM2) and aquatic beds (R-AB). Over 150 plant genera were included in the records, with Salix, Populus, Quercus, and Acer most frequently mentioned (47%, 34%, 24%, and 18%, respectively).

About 48% of the records did not state the riverine subsystem involved in the study or overview. Of the records that did specify riverine subsystem, lower perennial (R2) was the most discussed, followed by upper perennial (R3), intermittent (R4), and tidal (R1) (Table 1). Unconsolidated bottoms (UB), shores (US), or streambeds (SB) were discussed in 22% of the records.

Half of the 92 records stated a length of time for the investigation of a riparian site or system, and these varied from 1 to 13 years. About half of the records stating length of investigation presented data from 1 to 2 years of study; less than 10% had data from 8 or more years of study.

Fifty-three percent of the records provided quantitative results of responses to riparian ecosystem creation/restoration efforts. Often, qualitative responses consisted of only a list of species using the area or a general statement that erosion was reduced, hydrologic flow increased, water quality improved, and so forth.

Vegetation was the primary response investigated and discussed in the records (RESPONSE, Table 1). Animal response consisted of fish (22% of the records), nongame birds (16%), waterfowl (14%), shorebirds--including wading birds and seabirds (12%), aquatic invertebrates (14%), mammals (14%), reptiles (7%), and amphibians (4%). Hydrology was discussed in more articles than either water quality or soil properties.

Some discussion of economics was included in about 22% of the records (RESPONSE, Table 1). Records were coded "ECON" if they presented costs involved in creation or restoration planning, techniques, or construction, or discussed cost:benefit ratios. Only 23% of the articles on riparian ecosystems in the WCR Data Base attempted to discuss or evaluate the success of riparian ecosystem creation/restoration efforts (RESPONSE, Table 1).

STATUS OF RIPARIAN ECOSYSTEMS IN THE UNITED STATES

Over half of the wetland and riparian zones have been destroyed in the coterminous 48 States, and few remaining zones have not been adversely impacted (Fredrickson and Reid 1986). Because of their location in floodplains, destruction of riparian ecosystems is largely associated with man's activities, especially clearing for agriculture, stream-channel modifications, water impoundments, and urbanization. Narrower riparian areas are more easily altered and potentially degraded. Because riparian zones often follow the gradual elevational changes of a watershed, road and pipeline construction often impacts riparian ecosystems. Even recreational development can destroy natural plant diversity and structure, lead to soil compaction and erosion, and disturb wildlife.

Native riparian ecosystems, especially in the arid Southwest, are disappearing rapidly (Ohmart et al. 1977). About 1,200 ha/year of riparian vegetation are being removed along the lower Colorado River (Anderson et al. 1979). Many cottonwood (Populus spp.) communities of this area have been lost to expanding agriculture, livestock grazing, channelization projects, stream dewatering, inundation by reservoir construction, and groundwater depletion. Dams also have expedited the natural loss of riparian communities by stopping annual flooding. Cessation of annual floods and natural channel movements curtail the formation of the basic cottonwood seedling habitat--bare sandy soils with high water tables--which appears to be essential for seed germination. In addition, domestic livestock concentrate in riparian communities and heavily graze young cottonwoods.

Riparian areas are widely recognized as crucial to the overall ecological health of rangelands in the western U.S.; however, many are in degraded condition, largely as a result of poorly managed livestock grazing (U.S. General Accounting Office 1988). Riparian areas represent only about 1% of the more than 250 million acres of Federally owned rangeland. Riparian areas, however, have ecological importance far beyond their relatively small acreage because they have a greater quantity and diversity of plant species than adjoining land. Livestock tend to congregate in riparian areas for extended periods, eat much of the vegetation, and trample streambanks, often eliminating other benefits of riparian habitat (e.g., fish and wildlife habitat, erosion control, floodwater dissipation).

In the Pacific Northwest, stream corridors are major sources of erosion (Carlson 1979). Human activities such as logging, urban development, grazing, cropping, and recreational activity have increased surface runoff, removed protective riparian vegetation, and altered flows, often with catastrophic effects. About 10 million tons of sediment erode from streambanks each year in Oregon and Washington alone.

Mining activity, especially in the East, has destroyed many riparian habitats. For example, central Florida's phosphate district has been surface mined since 1908, and by 1975 over 60,000 acres (much of which was wetland) had been abandoned without reclamation (Clewell 1983). When reclamation of active mines became mandatory in 1975, most mine cuts were filled with overburden, sand tailings, and waste clays. Insufficient material remained to fill all mine cuts to the original grade of the land; thus, some cuts remained as relatively deep lakes, whereas others were filled and reclaimed as uplands. Reclamation of riparian and wetland habitats in Florida's phosphate district has been attempted only since 1978.

In the Southeast, over 90% of original bottomland forest has been converted to other land uses, primarily agriculture (Haynes and Moore 1988). Some major river systems also have had a long history of land alterations associated with flood control measures. Since the late 17th century, levees and borrow pits have been constructed along the lower Mississippi River (Landin 1985). The 600 miles of the river between the Gulf of Mexico and Cape Girardeau, Missouri, is contained by over 2,000 miles of levees and has about 40,000 acres of borrow pits from which the levee material was taken. As native riparian landscapes have been increasingly impacted by flood control projects, the need has grown for restorative mitigation, not only along existing rivers and streams but also on newly created floodways and distribution canals (Dawson 1984).

In urban communities one of the major problems facing local governments involves an economically and environmentally acceptable solution to increased flooding of urban streams (Keller and Hoffman 1976). Flood correction and control typically includes stream channelization (i.e., widening, straightening, or deepening a stream channel). Channelization tends to adversely affect the physical and biological environment and to reduce the aesthetic quality of the stream.

COSTS OF CREATION/RESTORATION

Cost is an important factor in riparian ecosystem creation or restoration, especially now as governmental agencies are increasingly required to adhere strictly to cost:benefit ratios (Dawson 1984). The greater the benefits and the lower the cost, the better chance a project has of proceeding.

Knowing the cost of revegetation projects is not the same as knowing the economic feasibility of revegetation (Anderson and Ohmart 1985). Answers to questions concerning feasibility are largely value judgments. Revegetation efforts are likely to be considered expensive; however, Anderson and Ohmart (1985) stress that a high degree of success in revegetating an area should be the major goal.

If funding is limited, certain measures can be taken to reduce the costs of creation or restoration. For example, by selecting a site requiring minimal preparation and having minimal weed problems, site preparation and subsequent labor costs associated with weeding could be reduced by 50%-75% (Anderson and Ohmart 1985). Cuttings are less expensive than seedling transplants in terms of labor and material costs, and have the added benefit of being selected from local plants, which are better adapted to the site and thus more likely to become established. Survival rates of cuttings, however, may be lower than that of seedling transplants, which decreases the costs savings due to necessary additional plantings.

Determining who pays the costs of restoring highly eroded streams and riparian ecosystems on private lands can be a problem. Although it would be advantageous for landowners to restore these habitats, in terms of erosion control and improved irrigation, the task often is too expensive for monetary benefits gained. In California, an informal task force of private landowners, private organizations, and public agencies has worked to develop methods and determine programs and funding resources available to help landowners solve erosion, fish and wildlife habitat, and irrigation problems on Willow Creek, a channelized stream flowing through irrigated pasture and cropland (Schultze 1984). Costs of stabilizing banks, regrading banks, revegetating, installing fish passages, and restocking trout would be shared by the private landowners, a private trout organization, the Soil Conservation Service, the Agricultural Stabilization and Conservation Service, and the California Departments of Fish and Game, Forestry, and Transportation.

The cost of restoring a site or implementing a mitigation measure may actually be substantially less than other land uses or the proposed alternative. For example, Anderson and Ohmart (1979) found that costs of revegetating and monitoring a desert riparian site in the lower Colorado River valley over a 10-year period were about $10,000/ha. Clearing an equivalent area for agriculture and farming it for 10 years would cost about four to six times that amount.

In an urban project on a channelized stream in Mecklenburg County, North Carolina, costs of restoring a channel (which included sloping banks, creating meander bends, and some riprapping on highly erosive bends) were $5-$7 per foot, compared to more than $200/foot for traditional channelization (stream straightening and deepening with heavy riprapping) (Keller and Hoffman 1976).

For mitigation of the proposed U.S. 65 Bypass, located in Pine Bluff, Arkansas, over 100 acres of wetlands will be created or restored, and about 158 acres of bottomland hardwood wetlands will be purchased and preserved (Richardson 1988). Integration of mitigation measures into project design will result in an estimated $4.7 million reduction in overall project cost. Mitigation will include purchasing land to preserve floodplain wetlands rather than providing frontage roads during construction, creating borrow areas and using borrow material for construction, and relocating bridges to lessen wetland impact, which consequently reduces proposed bridge length. Early coordination and incorporation of wetland mitigation into a project design can result in superior wetland mitigation, while actually reducing total project costs.

FUNCTIONS

A fundamental function of rivers, the transport of water and sediments, is influenced by the interaction of geologic, climatic, hydrologic, geomorphic, pedogenic (soil), and biotic processes (Platts et al. 1987b). The magnitude and direction of functional relationships in riparian zones are influenced by hydrology, topography, vegetation, and their interaction (Chapman et al. 1982). A major role of the riparian zone is to dissipate stream energies associated with high flows (Van Haveren and Jackson 1986). This, in turn, permits sediments to deposit and continue development of the alluvial valley floor.

Alluvial riparian zones also function as shallow aquifers that recharge at high flows and drain at low flows (Van Haveren and Jackson 1986). This interaction between surface flows and groundwater storage results in moderated high flows and enhanced or prolonged base flows. The shallow aquifer condition also creates moist soil conditions favorable for riparian plant growth.

Thus, geomorphic and hydrologic characteristics of riparian zones establish the basic components of biological habitat, including saturated soils and instream structural features such as pools, riffles, gravel, and streambanks (Van Haveren and Jackson 1986). Vegetation that thrives in riparian zones, in turn, contributes to geomorphic and hydrologic functioning. Disruption of normal geomorphic or hydrologic function, or the vegetation on which it depends, usually results in impairment to overall riparian resource values.

Vegetation supplies litter that, when covered with sediment during overflow, rapidly decomposes to release nutrients and adds humus to the soil. This process is vital to maintaining productive riparian ecosystems (Anderson et al. 1979). Litter is a key element in the productivity of wetlands and eventually determines the value of a site for animals (Fredrickson and Reid 1986). In seasonal environments, the entire above-ground biomass becomes litter following senescence. Structurally intact above-ground plants, living and dead, are colonized by periphyton that provide food for grazing macroinvertebrates, which in turn provide food sources for a variety of fish and wildlife species.

Ischinger and Schneller-McDonald (1988) analyzed information in the WCR Data Base on the creation and restoration of various freshwater habitats in the western U.S. and found that the function of riparian wetland as valuable wildlife habitat and its contribution to stream fish habitat had been documented. The sediment control, bank stabilization, and flood attenuation functions of riparian wetlands had been documented to some degree. However, the data base contained few articles that quantified functions of natural wetlands in the West or that compared restored or created wetland functions to those of undisturbed sites. Unfortunately, little or no information on the food chain support, water quality, or groundwater recharge/discharge function of wetlands was provided in the data base. This also is true of riparian information for other regions of the U.S. in the data base.

Providing fish and wildlife habitat was the most often stated objective of riparian ecosystem habitat literature in the WCR Data Base. Many of the articles on riparian ecosystem creation/restoration, particularly the more recent ones, include some discussion of wetland functions other than fish and wildlife habitat. However, few attempts have been made to evaluate the hydrologic flow, erosion control, or water quality improvement capabilities of created or restored wetlands.

FISH AND WILDLIFE HABITAT

Wise management of remaining riparian ecosystems or replacement of these communities is extremely important because of their high value as fish and wildlife habitat. Riparian ecosystems generally are characterized by increased structural diversity of vegetation compared to surrounding plant communities and an increased edge effect for area occupied. In the arid Southwest, riparian habitats support higher species richness and densities of wildlife than any other desert habitat (Anderson and Ohmart 1984). Riparian areas of Western rangelands provide food, water, shade, and cover for fish and wildlife, and forage for both wild and domestic grazing animals, as well as provide recreational areas (U.S. General Accounting Office 1988).

Fish and Aquatic Invertebrates

The riparian zone influences several elements of fish habitat, including temperature, cover, and food (Reeves and Roelofs 1982). Loss of vegetative cover and undercut banks can decrease the amount of suitable habitat, thereby reducing stream productivity and fish carrying capacity. Streambank vegetation also can be an important source of fish food. Small fish use slower water along margins of larger streams and depend on terrestrial organisms from streamside vegetation for food because most aquatic drift organisms escape them.

There are only a few reports of attempts to create, manage, or enhance man-made backwaters or to evaluate the effectiveness of specific backwater habitat manipulations (Matter and Mannan 1988). Longevity, productivity, and habitat quality of man-made backwaters are greatly affected by the amount of protection from main river channel flooding and sedimentation, number and type of connections to the river, flushing rate, and degree of water-level fluctuation. Studies of Colorado River and Mississippi River backwaters indicate that some interconnections of backwaters and river channel are important. Direct openings to the river permit water exchange that can prevent stagnation and oxygen depletion, renew organic material and nutrients, and allow export of materials such as detritus, plankton, and aquatic invertebrates to the river. Fish are known to readily enter backwaters, especially for spawning, and the free movement of fish into and out of these areas in response to changing conditions is important for maintaining healthy populations. However, if there are numerous uncontrolled connections to the main channel, then high rates of water movement throughout the backwater will flush out nutrients and preclude development of slow-water habitat features. Numerous openings also contribute to increased water-level fluctuations, which can be detrimental to aquatic plants and animals.

Water velocity, water depth, and cover are important factors regulating stream trout populations (Burgess 1985). In general, cover increases habitat complexity, which can lead to a richer species complex. Cover provides hiding places for both adults and fry to escape predation. Its slowing effect on water velocity provides a metabolic resting place and, under some circumstances, cover provides increased substrate for food items and for egg attachment.

Severe dewatering caused by water storage or diversions for extended periods of time can be detrimental or even disastrous to biological systems of streams, particularly fisheries. Trout have been shown to regularly use cover areas, either natural or artificial, particularly during these periods (Cooper and Wesche 1976). In areas where minimum instream flow criteria cannot be met, development of riparian ecosystems may serve to enhance trout habitat, thus easing the impact of low flows, which reduce trout habitat.

Observations of the physical development of several reclaimed streams in surface-mined areas of the Midwest indicated that erosion control, which is linked with proper stream channel design and rapid revegetation of side slopes, was as critical to stream fauna recovery as stream restoration (Thompson 1984). Habitat inundated by heavy silt loads becomes useless as fish and invertebrate habitat. Spoil materials that segregate out in these reclaimed streams form many microhabitats and thus add significantly to invertebrate diversity. Lack of riparian woodlands surrounding relocations had a detrimental effect on both fish and invertebrate recovery. Many species associated with habitats made available by riparian trees were absent from the relocations.

Robertson (1988) found that the density of macroinvertebrates inhabiting a relocated channel of Sink Branch in a mined area of central Florida was identical to that of an unmined control area 2 km upstream. The experimental site was a narrow, 1-ha corridor planted with a variety of native hydric and mesic tree species. After 8 months, species richness (total number of species collected) was 20% greater in the mined channel, indicating the development of new niches. Disparity in richness value was expected to persist until planted trees on the streambank formed a canopy over the channel and shaded out the abundant aquatic vegetation that had colonized the stream. Robertson et al. (1987) found that aquatic invertebrate richness of central Florida's phosphate-mined stream systems reclaimed by creation of marshy areas exceeded that of undisturbed streams, but richness of reclaimed lotic sections matched that of similar undisturbed streams after 2 years.

Birds and Mammals

Presence of riparian vegetation can substantially increase the wildlife value of created wetlands. For example, borrow pits surrounded by bottomland hardwoods along the lower Mississippi River were generally associated with a greater frequency of both bird and mammal observations compared to pits containing few hardwoods (Landin 1985; U.S. Army Engineer Waterways Experiment Station 1986). During a 3-year study of 26 pits, analysis of variance tests revealed numerous differences among pit characteristics, year, season, and mammal and bird use. Other factors contributing to greater frequency of bird and mammal use were reclaimed pits with moderately grazed or occasionally mowed understory, flooded less than 1 month yearly, at least 6 feet at bankful, at least 30 acres in size, and more than 1 mile from the river.

High foliage density and diversity in the vertical and horizontal dimension were among the variables most frequently associated with high avian densities and diversities in riparian zones along the lower Colorado River (Anderson and Ohmart 1985). Cottonwood and willow (Salix spp.) attracted, or were correlated with vegetational factors that attract, the greatest density and diversity of insectivorous birds. Doves and quail were associated with riparian shrubs. Riparian revegetation schemes should be directed toward achieving high diversity and density of woody vegetation if goals are to increase bird use of the habitat.

Riparian ecosystems not only supply breeding and foraging habitats for resident birds, but also provide productive habitats for migrants. A greater percentage of a bird's total energy may be channeled into reproduction if habitats used by migrants have provided adequate resources for physiological needs and for increasing endogenous reserves (Fredrickson and Reid 1986). Thus, revegetation schemes should incorporate habitat requirements for migrating birds as well as residents.

The study of mammalian populations in created or restored riparian ecosystems is generally lacking in the literature, and usually only occasionally referred to by noting occurrence of deer or small mammal sightings or use during routine surveys of other parameters. Anderson and Ohmart (1985) recommended creation of a riparian ecosystem that is horizontally diverse to benefit most rodent species. Habitat preferences varied considerably among rodent populations found on their study site along the lower Colorado River.

HYDROLOGIC FLOW

Hydrology is a key element in determining the composition and productivity of plants and corresponding animal associations (Fredrickson and Reid 1986). Plant composition, habitat structure, and productivity are determined by the timing, duration, and extent of flooding. Understanding the effects of short- and long-term fluctuations on the system is one of the greatest challenges facing managers because natural hydrology is continually modified by man's activities. Hydrologic regimes vary daily, seasonally, and over long periods, and wetland and riparian productivity is largely determined by these fluxes. Modification of the natural dynamic regime can lead to extended extremes of drought or flooding, with a resultant drastic decline in productivity.

In general, the amount and type of vegetational ground cover, the areal extent of the watershed, and the slope of the terrain are directly related to the percentage of water that will enter the drainage system as surface flow or as percolated water. In riparian areas of the lower Colorado River, efforts are being made to clear extensive stands of the exotic salt cedar (Tamarix chinensis) to reduce evapotranspirative losses and increase streambed capacity to carry floodwater (Anderson and Ohmart 1984). Revegetating cleared areas with native shrubs and trees results in a decrease in total foliage density, while enhancing riparian bird habitat.

Improvement of riparian ecosystems also may increase groundwater storage (Skinner et al. 1985). Storage of water in the semiarid West during periods of high flow has been a major justification for constructing dams and reservoirs. Lack of adequate sites for dams, present economic constraints, and concerns for existing environments now limit construction of new water storage facilities. Consequently, water planners should examine alternative methods to store water such as improving riparian zones of floodplains and adjoining aquifers of streams tributary to those dammed. Improved riparian zones could create desired aquatic habitat during decreased flow and still store water. However, it is imperative to understand riparian zone processes to meet flow regimes and to maintain desired aquatic conditions.

EROSION CONTROL

Vegetation influences soil erosion in several ways: (1) foliage and leaf residues intercept rainfall and dissipate energy, (2) root systems physically bind or restrain soil particles, (3) residues increase surface roughness and slow velocity of runoff, (4) roots and residues increase infiltration by maintaining soil porosity and permeability, and (5) plants deplete soil moisture through transpiration, giving the ground a "sponge effect" to allow it to absorb water (Abbey 1988).

In the Pacific Northwest, increased flow from upper watershed disturbance aggravates channel shifting and accelerates meandering in the floodplain (Carlson 1979). In many cases, natural vegetation does not provide sufficient resistance to counteract this increased flow. Loss of riparian vegetation in the channel has little effect on bank erosion, but loss of riparian vegetation in the floodplain zone does have a major impact on bank erosion. Revegetation in this zone can provide significant resistance to bank scouring because lower velocities permit plant establishment on most of the streambank. If not carefully planned and implemented, stream channel alteration (e.g., narrowing, straightening, diverting) also can greatly increase bank erosion. Erosive forces within a channel alteration can preclude use of vegetation to stabilize streambanks. Streambank revegetation usually is limited to slower-moving reaches with relatively flat gradients (<1 m/km) or in combination with structural measures on somewhat faster streams. The plant's ability to resist erosive stream flows must be considered in riparian ecosystem creation/restoration efforts.

WATER QUALITY IMPROVEMENT

Reclaiming degraded streams tributary to major river systems would help reduce nonpoint source pollution (Skinner et al. 1985). Vegetation traps sediment during high flow events. Nutrients are removed as water flows through mature riparian zones. Anaerobic bacterial activity is maximized in the riparian zone. Nutrients capable of being eliminated by anaerobic bacteria to a gaseous by-product could be reduced in well-managed riparian zones before polluting stream flow. The high potential plant production of riparian zones favors assimilation and retention of nutrients.

PLANNING

Two factors are especially important before one can either identify a problem or begin recovery processes in riparian ecosystems: (1) knowledge of the management objectives and (2) knowledge of the physical environment and biotic communities occupying the site, including the hydrologic regime, physical and chemical characteristics of the soils and substrates, potential for the site to support particular species and plant communities, and vegetation successional patterns (Chapman et al. 1982).

Creation of some riparian ecosystems may be extremely limited due to the difficulty of creating necessary hydrologic conditions. For example, Cooper (1988) doubts that Rocky Mountain peatlands can be restored once peat has been removed. Peat accumulation rates in Rocky Mountain wetlands range from 2,000-5,000 years per meter of peat. Cooper also doubts that the peatland ecosystem could be initiated in today's dry climate of the West. An important factor to consider in decisions of whether or not mountain wetlands can be created is that most fens in the Rocky Mountains today occur in sites where groundwater discharge occurs. This groundwater discharge alone may be sufficient to saturate wetland soils, or more likely the groundwater together with surface water are necessary for continued soil saturation. All sites that have significant groundwater discharge most likely are already wetlands, and a groundwater discharge situation cannot be created.

Plans to restore stream and riparian ecosystems should entail evaluations of the watershed (Platts et al. 1987b). Within a given watershed, the manner in which water and sediment move is influenced by the geomorphic parameters of valleys. The frequency and duration of flooding (water-regime) determine the distribution of contrasting riparian community types (e.g., forested, shrub, and herbaceous).

Anderson and Ohmart (1979) present six basic ingredients for adequate riparian ecosystem mitigation planning: (1) a solid base of data concerning wildlife in the project area and in the area set aside for mitigation; (2) a thorough analysis of the data; (3) creation of predictive models with which to create, in theory, a design for the mitigation; (4) design of required modifications, including site preparation (e.g., clearing, rootripping, leveling, installing an irrigation system), equipment needs, costs, and a careful analysis of probable delays; (5) design implementation, including labor requirements and labor sources; and (6) monitoring, including methods of gathering information, analytical and interpretive techniques, and staff requirements.

Mitigation plans for which adequate funds are not available should not be proposed or, if proposed, the shortage of funds should be explicit (Anderson and Ohmart 1985). The contracting agency should select a contractor whose mitigation proposal has a high chance of success rather than selecting the contractor with the lowest bid. Landowner cooperation is necessary for habitat restoration on private lands and the landowner's interests should be identified and incorporated into the project design.

When planning a creation or restoration project, close proximity to existing high quality riparian ecosystems is advantageous for the added benefit of recolonization. For example, an existing riparian ecosystem was destroyed when a portion of the Carrolls Channel on the Columbia River, Washington, was inadvertently filled during dredge emergency actions following the 1980 eruption of Mount St. Helens (U.S. Fish and Wildlife Service 1983). The contractor was required to remove the fill material to restore previous elevations. The newly created channel was graded into a small natural channel with a number of desirable emergent species. Silt from the Columbia River deposited over much of the area and by 1983 recolonization of plants and use by wildlife was far greater than expected.

Platts et al. (1987b) recommended that preliminary planning involve developers, contractors, engineers, environmental scientists, and representatives of regulatory agencies. The scope, goals, objectives, and general approach to restoration should be established during this preliminary stage.

GOALS AND OBJECTIVES

The first step in most plans is to set goals and objectives to give the project direction and commitments, which regulating agencies can evaluate (Miller 1988). A general goal is to reverse (or mitigate) the damage that has or will occur to a wetland, and to answer regulatory concerns. Goals are usually broad and not site specific. Goals direct the project to restore and improve wetland functions, such as flood storage, sediment trapping, food chain support, community diversity, biological productivity, and fish and wildlife habitat. Objectives, on the other hand, are more site specific and direct the actions of the project (e.g., to revegetate disturbed areas with native trees and shrubs to provide wildlife food, cover, and nest sites; to provide an additional 1-acre-foot of storage capacity within the wetland to function as a stormwater retention/detention basin).

The goal of a project may not be to reestablish the former riparian situation, if that situation is degraded, such as in an incised channel. The goal should be to establish a new equilibrium condition that supports a viable riparian zone (Van Haveren and Jackson 1986). The overriding consideration in planning a riparian ecosystem rehabilitation program may be to determine the rehabilitation potential of the target area and identify the root causes of the degraded condition. Causes must be resolved before an improvement project is initiated. Stream riparian zone rehabilitation should not circumvent the real causes of stream degradation. Natural recovery processes must be understood and incorporated in the rehabilitation. Objectives of the rehabilitation program should consider existing and future watershed condition, hydrologic regime, and the desired rate of recovery.

BASELINE DATA

Platts et al. (1987a) present a comprehensive set of methods used for evaluating riparian habitats, including techniques useful for collecting baseline data. Topics include sampling schemes, measuring vegetation, classifying riparian zone communities, determining various features of the soil, remote sensing, water column measurements, streambank morphology, measuring and mapping organic debris, historical evaluations, and use of benthic macroinvertebrates to evaluate stream riparian zone conditions. An appendix to this publication includes bibliographies, source materials, and repositories for information on historical riparian zone conditions.

Baseline studies are particularly problematic because little is known about the original condition of most rivers and streams. In degraded situations where historical information is insufficient to formulate a design format, the use of comparable areas that have been least disturbed and managed as natural areas may be necessary to guide the revegetation plan (Dawson 1984). Dawson (1984) discusses inventory techniques for assessing vegetative distribution patterns for formulating a working planting design. Such techniques involve a review of historical context and the selection of comparable areas to inventory for distribution, community and soil patterns, canopy heights, and elevational transects in relation to stream flow.

Knowledge of the geologic variability and geomorphological characteristics of drainage patterns can help predict water storage capacity for streams being reclaimed for riparian zone values (Skinner et al. 1985). Cairns et al. (1979) present an inertia index to determine a system's ability to resist displacement of structural and functional characteristics for two watersheds and an elasticity index to determine the potential of the system to recover should a displacement occur. Practical use of these models is limited by the paucity of information on organisms; however, they do point to the need to approach both structural and functional characteristics differently for major taxonomic groups.

Day et al. (1988) developed a conceptual model using the program TWINSPAN to describe relationships between vegetation (e.g., species richness, standing crop, amount of litter) and environmental factors (e.g., conductivity, water chemistry, elevation, pH, substrate) in riverine marsh vegetation along the Ottawa River, Ontario. The three main factors controlling vegetation composition were water depth, the effects of spring flooding in removing litter, and the fertility gradient produced by waves and flowing water. This information can then be used in the design of creation or restoration projects for Ottawa River riparian ecosystems.

Both site characteristics and the biological aspects of target species need to be considered in the management of riparian systems (Fredrickson and Reid 1986). Site characteristics include the climate (precipitation cycle, temperature ranges, length of growing season), soils (structure, fertility, topography, residual pesticides), water control potential (water supply/source, levees, control structures, pumps), plants (composition, structure and maturity, seedbank), and disturbance (man-induced perturbations, public use, research and management activities). Biological aspects of target species include chronology (migration, breeding, molt), nutritional requirements (population size, migration, breeding, molt), social behavior (foraging modes, breeding strategies), significance of location (local, regional, continental), status (endangered or rare, recreational value), and multispecies benefits.

Adamus (1987) presents an evaluation technique to identify the level of function of specific bottomland hardwood tracts in comparison to other tracts in the study region. This rapid assessment method involves rating functions that must be addressed under Section 404 of the Clean Water Act: water quality improvement, provision of fish and wildlife habitat, and maintenance of surface and groundwater quantity.

Another rapid assessment method is the Fish and Wildlife Service's Habitat Evaluation Procedures (HEP), which deals exclusively with wildlife or fish habitat functions. Several examples of the use of HEP are included in the WCR Data Base. Exum and Breedlove (1986) used HEP procedures to evaluate existing wetlands and propose design alternatives to maximize postdevelopment habitat for nonurban-adapted wildlife species within a 4,000-acre corridor along Shingle Creek in Orange County, Florida. Indicator species were chosen to represent various species groups of the corridor and included the barred owl (Stix nebulosa), white ibis (Eudocimus albus), pileated woodpecker (Dryocopus pileatus), mottled duck (Anas fulvigula), American alligator (Alligator mississippiensis), yellow-bellied slider (Chrysemys scripta), and largemouth bass (Micropterus salmoides). A mitigation plan and predicted changes in habitat units under this plan are presented. The plan was designed to maintain diverse, high value habitat in a contiguous system that would mimic natural riverine wetland assemblages and be maintained with a minimum amount of energy once constructed.

A modified version of HEP, the Pennsylvania Modified HEP (PAMHEP), was used to establish baseline fish and wildlife values for the Manasquan Reservoir System Project in Monmouth County, New Jersey (Hinkle 1988). The resulting mitigation plan involved enhancing existing riparian habitat along the Manasquan River to replace habitat units (HU) that would be lost due to reservoir construction.

Collection of water quality parameters should be incorporated into baseline data collection and is particularly critical in reclamation of mined land. The Piney Creek Watershed Project involved the use of a water analysis program to determine baseline water quality parameters: conductivity, pH, and sulfate, iron, and manganese concentrations, parameters used by most regulatory agencies to establish effluent quality guidelines (Byerly et al. 1978). Samples were collected monthly for a year during nearly all conditions of weather and stream flow. Both fish and invertebrate surveys were conducted to provide baseline data. Reclamation plans for 13 surface mines within the drainage basin were formalized from large-scale aerial photography and field surveys. Planning was designed to minimize mechanization to reduce excessive disturbance of spoil, which might increase pollution. Revegetation plans were developed primarily to curtail erosion and siltation problems; in addition, the creation of usable wildlife habitat was an important facet of the revegetation of the mines. The plan called for planting trees and shrubs, seeding cover plants, constructing silt structures on mined areas and haul roads, and sealing two underground mines.

DESIGN

Platts et al. (1987b) recommended that conceptual designs developed by pertinent specialists (e.g., fish and wildlife scientists, wetland ecologists, soil scientists, engineers) be integrated into a preliminary design plan. The design should be evaluated for conflicts and thoroughly reviewed by the contractor. Preliminary efforts should entail classification, inventory, and evaluations from which critical aspects of the project design can be determined.

In the past, governmental reclamation agencies have relied heavily on planting design techniques dependent on exotic plant materials to achieve simplistic goals of erosion control, environmental tolerance (e.g., drought or flooding tolerance, soil tolerance, browsing tolerance), and aesthetic improvement (Dawson 1984). Today, use of exotic plant materials still is entrenched in riparian projects. But the use of native riparian plants should be expected to increase as more managers realize the value and ecological diversity that native riparian systems offer. Perhaps the largest influence on riparian design philosophy has been a new attitude among the general populace and increasingly among environmental designers toward management of public lands. This new attitude places less value on engineered landscapes and more emphasis on the aesthetics of native landscapes (Dawson 1984). This is especially true in the West where native riparian plant communities provide a landscape pattern to otherwise homogeneous rangelands and biological diversity to largely evergreen forestlands. The traditional "garden" design of engineered landscapes is being replaced by the native riparian landscape.

Reclamation and re-creation of landscapes after drastic disturbance, such as phosphate mining, requires an understanding of the interplay between physical characteristics and ecological organization (Gross and Brown 1987). General design principles of reclaimed riparian ecosystems are acquired through systematic study of natural landscape organization. Gross and Brown (1987) studied general basin parameters (slope, stream length, percent hydric soils, watershed area) and vegetation types of 12 first order streams in Florida to design reclamation schemes for various types of streams.

Recently, planners have used the services of landscape architects to enhance the native character of the created or restored site, fitting the built landscape into the natural design of the surrounding area. Landscape architects on the Tangipohoa Scenic River Project, Tangipohoa Parish, Louisiana, were involved from the initial right-of-way planning through the pipeline maintenance phase (Abbey 1988).

Design objectives of relocating a segment of Beaver Creek due to construction of the Plaza Lodge in Avon, Colorado, identified the need to redesign the stream channel to provide visual and physical access to the stream; create flat, ponded areas; and restore native vegetation and stream habitat (Tupa et al. 1988). To address design objectives, a design team, consisting of a landscape architect, a hydrologist, and an ecologist, was assembled. The landscape architect was involved with aspects such as visual analysis, site conditions, pedestrian concerns, developer's ideas, and planting plans. The hydrologist provided input on sediment load, meander frequency, channel flood levels, channel design, control structures, and water features. The ecologist provided advice on vegetation types, habitat conditions, wildlife and fisheries, habitat treatments, and construction plans.

Information needed for an adequate engineering design for the restoration of a gold-mined section of the Blue River near Breckenridge, Colorado, included drilling wells to monitor groundwater levels, establishing stream measuring stations, collecting sediment transport data, and surveying existing channel and adjacent rockpiles (Roesser 1988). From observation of the existing channel and accounts of historical behavior, it was obvious that the system in its existing condition was highly unstable. The design consisting of reducing channel slope, installing drop structures, and constructing localized areas of bank protection was the most economical and aesthetically pleasing alternative.

Highway construction projects may involve relocation of a portion of a stream or river. Design of these relocated sections should follow natural, high quality sections of the stream. In highly degraded streams, designing a more stable stream channel may be prerequisite to reestablishment of channel bank and floodplain vegetation (Jackson and Van Haveren 1984). Especially important is assessing the direction of the disturbance from the geomorphic norm and determining both the probable cause and current watershed conditions. A disturbed channel is an effect of watershed conditions, and the conditions causing the disturbance must be corrected or the design will most likely fail. Channel design involves duplicating the geomorphic characteristics of the more stable channel reaches in the same physiographic setting and making necessary modifications for sufficient bank stability to promote vegetation.

TECHNIQUES

A number of general manuals in the WCR Data Base include techniques useful for riparian ecosystem creation/restoration, or habitat improvement measures directed toward wildlife. Ambrose et al. (1983) present guidelines for mined lands in the south-central U.S., including fish and wildlife needs (food, water, cover), revegetation (bed preparation, seeding, transplanting, maintaining vegetation), stabilizing soil, stream improvement, and fencing. Leedy and Franklin (1981) discuss approaches for fish and wildlife planning and management for coal surface-mining reclamation in the eastern U.S. Topics useful for riparian restoration include reclamation planning; protection of existing streams; establishing and managing streamside vegetation; fencing; providing nesting, resting, and cover devices for fish and wildlife; and evaluating management success.

Nelson et al. (1978) developed a guide for selecting effective habitat improvements for streams and reservoirs. Measures recommended by the FWS are identified, and the effectiveness of these measures is critically evaluated. The guide includes discussions of dam discharge, stream flow, instream devices, artificial meanders, bank cover, bank stabilization, food and cover plantings, grazing control, zoning, and a variety of fish and wildlife habitat improvement measures (e.g., nesting structures, fishways, wildlife crossings). The main emphasis of the guide is not riparian ecosystems; however, some techniques are useful for riparian ecosystem creation or restoration.

Platts et al. (1987a) present a summary of techniques that have been used to prepare, seed, plant, and protect riparian revegetation sites. McCluskey et al. (1983) present a guide to planting willow cuttings. For many areas, cuttings of willows are easier to obtain and cheaper than transplants and can be taken from local sources better adapted to specific site conditions. A short discussion of evaluating a stream for need and suitability for willow plantings and maintaining the project site also is included.

The North Carolina Wildlife Resources Commission (1979) has set standard guidelines for stream relocations in the State to facilitate road project reviews by the Commission and to assist engineers in designing projects. Topics include matching original channel length, slope, meander pattern, depth, and width; sloping banks; stabilizing banks with riprap and vegetation; planting trees and shrubs; fencing; using suitable substrates; installing culverts and stream crossings; and using instream structures (boulders, low rock and stone dams, deflectors) to enhance habitats of low-, medium-, and high-gradient streams.

The American Fisheries Society--Western Division (1982) presents best management practices for Western streams, including tailing pond construction in mined areas (used to settle out finely ground rock and prevent accidental release of toxic materials to the aquatic ecosystem), mine pond reclamation, enhancing channelized streams, stream relocation, revegetation techniques, and restoration of riparian ecosystems.

Consideration of natural succession on man-made habitats is important in any creation effort. Unfortunately, few studies have examined natural succession on created riparian ecosystems. An investigation of plant succession on dredge spoils (consisting of unsorted boulders and cobbles with intervening swales of fine-textured soils and standing water) on the Merced River in central California revealed that vegetation is generally not diverse due to slow weathering of spoil and lack of soil moisture (Whitlow and Bahre 1984). Only in a few swales with moist, shallow soils and standing water was vegetation diverse or structurally complex. Results indicated that 50 years or more were required for the accumulation of well-developed flora. Structural changes are expected to be even slower, correlating with slow soil development.

A study of vegetation succession in relation to age of river stabilization structure along the Missouri River floodplain from Sioux City, Iowa, to Rulo, Nebraska, revealed that early herbaceous vegetation had little or no significance in the future course of succession (Vaubel and Hoffman 1975). Initial stages of succession began with willow and cottonwood (Populus deltoides); shrub species did not appear until 18 years later. Few relationships were found between soil characteristics and plant communities, probably as a result of immature soils exhibiting parent material characteristics. However, soils tended to have a higher clay content and greater amounts of nitrogen and organic matter in mature floodplain communities dominated by oaks (Quercus spp.), basswoods (Tilia spp.), and hickories (Carya spp.). Relating vegetation succession to age of river structure was found to be a precise method of developing a time-scale of vegetation development, which could be valuable in managing riparian habitats along these structures.

Although some channelized streams revegetate by natural succession, the extent and rate at which reestablishment occurs is unpredictable and depends on a number of little-understood variables (Goldner 1984). These variables include channel slope lining (concrete or riprap), availability of upstream seed sources, soil temperature and moisture, streamflow regime and velocities, steepness of side slopes, fertility and compactness of fill material, and intensity of vegetation and sediment removal in the channel to maintain the constructed flow capacity.

Removal of competing vegetation can result in a substantial increase in emergence and growth rates of new willow shoots (Harrington 1986). New stems appear to be suppressed by existing stems. Survival of new stems also is affected by water table fluctuations. Constant water table level throughout the growing season resulted in the greatest spreading rates of clonal sandbar willow (Salix interior) in Wisconsin.

Various smaller-scale case studies and laboratory or field experiments demonstrate the usefulness of some techniques used to create or restore riparian habitats (Table 2) and are included in the discussion below under the main technique used in the creation/restoration effort. Examples of more extensive case studies, well documented in the literature, are discussed in the Case Studies section.

Table 2. Some experimental field studies and smaller-scale case examples from the WCR Data Base involving various techniques (grouped by main technique) used to create or restore riparian ecosystems.

Technique(s)	Location (source)
Planting	
Cottonwood cuttings; irrigate; fertilize	Lower Colorado River, border of Arizona and California (Anderson et al. 1984; Disano et al. 1984)
Various trees and shrubs; weed; irrigate; fertilize; use herbicides	Flood control channels, Santa Clara County, California (Goldner 1984)
Cottonwoods and willows at various depths; fence; control beaver	Rio Grande floodplain, south of Albuquerque, New Mexico (Swenson and Mullins 1985; Swenson 1988)
Various trees and shrubs; irrigate with wastewater	Escondido Creek, San Diego, California (LaRosa 1984)
Fencing	
Fence only	Big Creek, Rich County, Utah (Duff 1979)
Fence only	Rattlesnake Springs, south-central Washington (Rickard and Cushing 1982)
Plant trees and shrubs; slope banks; install gabions; riprap	Texas Creek, Colorado (Prichard and Upham 1986)
Slope banks; riprap; seed grasses	Fifteenmile Creek, Wasco County, Oregon (Newton 1984)
Introduce beaver	Several streams in southwestern Wyoming (Apple et al. 1984)
Install artificial redds; stock trout	Bone Draw, near Eden, Wyoming (Smith and Dunder 1984)

(Continued)

Table 2. (Continued)

Technique(s)	Location (source)
Landforming	
Create rock sills in a high mountain wet meadow	Willow Creek, California (Clay 1984)
Remove debris and dead trees blocking flow; slope banks; riprap	Briar Creek, Mecklenburg County, North Carolina (Keller and Hoffman 1976)
Meander stream; slope banks; remove silt from channel; provide fish shelter; plant trees and shrubs	South Fork Yuba River, Placer County, California (Warner 1965)
Create meanders, pools, and riffles; install deflectors, log structures, and boulders	Three streams on mined land in Illinois and Indiana (Thompson 1984)
Create ponds and marshes; grade slopes; transplant topsoil; seed grasses; transplant and plant trees, shrubs, and herbaceous plants; transplant stumps	South Prong Alafia River tributaries, west-central Florida (Robertson et al. 1987)
Relocate stream; create ponds; plant shrubs and herbaceous plants; place boulders and cobbles in streambed and on bank; install drop structures	Beaver Creek, near Avon, Colorado (Tupa et al. 1988)
Recontour channel; remove rocks and cobbles; plant shrubs and trees; seed grasses; grade slopes; install drop structures; transplant topsoil	Gold-mined section of Blue River, Breckenridge, Colorado (Roesser 1988)
Create impoundments in bottomland hardwoods and vary water levels	Mississippi Delta, near Greenville, Mississippi (Broadfoot 1967)

(Continued)

Table 2. (Concluded)

Technique(s)	Location (source)
<u>Installing instream devices</u>	
Small rock dams; restore gravel beds; increase fish access	Stream near Montreal, Quebec, Canada (Burgess 1985)
Boulders and snags; riprap; slope banks; plant trees and shrubs	Tongue River, Wyoming (Gore and Johnson 1979)
Check dams; grade slopes; transplant topsoil; fertilize; seed grasses; fence	Alkali Creek, west-central Colorado (Heede 1979)
<u>Treating soil</u>	
Spread and disk-in limestone; fertilize; seed grasses; plant trees and shrubs	Surface-mined land, Ollis Creek, Campbell County, Tennessee (Starnes et al. 1978)
Various trees; grade slopes; transplant topsoil	Small streams, marshes, and bottom-land hardwood forests at Big Four Mine, west-central Florida (Sandrick and Crabill 1983)
Cover soil with mixture of overburden and clay or topsoil; fertilize; fence; plant trees and shrubs	Phosphate-mined land, Sink Branch, central Florida (Robertson 1984)

PLANTING

Over half the experimental field studies and smaller-scale case examples from the WCR Data Base (Table 2) involved planting or seeding either as the main technique used or to supplement other techniques (e.g., seeding grasses to accelerate vegetation recovery on fenced sites; planting trees or shrubs to accelerate establishment of riparian growth on banks of relocated streams). These case examples and other records in the data base that discuss laboratory studies or present general overviews were used to summarize information concerning three aspects of planting riparian vegetation: selecting plant species, seeding, and transplanting vegetation.

Selecting Plants

Vegetation should be selected on a site-specific basis (Chapman et al. 1982). Knowledge of particular combinations of substrate, microclimate, nutrient and water level regime, and the dynamics of riparian plant communities in both time and space, will greatly aid in riparian ecosystem creation or restoration.

Because of their high edge-to-area ratio, riparian ecosystems have large energy, nutrient, and biotic interchanges between aquatic and terrestrial systems (Fredrickson and Reid 1986). Plant composition, habitat structure, and productivity are largely determined by the timing, duration, and extent of flooding.

The physiological impact of changes in water level on trees depends on the tolerance of the tree to maintain its present root system, the soil conditions, and water level changes. Short- and long-term impacts of water level changes on reproduction, roots, hormones, photosynthesis, and growth are discussed by Tesky and Hinckley (1977). The authors also present an overview of the physical and metabolic mechanisms of tolerance and soil- and water-level factors that affect plant response. The oxygen content, chemistry, and nutrient availability of the soil can influence how well plants respond to flooding. For example, high concentrations of sodium, manganese, aluminum, iron, nitrites, and sulfides during flooding are often responsible for plant toxicities.

Significance of a particular hydrological event for a plant species' distribution must be judged in a temporal perspective that takes into consideration the plant's length of life, its growing season, and particular times in its life cycle that may be more sensitive to submergence (Wakefield 1966). For example, growth of annuals and perennials of riparian zones on an alluvial fan of the Snake River near Clarkston, Washington, was related to somewhat different hydrologic phenomena. The lower distribution of spring annuals was related to winter flood peaks and time period during the growing season that a given level of the fan was exposed. The lower distribution limits of perennials appeared to be affected by exposure period during the growing season, duration they were submerged, and effects of flooding during critical periods of development (e.g., germination, seedling).

Assuming that stream flow is a major vehicle of seed dispersal to riparian zones, it is logical to consider controlled flooding as a method of vegetation establishment (Platts et al. 1987b). Timing of flooding is critical because seed viability of some species is short (e.g., less than 2 weeks for willows). Flooding should be avoided during periods when the stream is transporting noxious weeds.

Selection of plants for revegetation may involve not only consideration of native wildlife species, but also of plants that provide necessary resistance to erosive stream flows in heavily eroded areas. Revegetation specifications should be developed based on an inventory of stream hydraulics and other site conditions and a design that considers adapted plants and their erosion control characteristics, hydraulic limitations of revegetation, desired fish and wildlife habitat, and suitable methods of installation and maintenance (Carlson 1979).

Carlson (1979) discusses these characteristics and methods for streamside revegetation efforts in the Pacific Northwest.

Usually, flood control maintenance in California is more involved with clearing riparian vegetation than planting it; however, efforts are being made to plant vegetation on highly erodible sites. On the Murphy Slough of the Sacramento River near Chico, willows and cottonwoods are being planted to aid in eventually reclosing the mouth of the Slough (Chaimson 1984). Benefits other than providing wildlife habitat include sediment deposition, velocity reduction, and redirection of flows. In Santa Clara County, California, revegetation along flood control channels was more successful when predominantly natives associated with riparian communities of the county were planted, weeds were removed from the site, and an irrigation system was used to promote initial growth (Goldner 1984).

Sediment texture also can influence establishment of riparian seedlings. On gravel bars of lower Dry Creek, Sonoma County, California, willow establishment was higher on bars where surface sediment size was less than 0.2 cm (McBride and Strahan 1984). Cottonwood (Populus fremontii) established more densely on areas of intermediate and large-sized sediments (0.2-1.0 cm), and mule fat (Baccharis viminea) dominated on larger sediments. Changes in gravel bar landforms can result in significant losses of established trees as well as young seedlings and saplings. Areas protected from swiftest currents are best suited to withstand high winter flows that can occur in this area.

A number of limiting factors may affect the success of bottomland hardwood plantings in the Southeast (Haynes and Moore 1988). Native regeneration relative to achieving a diversity of tree species was an important consideration on National Wildlife Refuges in this region. Other factors were: (1) drought during the growing season or a late freeze following plantings; (2) standing water and high temperature on sites with young seedlings; (3) flooding on sites where the species planted are not adapted for the duration or depth of flooding; (4) damage or destruction of seeds or seedlings by rodents, rabbits, or deer; and (5) poor seed viability or poor quality of nursery stock.

Field and experimental studies have demonstrated the influence of various environmental conditions on the species composition of bottomland hardwoods. Hosner and Boyce's (1962) study on the tolerance of various bottomland hardwoods to water-saturated soil indicated that occurrence of continuously saturated soil conditions for long, but varying, periods in bottomlands results in a competitive advantage for certain species (e.g., green ash [Fraxinus pennsylvanica], willows) and subsequently affects species composition of bottomland stands. Amount of exposure to direct sunlight and amount of litter and ground cover also can affect species composition, with cottonwood (Populus deltoides) and willow seedlings preferring direct sunlight and lack of litter (Hosner and Minckler 1960).

Selection of plant species for revegetation can be complicated by the fact that riparian communities are not always a distinct climax biotic community. On Sycamore Creek in central Arizona, Campbell and Green (1968) sampled a 21-mile sector of mountainous terrain and determined that due to large-scale changes in habitats caused by recurring floods, erosion, and deposition, development of immature stages of species is common, and the riparian association never reaches a climax stage because of these physiographic factors. Thus, in this semiarid location, the stream-channel vegetation is undergoing perpetual succession, which must be considered in efforts to restore this habitat.

A list of grass, broadleaf, and woody riparian species recommended for planting in various disturbed riparian zones is presented in Platts et al. (1987a). Monsen (1983) discusses planting conditions in riparian zones of the Intermountain Region and presents a list of grasses and broadleaf herbs recommended for riparian plantings within major plant communities of this region.

Wildlife values should be considered in both the selection of plant species and the structural arrangement of the plantings to achieve the highest functional use as wildlife habitat. For example, avian populations were rapidly enhanced by revegetating riparian zones with native riparian species of vegetation along the lower Colorado River (Anderson and Ohmart 1984). Under appropriate planting conditions, native trees grew 2-3 meters annually and shrubs matured and fruited the first year. Careful planning ensured almost immediate use of the area by a large and diverse avian population during most seasons. Clearing of the restoration site (if required) should be done selectively so that all native trees and all dead trees or trees with large dead snags are left intact to attract bird species that use snags as perches and cavities for nesting.

Seeding

Seeding sites is less expensive than transplanting cuttings or seedlings (Ambrose et al. 1983; Haynes and Moore 1988). Direct seeding eliminates costs associated with growing seedlings in a nursery and is less time-consuming than transplanting seedlings. However, seeding of shrubs and trees is generally less successful than transplanting cuttings or seedlings (Ambrose et al. 1983). One exception to this is direct seeding of bottomland hardwoods of the Southeast (Haynes and Moore 1988). Direct seeding appears to result in some survival advantages with regard to climatic and soil conditions at the time of planting. For example, an acorn planted under adverse conditions would likely remain in a dormant state until germination conditions are satisfactory. On the other hand, a seedling planted under adverse conditions would be stressed and possibly killed. A disadvantage in direct seeding of acorns is that rodents can cause these plantings to fail by digging up and eating the seeds. But this has generally not been a problem except if acorns are planted under an existing canopy. Transplanting of seedlings appears to be a better method for light-seeded hardwood species in the Southeast (e.g., cypress [*Taxodium* spp.] and tupelo [*Nyssa* spp.]).

Sandrik and Crabill (1983) found that red maples (*Acer rubrum*), wax myrtles (*Myrica cerifera*), and bay species naturally reseeded disturbed sites from adjacent floodplain forests at the Amax Big Four Mine in west-central Florida. Red maples reached 15 feet in height 6 years after the experiment started. Survival of potted or bare-root trees varied with species planted.

Covering seeds is essential to most germination and seedling establishment. Various methods can be used to enhance success rate of the simple hand broadcast method of seeding, including seed drilling, hydroseeding, or cyclone seeders (Ambrose et al. 1983; Platts et al. 1987a).

Erosion control matting/blankets of dead plant materials or organic material provide temporary cover for exposed soils and moderate the effects of rainfall impact, runoff velocity, and blowing winds, and are particularly important when seeding slopes to provide protective cover for seedbeds, reduce evaporative losses, and stabilize seed location until germination (Abbey 1988). Matting made of straw, wood or coconut fibers, or synthetic materials costs more than simple layers of straw, but is more efficient.

Transplanting

Transplanting cuttings or seedlings is normally required to assure revegetation of trees and shrubs. Cuttings taken from local native stock are recommended (Anderson and Ohmart 1979; Anderson et al. 1984). Cuttings started in a nursery survive and grow better than direct plantings to the field (Anderson and Ohmart 1979, 1985). Fertilization and irrigation often are used to enhance initial seedling establishment. Fencing may be necessary to protect seedlings from wildlife (e.g., rabbits, deer) or cattle grazing.

Irrigation generally is required for successful riparian revegetation efforts in the arid Southwest (Disano et al. 1984). Irrigation for the first 150 days may be necessary for successful establishment of cottonwoods planted in these regions. In desert riparian areas, which are subject to prolonged and extreme desiccation, it is imperative to ensure that roots of the new vegetation gain access to the water table (Anderson and Ohmart 1979). Time of planting is important. Winter is the best time for planting desert riparian areas due to lower evaporation rates and thus greater saturation of soil from surface to water table. Trees or shrubs planted in winter will have a developed root system and suffer few side effects should the irrigation system fail.

During a severe 2-year drought in California, planting of various trees and shrubs along flood control channels in Santa Clara County without the use of irrigation systems resulted in the loss of about 75% of the plants (Goldner 1984). Later projects that incorporated a drip irrigation system with an emitter head placed under the mulch of each watering basin resulted in loss of only 10%-15% of planted trees and shrubs. Vandalism of the irrigation system and predation by rabbits and squirrels were responsible for most losses.

In river bottoms, water table depth usually determines moisture supplies to tree roots. In some cases, the water table may be so near the soil surface that it limits aeration, in others it may be below the reach of young roots. Juvenile cottonwoods benefit by water tables in the lower portion of the normal root zone; however, they will likely die in high water tables where soil is saturated for extended periods (Broadfoot 1973).

Large cuttings (13 to 20 feet long) of cottonwood (Populus fremontii and P. angustifolia) and willow (Salix nigra) were successfully established in areas of deep water tables (7 to 12 feet) on the Rio Grande floodplain south of Albuquerque, New Mexico (Swenson and Mullins 1985). Using dormant cuttings and planting cuttings at anticipated growing season water table depth (rather than above it) were recommended for best survival. Dormant poles of cottonwood and willow planted on plots with naturally fluctuating water levels had lower survival rates than those with constant water levels (Swenson 1988). Poles set above the growing season water table had lower survival, as did poles cut after breaking dormancy. Certain precautions are necessary when using this method, including fencing the area from livestock, avoiding flooding for periods longer than 3 weeks, and controlling beaver (Castor canadensis) activity.

In San Diego, the Escondido Creek Project design involves use of wastewater from a planned water reclamation facility to irrigate 2,000 native tree plantings over 4 ha of floodplain (LaRosa 1984). Wastewater must meet State and local regulatory agencies' criteria for levels of constituents (chemical, physical, bacterial, and other biological properties). Reclaimed water in California presently is used to irrigate fodder crops, greenbelts, golf courses, orchards, and vineyards. Problems of using treated wastewater include the higher content of salts and nutrients. Although many species proposed for planting are salt-tolerant, water management plans for irrigation must consider salt build-up in root zones, changes in groundwater quality, and other impacts of wastewater reuse. Enough water must pass through the soil profile to carry away dissolved minerals.

FENCING

Fencing created or restored riparian zones from livestock grazing is used particularly in the western U.S. (Table 2). Livestock grazing can have detrimental effects on riparian vegetation. Areas with heavy livestock use also have increased total and fecal coliforms in waters compared to ungrazed or lightly grazed areas, decreased invertebrate diversity, and decreased use by spawning fish due to increased silt-sediments (Duff 1979).

Duff (1979) stresses the need to consider riparian-aquatic habitats as separate pastures from uplands within grazing management allotments of the Bureau of Land Management to ensure protection of this sensitive habitat from overgrazing. A minimum of 8 years of exclosure of riparian vegetation on Big Creek, Rich County, Utah, was necessary to restore the habitat for productive fish and wildlife uses, as well as water-quality maintenance (Duff 1979). After 10 years of livestock exclusion, Rattlesnake Springs, a small permanent spring/stream in south-central Washington, supported a nearly continuous narrow corridor compared to the extremely sparse amount of riparian trees and shrubs present before fencing (Rickard and Cushing 1982).

Experimental habitat treatments on three segments of Texas Creek in Colorado consisted of: (1) deferred seasonal livestock grazing with no habitat treatment; (2) fencing to exclude livestock with intensive habitat treatment of gabion drop structures, planting willows, resloping, and placing riprap along a portion of the streambank; and (3) fencing with no habitat treatment (Prichard and Upham 1986). The best improvement in habitat quality occurred on the area fenced and under intensive habitat treatment. Gabions instantly improved the pool/riffle ratio, began to develop well-defined redds at the tail of each pool, and greatly enhanced the recovery of vegetation by subirrigation. In 3 years, banks were stabilized; undercuts were well developed in 5 years. In 6 years, heavy bank cover of medium to tall trees and shrubs developed, augmented by willow plantings and streambank stabilization. All three areas showed an increase in brown trout (Salmo trutta), with the second treatment showing the widest range in trout size, relating directly to habitat treatments. In this case, removing livestock alone did not greatly improve the riparian habitat over the 6 years of the study.

Fifteenmile Creek, a small Columbia River tributary in north-central Oregon, had been seriously degraded due to increased crop production, livestock grazing, fires, herbicides, and rechanneling by landowners attempting to reduce field erosion and produce more regularly shaped fields to ease cultivation and irrigation (Newton 1984). Severe flooding problems prompted the Wasco County Soil and Water Conservation District to develop methods to prevent future floodings. Corrective practices included sloping vertical cut banks, seeding banks with grass, armoring vulnerable sites with riprap, constructing rock check dams to reduce stream velocity, and fencing the stream corridor to exclude livestock and encourage revegetation. The level of stream corridor recovery was dramatic, but on areas of continual livestock grazing, vegetative cover was severely retarded or nonexistent. Thus, fencing was necessary through agricultural areas for recovery of the riparian vegetation along this severely degraded stream. In areas of livestock exclosures, continuous bands of young trees formed within 5 years, and grasses, sedges, and rushes effectively armored previously erodible banks.

In southwestern Wyoming, the use of fencing was supplemented by the introduction of beavers to encourage the development of willow and other riparian plants in an expanded riparian zone (Apple et al. 1984). The technique appears to be successful in stabilizing streambanks and improving riparian and aquatic habitat in cold desert, gully-cut stream systems of this region.

Livestock grazing in riparian habitats can result in heavy siltation of streams, making them unsuitable for fish spawning. In addition to fencing the area to prevent further grazing pressure, other habitat improvement methods directed toward improving the fisheries may be necessary. Due to poor streambed conditions on Bone Draw, an ephemeral tributary of the Big Sandy River in Wyoming, artificial redds were placed in the streambed to create suitable habitat for establishment of a seasonal anadromous trout run and the stream was stocked with trout (Smith and Dunder 1984). Siltation was still a problem after initial placement of gravel for the redds, but should improve as the riparian habitat recovers from grazing pressure.

Stock water access, stream crossings, and impacts of flooding need to be considered in fencing designs on private land. Reichard (1984) presents some designs for livestock barriers, stream crossings, and water access points. She also presents designs for various bank stabilizing methods to create stable ground for the growth of planted or volunteer riparian vegetation: willow mattresses, brush and tree deflectors, and double fence revetment. Planting vegetation on protected streamside land may significantly accelerate riparian thicket recovery. In some situations, competition from pasture plants and moisture stress can be the primary limiting factors for rate of riparian reestablishment. Irrigation and suppression of competing pasture plants may be necessary for native plant establishment.

LANDFORMING

Creation of riparian ecosystems, or restoration of severe channel damage, typically involves some type of landforming. Landforming can consist of relocating a stream, recontouring a channel by sloping banks, building meanders, creating pools, or creating marshes or ponds within the stream (Table 2).

Rock sills have been used to reform wet meadows drained as a result of stream erosion, brought about by livestock grazing. On Willow Creek in California, grazing had impacted vegetation so severely that gullies 1-2 meters deep had formed through wet meadows and eroded in an upstream direction, changing the moisture regime so that native grasses and other meadow plants could no longer survive (Clay 1984). With loss of vegetative cover, erosion was accelerated and eventually the entire area was converted to bare ground or brush. Slots cut across the channel formed large rock sills that allowed deposition to fill the channel upstream from each sill to its crest, raising the channel bottom and thus the water table. The sides of the channel developed a gentle slope, which allowed wet grasses and shrubs to become established.

In urban areas, stream restoration is an alternative to conventional channelization involving stream straightening and deepening with heavily riprapped banks. On Briar Creek in Mecklenburg County, North Carolina, a channelized stream was restored by removing brush, debris, and dead trees that blocked water flow; sloping banks to less than vertical inclination; sloping meander bends to produce sandbars; seeding banks; and sparingly using riprap along highly erosive slopes (Keller and Hoffman 1976). The result was an esthetically pleasing urban stream with greater wildlife habitat potential and lower flood hazard.

On a relocated section of the South Fork of the Yuba River in California, efforts were made to provide fish habitat by: (1) correcting the ditchlike appearance by meandering the stream as much as possible within the limited area available, (2) sloping and stabilizing stream banks to prevent additional silt from entering the stream, (3) removing silt from the stream channel to provide food-producing and spawning areas for fish, (4) providing shelter for fish, and (5) providing streamside vegetation (Warner 1965). A tree-planting operation improved the appearance of the streambank and provided shade for both fish and anglers.

The need to relocate streams in surface-mined areas is quite common due to the great expanses of land that mines encompass. To better understand how to ensure proper aquatic habitat restoration in mine locations, fish and invertebrate populations were studied at three stream relocation sites: Pipestone Creek, Perry County, Illinois; Otter Creek, Fulton County, Illinois; and Honey Creek, Clay and Vigo Counties, Indiana (Thompson 1984).

Few habitat improvement techniques were used on Otter Creek, although some shale and small gravel was available within the new streambed for habitat development to occur. After 6.5 years, Otter Creek was not comparable in most aspects to the natural channel and appeared to be more sensitive to natural perturbations, such as flooding and drought conditions, than the other relocations.

The Honey Creek site had the most extensive habitat treatment, including creation of meanders, large pools, and riffles, and the installation of wing deflectors, log structures, and random placement of boulders. No extensive riparian tree zones existed along the sites, but they were at least partially shaded and had up to 100% cover. Of the three sites, Honey Creek developed the greatest amount of habitat diversity and showed the most habitat stability resulting in the closest match in species composition of fish and invertebrates with higher quality natural channels.

Traditional habitat reconstruction techniques appear to work well in stream relocations in surface-mined land, but the type and quantity to be included should be based on premine conditions and the anticipated postmine location. In addition, habitat replacement should be tied closely with proper stream channel design and erosion control. Based on results of Thompson's (1984) study, it appears that streams can be relocated and recover to premine conditions if all major habitat components are restored. This is accomplished primarily through proper preplanning and implementation.

Tributaries of the South Prong Alafia River in the phosphate mine district of west-central Florida were reclaimed by creation of ponds and marshes within the stream. Other techniques included transplanting topsoil and planting various woody and herbaceous plants (Robertson et al. 1987). Aquatic invertebrate data from the first several years after reclamation indicated that richness of stream systems reclaimed with marshy areas exceeded that of undisturbed streams, but richness of reclaimed lotic sections matched that of similar undisturbed streams.

Creation of ponds in a stream also was used in the Beaver Creek Relocation Project near Avon, Colorado (Tupa et al. 1988). A segment of the creek was relocated to facilitate construction of a ski lodge. Problems associated with pond construction included minor sedimentation. Detailed manipulation of pond flow characteristics had to be adjusted to ensure that the majority of stream sediment stayed in the channel and did not fill the ponds.

Restoration of a section of the Blue River near Breckenridge, Colorado, involved nearly complete restructuring of the channel (Roesser 1988). The area had been heavily gold-mined from the late 1800's through 1942. Rock and cobble piles reached 30 feet above old channel grades, and most of the river flowed beneath and through the piles. Restoration consisted mainly of removing rocks and cobbles, recontouring the channel, and revegetation. Drop structures were used to create a stable channel. Although considered highly experimental, these techniques appear to be successfully restoring the channel's stability.

In areas of the Mississippi Delta, shallow impoundments have been created to supply soil moisture to bottomland hardwoods that have experienced considerable dieback and mortality due to drought in the 1950's (Broadfoot 1967). Average increase of radial growth was about 50% for all species of hardwoods impounded on an experimental area near Greenville, Mississippi, and subjected to various flooding regimes. Oxygen supply could potentially be a problem in using this technique. However, most artificial impoundments are charged either by rainfall or ground wells within the forest and are relatively free of sediment.

INSTALLING INSTREAM DEVICES

Several studies have used instream devices in conjunction with efforts to restore riparian ecosystems (Table 2). Instream devices are primarily used to enhance fish habitat by increasing flow, creating riffles and pools, restoring gravel spawning beds, and increasing fish access. Instream devices also can provide bank stability, thereby aiding in restoration of riparian vegetation. Hall and Baker (1982) summarized use of instream devices over the last 50 years for rehabilitating and enhancing fish habitat in the West. These techniques are further described in Reeves and Roelofs (1982).

Even simple techniques involving construction of small rock dams and deflectors result in creation of pools and deepening of stream channels to enhance trout populations. Instream cover and bank cover also are commonly used fish habitat improvement techniques. Burgess (1985) demonstrated that in addition to increasing trout biomass, these stream habitat improvement techniques also affected populations of nontarget organisms on a study site in Quebec. Crayfish populations increased substantially in the improved section, which likely resulted in increased use of the area by mink (*Mustela vison*) and raccoons (*Procyon lotor*). These low cost fish improvement techniques may have great potential for improving habitat for invertebrate and mammalian populations in other areas.

The majority of the Tongue River restoration project in Wyoming was directed toward instream improvements (e.g., boulder placement, riprap, slope grading) (Gore and Johnson 1979). In addition, banks were hydromulched and planted with various combinations of local riparian trees and shrubs as part of an effort to restore the fisheries. Snags consisting of pine trees anchored and cabled into the bank were found to provide the only substantial cover and habitat for colonizing game and nongame fish.

A project in west-central Colorado demonstrated that a watershed dissected by a dense gully network can be stabilized and rehabilitated by the use of check dam systems, aided by improved vegetative cover through reduced cattle grazing and plantings (Heede 1979). The dams stabilized not only the structurally treated gullies, but also gullies within the network that were not structurally treated. Comparison with untreated gullies outside the project area showed that outside gullies widened three times as much as structurally untreated inside gullies. Check dams decreased gully depth by accumulating sediment deposits. In turn, gully bank stabilization was hastened and alluvial aquifer volumes increased. This increase, plus higher infiltration rates as a result of denser vegetation, led to renewed perennial streamflow after 7 years. Within 11 years after treatment, the check dam system and improved vegetation had reduced sediment loads in the flows by more than 90%, providing a substantial benefit to farmlands and ponds downstream. From this work, Heede (1979) concluded that only part of a gully network requires structural treatment: the mainstem gully and those tributaries controlling the local base levels of others.

TREATING SOIL

Soil treatments are used particularly for previously mined sites (Table 2). Riparian creation and restoration on these lands poses several unique problems. Spoil areas can be toxic to plants and thus revegetation can be difficult. Failure to revegetate spoil can lead to siltation and acid mine drainage that affects receiving streams and water supply reservoirs.

Along with disturbance from surface mining in the early 1970's, the Ollis Creek watershed, Campbell County, Tennessee, has been impacted by active logging for many years, barren lands because of acid spoil conditions, and old deep mines with acid mine drainage potential (Starnes et al. 1978). Due to pyritic materials associated with coal seams mixed with overburden material, efforts in the early 1970's to plant over a half million trees and to seed approximately nine tons of grass generally failed to provide the necessary cover. When the soil weathered, sulfuric acid formed, causing spoil pH to decrease (4.7-3.0). Water quality in receiving streams began to deteriorate. Silt carried by the streams was reaching a downstream reservoir, thus reducing its storage capacity.

To remedy these problems, the Tennessee Valley Authority used various combinations of soil treatments, regrading, and applying topsoil to the most critical areas. Treatments initiated during fall 1974 included spreading and disking-in agricultural limestone to raise spoil pH, fertilizing, seeding with grasses and legumes to provide a protective ground cover, and planting trees and shrubs the following planting season. Three years later, treatment sites contained 39% to 76% herbaceous cover and 1,727 to 4,868 woody plants/ha. Incorporation of lime and fertilizer into spoils was essential for successful revegetation of the acid sites. In addition, stream pH increased and other water quality parameters improved (e.g., turbidity, sulfates, and certain metals). Aquatic invertebrate fauna responded slowly to remedial treatments, but did appear to show trends toward recovery. No permanent fish populations were present, but fish periodically used the Ollis Creek tributaries.

Numerous attempts have been made to rehabilitate wetlands of the phosphate mine region of central Florida (Clewell 1983). Restoration of forested wetlands has been generally less successful than marsh restoration. Restoration of forested wetlands has focused on techniques of tree planting and not on introduction of understory plants. Various techniques for planting trees have been attempted. Successful restoration appears to be dependent on using a combination of techniques, including mulching with riverine forest topsoil. Irrigation is necessary for the first few years, unless near-saturated soils can be maintained during dry seasons. Several reforestation methods should be attempted to ensure a dense initial growth of trees. If these trees grow quickly, a canopy will begin to close within 4-5 years, protecting preferred undergrowth species transferred in the mulch.

Sandrik and Crabill (1983) found that transplanting organic mulch to restoration sites at the Amax Big Four Mine in west-central Florida provided a diverse seed and plant source and a quick start for marsh revegetation. In addition, this technique appeared to help control rapid cattail (*Typha* spp.) invasion on unvegetated wetland sites, which created undesirable monocultures.

Sink Branch, a perennial stream located in the phosphate mine region of central Florida, was diverted from its original course into a channel excavated on mined land reclaimed with a complex mixture of overburden and clay (Robertson 1984). Other restoration techniques included planting nine species of native tree seedlings, planting of emergent vegetation in the stream, and fencing to exclude cattle. Soil treatments incorporated into the experimental design were: (1) addition of fertilizer to holes in which trees were planted, (2) application of a 15-cm layer of organic topsoil, (3) application of a 30-cm layer, and (4) the control site (no treatment). Soil amendments incorporated into the reclamation plan at the mined site had no effect on growth or survival of trees planted over a 3-year period. However, overall survival differed greatly between species: Florida elm (Ulmus floridana), 94%; bald cypress (Taxodium distichum), 1%; sweetbay (Magnolia virginiana), 6%; and dogwood (Cornus foemina), 6%.

Physical water quality data after 6 months was similar between treated and control sites. Water flowing out of the channel was slightly lower in nitrogen and orthophosphate than water entering the channel, indicating that the channel had a slight positive effect on water quality by reducing the nutrient content of the water. After 1 year, density and diversity of aquatic invertebrates were similar between treated and control sites; however, the two sites supported different groups of species (e.g., isopods, amphipods, and snails from the treated channel; mosquitoes and predaceous diving beetles from the control site). Species richness was greater in the reclaimed channel than in the undisturbed control site.

MONITORING

Many techniques used to document and monitor riparian habitats are untested, and some were designed to optimize time rather than accuracy (Platts et al. 1987a). The value of information obtained from monitoring riparian ecosystem creation/restoration projects depends on the precision, accuracy, and comprehensiveness of the data used for interpretation and decisionmaking. Because past measurements can seldom be verified for quality, data must be collected with tested methods using a valid sampling design, followed by proper analysis and interpretation.

Platts et al. (1987a) present a comprehensive review of methods used to evaluate various components of riparian ecosystems. Guidelines useful for monitoring riparian ecosystem creation/restoration efforts are included in sections concerning sampling schemes, measuring vegetation, classifying riparian communities, determining various features of the soil, remote sensing, water column measurements, streambank morphology, measuring and mapping organic debris, and use of benthic macroinvertebrates to evaluate stream riparian conditions.

Determination of parameters to be monitored should be based on project goals and objectives (Platts et al. 1987b) and may include both independent (i.e., habitat) and dependent (i.e., population) parameters. Examples of independent parameters include frequency and duration of flooding; groundwater dynamics; channel morphology; streambank stability; streamflow characteristics;

water quality; vegetative composition, cover, and production; and stream shading. Dependent parameters may include density and diversity of fish and wildlife populations. Frequency of monitoring is based on project goals and deadlines. Monitoring can be conducted frequently in the beginning and less frequently after rates of trends are determined.

By far, the most common monitoring method has been to evaluate plant growth and survival over time. Monitoring plant species distribution below the level of community dominants provides superior benchmark information as well as a more sensitive scale to detect changes in water level, substrate type, and nutrient status (Chapman et al. 1982). If productivity studies are combined with detailed floristic measurements, results will yield far more sensitive and useful information regarding both the structure and function of the ecosystem than simple observations of dominant species distribution or survival.

Hydrologic responses should be monitored when riparian ecosystems are manipulated; however, this is usually left out of most research efforts (Skinner et al. 1985). Riparian ecosystem research should include determining: (1) water storage differences between degraded, natural, and improved habitats; (2) various water storage capabilities among different stream reaches; (3) improved riparian zone changes in flow regime, and possible prolonged release of water for downstream users; (4) hydrologic responses associated with each riparian zone improvement practice; (5) mechanisms of any possible reduction in nonpoint source pollution downstream as a result of riparian zone improvement practices; (6) hydrologic responses associated with grazing of improved riparian zones by livestock and wildlife; and (7) economic costs and benefits of improved riparian zones.

Monitoring methods need to be kept constant throughout data gathering (Anderson and Ohmart 1979). Pioneer efforts should be monitored until desired objectives have been achieved. Anderson and Ohmart (1979) recommended monitoring desert riparian systems in the lower Colorado River valley for at least 7 years to fully document establishment of plant communities. Anderson et al. (1979) stressed that long-term monitoring is especially necessary when restoration involves initial clearing of woody vegetation (e.g., to remove exotic vegetation) because habitat components are being removed. In addition, survival of riparian trees (e.g., cottonwoods) may change due to wind damage or disease before reaching maturity, which needs to be documented. Haynes and Moore (1988) reviewed efforts to reestablish bottomland hardwoods on 12 National Wildlife Refuges in the Southeast and found that even after 7 years desired plant species diversity had not yet been achieved on planted sites where natural regenerative processes were relied on to establish herbaceous understory plants.

Matter and Mannan (1988) stressed more frequent monitoring of creation/restoration efforts over the first 1-2 years after habitat construction so that unsuccessful manipulations (e.g., failed plantings) can be replaced or revised as necessary. Periodic (every 3-5 years) monitoring of selected conditions (e.g., amount and types of major plant and animal species) should be conducted to ensure that habitat, once established, is not lost.

A monitoring study also needs to be of adequate duration to determine how climate affects the ways in which wildlife reacts to vegetative structure

(Anderson and Ohmart 1979). Only then can a realistic evaluation of the impact or a prediction of the outcome of manipulation designed for enhancement be made. Anderson and Ohmart (1979) recommended that population data be collected for all major groups of animals (birds, mammals, reptiles, and amphibians) on a monthly or seasonal basis. Birds were found to be extremely responsive to habitat changes on the lower Colorado River and were used as the primary test group for Anderson and Ohmart's (1979) study.

Many avian population studies reported in the literature involve only the breeding season; however, this may not be the most critical season. Anderson and Ohmart (1979) found that bird populations reacted to structure (e.g., patchiness, vertical diversity, responses to particular plant species) less in summer than in other seasons. Populations in various plant communities tended to be more similar in summer than winter.

To determine effects of stream modifications (including improving riparian zones to provide cover for fish), Cooper and Wesche (1976) recommended monitoring trout populations for at least 5 years after stream restoration to follow 1 year-class through a life cycle.

Riparian ecosystem creation/restoration projects are often in impacted areas. Maintenance of ecosystem quality of the site requires three basic components related to monitoring: (1) a baseline biological-chemical-physical study of present conditions, (2) hazard evaluation based on knowledge of known potential pollutants entering the system and the estimated biological response to pollutants, and (3) a systematic and regular surveillance system designed to give early warning of impending harm (Cairns et al. 1979).

Proper monitoring of a created or restored riparian site over a long period of time and thorough analysis of the vegetation, animals, hydrologic regime, water quality, sediment deposition, and recreational use of this habitat will provide much-needed information for future creation/restoration efforts.

EVALUATING SUCCESS

A properly designed monitoring system is vital to determining success of riparian ecosystem creation/restoration efforts. Equally important is that project objectives be stated in quantifiable and measurable terms (Platts et al. 1987a). Unfortunately, objectives of creation/restoration projects are rarely stated in quantifiable terms, making evaluation of project success difficult, if not impossible.

Meeting an objective of returning a riparian site to "original conditions," or a close approximation thereof, may be difficult because those conditions may not be known due to the site's long history of human impacts (Cairns et al. 1979). Collection of historical data on the site can greatly aid in development of a restoration site plan and success criteria. Several studies have used historical regional lists to determine desired plant or animal diversity of the completed site (e.g., Anderson and Ohmart 1985; Hey and Philippi 1985a). Gross and Brown (1987) stressed that the long-term success of mine reclamation projects should be measured by how well the landscape functions, not by how well the design mimics the landscape that existed prior to mining.

Unfortunately, little information is available regarding success of riparian ecosystem creation/restoration projects (Platts et al. 1987b; Ischinger and Schneller-McDonald 1988). Data on survival and growth of planted vegetation have been the most commonly used parameters to support the success of these projects. Typically, these variables are measured for only the first few growing seasons. However, it may take several years beyond that time for the revegetated site to achieve desired species diversity. This is particularly true for the relatively slower growth of riparian hardwoods. A reestablished bottomland forest can take 40-60 years to become self-regenerating, and to produce the full value to many wildlife species (Haynes and Moore 1988).

The Washington State Department of Transportation sets standards for success of wetland mitigation projects as measured by the survival and growth of plants (Miller 1988). Projects are monitored annually using standard vegetation sampling techniques to measure coverage and species composition. Sites also are evaluated for wetland values. At the end of the first year of monitoring, the project should have 50% survival of species indicated on the revegetation plan. At the end of the fifth year of monitoring, a wetland project is considered successful if areal coverage by wetland species is 90% of adjacent natural wetland areas.

Ideally, success of a creation/restoration project should be based on a number of variables. One project that is attempting to measure a variety of parameters is the Des Plaines River Wetlands Demonstration Project in northeastern Illinois (Hey and Philippi 1985a; Hey 1988). To document changes in physical structure and vegetation with change in faunal composition over a 5-year period following habitat creation and restoration, baseline and subsequent data collecting will include water quality and chemistry, hydrology, soils, microorganisms, invertebrates, fish, amphibians, reptiles, birds, mammals, and human use, along with vegetation and productivity studies. The Fish and Wildlife Service Habitat Evaluation Procedures and Habitat Suitability Indices will be used for three species of mammals, nine nongame birds, and six fishes.

Quantitative comparisons with control sites lends support for documenting success of a creation/restoration effort. On the Lower Colorado River Project, a 4-year preliminary study of control sites was used to determine which species and components of vegetation attracted birds and nocturnal rodents during various seasons (Anderson et al. 1979). The information was used to design the revegetation project and to quantify expected avian and mammalian use of the proposed site. Success could then be quantified by comparing resulting use of the site with expected use by chi-square analysis.

Platts et al. (1987a) stressed inclusion of control areas that do not receive management treatments in evaluating success of riparian habitat improvement efforts. Treatment and control sites must have the same premanagement characteristics and the same potential for response to management to document changes actually attributable to management. Resources are frequently not monitored long enough to permit management responses to occur.

Unfortunately, there has been a tendency for neglecting advance consideration of statistical tests, often resulting in data that cannot be used to quantitatively support determination of project success.

Success of stream relocation projects involving riparian habitat improvements in mined areas has been determined by comparing aquatic invertebrate or fish populations with natural sites (e.g., Thompson 1984; Robertson et al. 1987). The Florida Department of Environmental Regulation often includes an assessment of aquatic macroinvertebrate colonization as one of its measures of success. Diversity must be similar to that in a reference wetland, either the identical wetland monitored before mining occurred, or in a nearby wetland with similar characteristics (Robertson et al. 1987).

Evaluation of the success of the Agrico Swamp Restoration Project in Florida involved comparisons between natural and reclaimed sites over 4 years, once sites had stabilized (Erwin 1986). Species richness, percent cover, survival, and growth of vegetation were measured. Diversity and abundance of macroinvertebrates of reclaimed sites were compared to natural communities. Improvement of water quality was termed successful as confirmed by State water quality standards. Monitoring of hydrology, tree seedling survival and growth, and wildlife and fish use of the reclaimed habitat will continue for 3 additional years.

Comparing success of creation/restoration projects conducted by different agencies or organizations can be difficult due to the wide variation in monitoring and evaluation techniques used. Nelson et al. (1978) addressed this problem in their documentation of successful and potentially successful habitat and population improvement measures accompanying water resource development projects (e.g., construction of dams and reservoirs) recommended by the Fish and Wildlife Service for reservoirs and streams of the western U.S. They classified the improvement as successful if it apparently accomplished a major part of its intended purpose, marginally successful if it accomplished a moderate part, and unsuccessful if it accomplished only a minor part, in terms of habitat and population categories. Confidence in the estimate of success as a function of the reliability of reports on actual biological effects was rated high, medium, or low. This rating was determined by whether the reported effects of a habitat or population improvement measure were derived quantitatively from field measurements or qualitatively from direct field observations or indirect reports of anglers or hunters.

Continued success of creation/restoration projects may depend on management, particularly in grazing-impacted areas. For example, Clay (1984) documented success of a high mountain meadow restoration project (as indicated by stabilized banks, raised water table and channel bottom, and filled eroded channels) in Modoc County, California, after 3 years of fencing. He stated that fencing could be removed, but only if grazing was managed. The U.S. General Accounting Office (1988) reviewed 22 riparian areas restored by the Bureau of Land Management or the Forest Service in the western U.S. and noted that the overriding factor in achieving success was improving the management of livestock to give the native vegetation more opportunity to grow. In some cases, fences were built to keep the livestock out of the area, either permanently or until the vegetation had recovered and streambanks were stabilized. In others, livestock continued to graze in the area, but their use was restricted by herding or fences, or a combination of both, to a shorter period of time, specific season, or only part of the area.

CASE STUDIES

Three well-documented case studies in the WCR Data Base (Table 3) further demonstrate techniques used for planning, implementing, and monitoring individual riparian ecosystem creation/restoration projects.

LOWER COLORADO RIVER

One of the most well-documented case studies is Anderson, Ohmart, and associates' riparian revegetation study on the lower Colorado River on the border of Arizona and California (Table 3). A detailed historical account is presented in Ohmart et al. (1977), which documents the continued decline in cottonwood communities along the lower Colorado River. This type of analysis is helpful in providing impetus for management decisions relative to wetland creation/restoration. Examining past conditions permits an evaluation of changes and a postulation of causes. Knowledge of the past also aids in formulating management plans for the future.

The first phase of the lower Colorado River study involved determination of vegetative parameters associated with large avian densities and diversities prior to restoration (Anderson et al. 1979). Birds were surveyed two or three times each month over a 2-year period. Communities were classified according to predominant vegetation and vertical structure. Differences in bird densities in 23 community types were documented by analysis of variance tests. A revegetation design was developed that maximized vertical and horizontal foliage diversity and included plant species of proven value to wildlife.

Revegetation efforts involved removal of the exotic salt cedar from a site and replanting this site and a nearly devoid dredge spoil site with native vegetation. Holes were augered for trees, and an irrigation system was installed to aid in plant establishment in this arid region. Three communities were superimposed on a single area. An early ephemeral stage was dominated by annuals of high wildlife value. Shrubs, the second stage, were planted to help offset early losses from clearing and to provide habitat diversity. The third stage of planted trees (e.g., cottonwoods, willows) provided the dominant vegetation. As trees mature their full potential value to wildlife will be achieved and a new balance of shrubs and trees will develop.

During the second phase, monitoring of changes, not only in vegetation but also in birds, mammals, reptiles, and invertebrates began, and statistical comparisons were made with control (native) areas. Changes in vegetation composition, community structure, and vertebrate densities and use have been documented in various reports over the 5 years of monitoring (Anderson and Ohmart 1982, 1985; Anderson et al. 1984).

Table 3. Three well-documented case studies of riparian ecosystem creation/restoration projects from the WCR Data Base.

Location	Objectives	Techniques used	Responses measured	Source(s)
Lower Colorado River				
Imperial County, border of Arizona and California	Restore/create wildlife habitat on dredge spoil.	Remove salt cedar; till; fertilize; plant trees and shrubs; seed grasses; stabilize banks; irrigate.	Vegetation; nongame birds; shorebirds; waterfowl; mammals; reptiles; invertebrates; soil; water quality; hydrology.	Ohmart et al. (1977), Anderson and Ohmart (1979, 1982, 1984, 1985), Anderson et al. al. (1979, 1984), Disano et al. (1984)
Des Plaines River Wetlands Demonstration Project				
Lake County, Illinois	Restore braided stream for wildlife habitat, flood control, water quality improvement, and recreation.	Widen floodway; form braided stream; create pond shelf in gravel pit; increase river surface area; decrease river depth; plant trees and shrubs; seed grasses.	Vegetation; water quality; water chemistry; waterfowl; shorebirds; fish; amphibians; reptiles; human use; economics; hydrology.	Hey et al. (1982), Hey and Philippi (1985a,b), Smith and Sather (1985), Holtz (1986), Hey (1988)
Agrico Swamp Reclamation Project				
Polk County, Florida	Restore wildlife habitat and water quality of phosphate-mined land.	Recontour land; form ponds; add soil; plant trees, shrubs, and emergents.	Vegetation; invertebrates; water quality; hydrology; fish; nongame birds; waterfowl.	Erwin (1986)

Growth and survival of planted trees have been well documented (Anderson and Ohmart 1982; Anderson et al. 1984). Soil and salinity data also were collected. Soil analysis included vertical and horizontal variation in soil distribution (Anderson and Ohmart 1982).

The lower Colorado River study exemplifies a well-planned effort to restore riparian habitat for wildlife. A historical evaluation and prerestoration surveys of vertebrates and vegetation provided baseline information to aid in the design of the creation/restoration effort. Changes in habitat and wildlife populations were carefully monitored and statistically tested, and results were published in numerous papers. The authors of these papers have stressed the need for careful site planning, development of diverse habitats, and continued monitoring of revegetation efforts. Anderson and Ohmart (1982) cautioned against using findings from a 2-year study to make predictions about growth and mortality of vegetation after 4 to 10 years. They stated that results should be considered preliminary until the site is at least 15-20 years old. Two years is not enough time from which to draw any conclusions beyond that time or beyond the range of variables studied.

DES PLAINES RIVER WETLANDS DEMONSTRATION PROJECT

In 1980, near Chicago, Illinois, a group of scientists, engineers, public officials, and citizens banded together to develop a convincing case for wetland restoration by forming Wetlands Research, Inc., with Dr. Donald Hey as director. Their goal was to develop and test design principles, construction methods, and management programs needed to re-create and maintain wetlands (Hey 1988). They also intended to show how reconstructed wetlands function. The ultimate goal was to redirect and reform current environmental policies and thereby change investment and management programs. The strategy for achieving these goals and objectives was to be embodied in a wetlands demonstration project.

The group began the project with a literature search of computerized environmental data bases to obtain pertinent information and develop a list of researchers to use as contacts (Hey et al. 1982). This information-gathering process was followed by field trips to representative wetlands to examine existing functions of wetlands.

Criteria for selecting a project site were established. These criteria included that the site was disturbed (thus would most benefit from restoration), was in public ownership, and had a low level of recreational use (for less impact during construction). A site incorporating 2.8 miles of the Des Plaines River and 450 acres of riparian land, 35 miles north of Chicago in Lake County, Illinois, fit the criteria and became Wetlands Research, Inc.'s Des Plaines River Wetlands Demonstration Project.

The Des Plaines River is polluted with both nonpoint source contaminants from a variety of land uses, including agriculture, and point source contaminants from small wastewater treatment plants. Vegetation was heavily grazed, and the site contained three abandoned gravel pits. The site was owned by the Lake County Forest Preserve District and received relatively minor recreational use by fishermen.

A baseline inventory of the site was used as the basis for the conceptual plan. The inventory included collecting data on landforms, soils, hydrology, water quality, vegetation, wildlife, and public access and use.

The conceptual plan included widening the floodway to increase river surface area and reduce depth, forming a braided channel, creating a shelf along the shore of a gravel pit lake to promote emergent plant growth, removing topsoil and stockpiling for later placement after landforming, reintroducing a variety of native wetland vegetation, and monitoring the water quality, natural habitats, flooding, and public use of the site. To aid in modifying the seasonal distribution of stream flow, water will be redistributed to river terraces by pumping, banks will be lowered, and old levees will be removed. Water quality will be enhanced by the increased evapotranspiration, infiltration, and recharge. Detention time will increase, providing greater opportunities for sediment settling and nutrient uptake.

Five distinct habitats are included in the plan: woodland, prairie, moist river terrace, marsh, and aquatic. Selection of species for plantings included applying an autecological rating based on the plant's ability to volunteer, rarity in the region, and adaptiveness to site conditions. Providing a high diversity of plant species also was a priority. Management of the completed project was expected to be fairly low. Pumping of water from the river up to the irrigated river terraces would not be a continuous or regular event; instead, it would depend on moisture needs and flood control. Prescribed burning will be used as a tool against invasion of detrimental weeds. Woody vegetation would have to be cleared if it encroached on the river's main channel. Recreation management is not expected to be intense because the area will be used as a self-guided interpretive trail system and a canoe trail.

The benefits of the project are difficult to quantify, but include improved wildlife habitat, water quality enhancement, flood control, and recreation. Hey et al. (1982) discussed some of these benefits, particularly reduced cost of water quality enhancement compared to conventional wastewater treatment systems. One of the central issues of the project is to demonstrate that wetland restoration will be a cheaper and more effective way of solving water quality and flooding problems than the various structural solutions of the past (Holtz 1986).

In 1987, about one-third of the restoration work was completed. Once completed, research on the area will continue for 5 years, and then the area will be managed by the Lake County Forest Preserve District (Holtz 1986). Four tangible products will be produced by this project: (1) a design manual describing the physical and biological parameters for constructing wetlands; (2) a management-operations manual describing long-term monitoring needs and operational strategies to maintain critical wetlands functions; (3) a documentary film showing the site as it was before, during, and after restoration, to illustrate changes in plant and wildlife communities and document improvement in water quality and water attenuation; and (4) a living demonstration, the restored site, maintained by the Lake County Forest Preserve District (Hey 1988).

Presently, detailed publications concerning baseline survey results; design, construction specifications, and site management; and research plans for the Des Plaines River Wetlands Demonstration Project are available through Wetlands Research, Inc. Research plans include examinations of the hydrology, water quality, geology, vegetation, soils, microorganisms, aquatic macrophytes, terrestrial insects, amphibians, reptiles, fish, birds, mammals, and public use of the area (Smith and Sather 1985).

The solution to water resource problems does not use restoration technology as an aesthetic touch; it needs it to function (Holtz 1986). If successful, the Des Plaines River Wetlands Demonstration Project may help to establish the use of wetland restoration as a viable, economical, and preferred method for stream improvement along similarly degraded streams in the U.S.

AGRICO SWAMP RECLAMATION PROJECT

The Agrico Swamp Reclamation Project at the Fort Green Mine site, adjacent to the western boundary of the Payne Creek floodplain, Polk County, Florida, was designed and constructed to create freshwater marsh, hardwood swamp, open water, and upland habitats at a previously phosphate-mined site (Erwin 1986). Reports from each year of the study are available through Agrico Chemical Co., Mulberry, Florida; information presented here was obtained from the Fourth Annual Report of the Fort Green Reclamation Project.

The goal of the project was to reclaim a high quality wetland ecosystem, including suitable habitat for fish and wildlife. This goal required the development of a design that, based on ecological principles, is self-maintaining and in harmony with natural systems. A water budget for the project was developed to evaluate the disposition of storage, inflow, and outflow of water within the project area during a typical year.

After surface mining, the project area was recontoured; levees were installed to impound drainage from a 366-acre watershed to form wetlands; ponds were constructed within wetlands to maintain open water all year; and mulch from a wetland borrow site was used to provide a seedbank for vegetation on some areas, whereas other areas were covered with overburden materials. In 1982, over 65,000 tree seedlings were planted on 60 acres. Principal species included bald cypress, sweet gum (Liquidambar styraciflua), loblolly bay (Gordonia lasianthus), red bay (Persea borbonia), red maple, Carolina ash (Fraxinus caroliniana), sycamore (Plantanus occidentalis), elm (Ulmus americana), holly (Ilex cassine), and black gum (Nyssa sylvatica).

In fall 1982, seasonal monitoring of vegetation began. Line-intercept and line-strip techniques were used to determine percent cover, frequency, and species richness, in addition to the relation of various water levels to plants. Both mulched and overburden areas were sampled and compared. Monitoring of trees included assessing the forest community development from wetland edge to upland. Data on condition, survival, and growth of seedlings were collected.

Benthic invertebrates were collected beginning in 1984. Core, artificial substrate, and macrophyte sampling techniques were used to determine density, percent composition, Shannon-Weaver diversity values, and community structure. The objective of the sampling was to develop a predicted model of success on the long-term trends in biological community development in a reclaimed wetland ecosystem. Invertebrate sampling will aid in documenting succession in new marshes and determining the influence of macrophytes on invertebrate populations.

Water quality parameters have been sampled quarterly since 1982 to assess both surface water and groundwater quality on the site, as well as in receiving waters of Payne Creek. Measurements include dissolved oxygen, biological oxygen demand, temperature, pH, turbidity, specific conductance, bicarbonates, dissolved and suspended solids, metals, nitrogen, and radioactivity.

Observations of birds were tallied during routine aquatic invertebrate and water quality sampling; species lists were provided for each season. Fish were electroshocked during spring 1986, and species and lengths were recorded.

After 2 years of sampling benthic invertebrates, results indicated that a rich, diverse benthic community had established. The most significant influence on the numbers and type of taxa at each station appeared to be the amount of stream flow during the sampling period. Of the water quality parameters, pH was the only one that generally did not conform to State water quality standards. The current high pH of open water areas does not appear to be affecting groundwater or Payne Creek; pH is expected to decline over the long term as organic material accumulates in the swamp.

Plans are to continue collecting and analyzing data over the next several years, which should aid in the evaluation of techniques used in this project and the types of improvements required. Monitoring of the water quality of Payne Creek also will continue.

DISCUSSION

The summary of literature on riparian ecosystems obtained from 92 records in the WCR Data Base provided an overview, and relative comparison of the amount, of information available concerning various topics related to creation and restoration of riparian ecosystems (Table 4). Although some aspects of riparian ecosystem creation/restoration were frequently discussed in the literature, information was lacking and is needed for other aspects (Table 4).

As the literature in the WCR Data Base emphasizes, riparian ecosystems generally occupy relatively small areas, and their occurrence along waterways makes them vulnerable to severe alteration caused by a variety of development activities. The status of wetland and riparian ecosystems within the U.S. has been well documented, with estimates of over 50% already destroyed within the coterminous 48 States and few remaining unimpacted. Impacts include expanding agriculture; channelization projects; reservoir and dam construction; heavy livestock grazing (primarily in the West); road, bridge, and pipeline construction; logging activities (particularly in the Northwest); flood control projects; and mining activities (especially in the East).

Table 4. Riparian ecosystem creation/restoration information availability and need as indicated by the synthesis of 92 riparian records in the WCR Data Base. (Availability and need are listed in approximate decreasing order).

Availability	Need
<u>Status</u>	
U.S.; regional; local	Ecology of natural, undisturbed riparian ecosystems (particularly in the West)
<u>Costs</u>	
Planting; other techniques; construction; labor; monitoring; total project; planning; cost: benefit ratios	Cost:benefit analyses (including comparisons with conventional methods, e.g., sewage treatment); costs of all project aspects
<u>Functions</u>	
Fish and wildlife habitat; hydrologic flow (including flood control); erosion control; water quality improvement; groundwater recharge/discharge; food chain support; recreation; food/ timber production	Creating and restoring riparian habitat functions (particularly other than fish and wildlife habitat); monitoring functions; evaluating functions of created or restored riparian ecosystems
<u>Planning</u>	
Baseline data (vegetation, hydrology, fish and wildlife, water quality, soil, historical, models); goals and objectives; site selection (created/restored, control); design; planning team	Quantifying objectives; incorporating habitat functions in the design; determining causes for ecosystem degradation; evaluating existing and future watershed conditions; determining hydrologic regimes; quantifying desired recover rates

(Continued)

Table 4. (Concluded)

Availability	Need
<u>Techniques</u>	
Planting (including plant selection, seeding, transplanting, controlling water levels, irrigating, fertilizing, clearing, burning, and using biocides); fencing from cattle; landforming; bank stabilizing and installing instream devices; treating soil (including transplanting soil); stocking fish or beaver	Landforming to incorporate wetland functions; selection and propagation of native plants; selection of plants to fulfill riparian ecosystem functions (e.g., wildlife habitat, erosion control)
<u>Monitoring</u>	
Parameters (vegetation, hydrology, fish, birds, water quality, soil, invertebrates, mammals, water and soil chemistry, reptiles, amphibians, human use); techniques; time period and frequency	Collecting, analytical, and interpretive techniques; various habitat functions; long-term; nonresident wildlife; mammals; nongame species; nonobligate riparian wildlife
<u>Evaluating success</u>	
Plant survival, growth, and succession; fish, wildlife, and invertebrate populations; hydrologic factors; water quality; sedimentation; comparisons with control, natural site, and preproject site	Variety of physical and biotic variables; comparisons with control, natural site, and preproject site; ecosystem functions; long-term evaluations

Riparian ecosystems generally are more structurally diverse and more productive in terms of plant and animal biomass than surrounding areas. Fredrickson and Reid (1986) stress that in the few places where functional natural systems remain, effective and responsive management requires protection of the habitat rather than manipulation. Action agencies should explore all alternatives prior to destroying valuable riparian habitat (Anderson and Ohmart

1979). Although protecting our wetland resources is imperative, restoration is the only way to make up for past, present, and future losses (Hey 1988).

A number of difficulties are encountered when attempting to restore riparian zones to their original condition: (1) the historical condition of rivers might not be well known; (2) ecological means of returning to a known prior condition are not understood, nor is it certain that this is possible; and (3) presence of man-caused phenomena for long periods of time may genetically alter a species to the extent that restoration may affect it unfavorably (Cairns et al. 1979).

Several records in the WCR Data Base point to the lack of information on riparian ecosystem creation/restoration for specific regions of the U.S., particularly the West. Platts et al. (1987b) stated that research and experience in restoring riverine/riparian ecosystems in the Great Basin and Snake River watersheds are limited. Given the lack of information, they recommended that restoration be approached from a more fundamental level, using undisturbed ecosystems as models and borrowing designs from nature. However, lack of relatively pristine watersheds in this region results in scientists only hypothesizing on the undisturbed condition of riverine/riparian ecosystems. Platts et al. (1987b) suggested that representative ecosystems in relatively unimpaired conditions be protected and used as reference sites for riparian habitat creation/restoration efforts.

Much remains to be learned about the ecology of riparian communities, and unfortunately, little information is available on the natural history of most plant species of these communities (Ohmart et al. 1977). This information is crucial for developing adequate revegetation plans and techniques. Roesser (1988) conducted a literature review to aid in selection of appropriate wetland revegetation techniques to be implemented on the Blue River in central Colorado. Interviews were conducted with a number of individuals representing a wide range of institutions and agencies concerned with wetland reconstruction. Results indicated that a large body of detailed literature was available concerning saltwater marsh, dredge spoil, and freshwater pond/marsh revegetation. However, little information was available concerning riverine wetland reconstruction. No studies were known to exist, at that time, dealing with total wetland reconstruction along high altitude river systems.

The need for development of revegetation techniques has increased in Alaska due to man-caused disturbances, primarily hydroelectric and pipeline projects (Johnson and Specht 1975). Conditions of low temperatures and long winters, largely responsible for the discontinuous permafrost of the subarctic, plus the relatively low rainfall, limit the effectiveness of revegetation techniques developed for temperate regions. Research on the use of native vegetation, response of plants to fertilizers, competition among invading nonnative and native plants, and the effective erosion control ability of plants is needed, particularly for this region.

Probably the most critical aspect of restoration projects (at least from the perspective of developers) is cost (Platts et al. 1987b). Cost of restoring a riparian ecosystem to original condition might be so great as to be considered unrealistic by most members of society, although a return of some of the greatly appreciated amenities might be considered a reasonable financial burden (Cairns et al. 1979). Anderson and Ohmart (1979) stressed that if destruction of a riparian ecosystem is necessary, agencies should be prepared to meet the high cost to replace it in kind and place.

Cost evaluation of riparian ecosystem creation/restoration is complicated by the difficulty in placing monetary values on the resources and by the uncertainties (success/failure) associated with restoration efforts (Platts et al. 1987b). Cost:benefit analyses were generally lacking in the WCR Data Base (Table 4) and are needed to support future funding of riparian ecosystem creation/restoration projects. Inclusion of costs in published works concerning creation/restoration projects and techniques will aid in developing cost:benefit analyses in the future. Sandrik and Crabill (1983) suggested that costs of wetland and riparian ecosystem creation/restoration will most likely diminish as more projects are attempted and more data are collected, which will aid in planning future projects.

Although, the primary function of riparian ecosystem creation or restoration discussed in the WCR Data Base was the provision of fish and wildlife habitat (Table 4), floodplain wetlands are complex, dynamic systems heavily influenced by hydrology. As previous discussions of riparian ecosystem functions and plant life indicate, hydrology, soil properties, and water quality have major impacts on development of the wetland plant community, which thus influences the wildlife and fish populations of the created or restored site. Especially in the West, interrelationships between surface water and groundwater hydrology, hydric soils, and riparian plant communities are poorly understood (Ischinger and Schneller-McDonald 1988). Plant community distribution and tolerances of saturated soil conditions along environmental gradients should be documented, as well as the impact of streamflow depletions on riparian wetland ecosystems.

As land becomes increasingly degraded by man's activities, the impetus to create or restore riparian zones to improve the hydrologic flow, flood control ability, erosion control, and water quality will undoubtedly play a more prominent role in creation/restoration efforts and possibly provide needed cost:benefit ratios, which may promote more riparian ecosystem creation/restoration efforts.

The WCR Data Base literature contains useful information on planning riparian ecosystem creation/restoration projects, with particular attention to collecting baseline data, determining goals and objectives, and site selection (Table 4). Most information on collection of baseline data concerns measuring vegetation parameters.

To aid in planning creation/restoration projects, research is needed to determine: (1) means of predicting recovery rates, (2) management techniques to enhance the recovery process, and (3) methods for maintenance of restored systems and preventing further damage (Cairns et al. 1979).

The most frequently discussed techniques in the WCR Data Base concern revegetating creation/restoration sites (Table 4). However, information concerning selection of native vegetation and obtaining plants to revegetate sites still is lacking for most areas. Fortunately, efforts are being made to provide a broad genetic base and wide selection of plants adapted to specific areas. For example, the New Mexico Department of Game and Fish, jointly with five Federal agencies, is conducting research on riparian plants in New Mexico to expand the number of native riparian plant species commercially available for use in riparian revegetation programs (Swenson 1988).

Vegetation also is the most commonly monitored parameter in the WCR Data Base (Table 4). Informed decisions on planning creation/restoration projects can only be made with adequate information from past efforts. Adapting sampling and monitoring designs, such as proposed in Platts et al. (1987a), and statistically testing results will provide more detailed information from which to base future efforts. As Erwin (1986) noted, the literature on wetland restoration does contain information on vegetation survival and succession, but little comprehensive information on water quality, biological integrity, or the ecological interrelationships in a functional reclaimed wetland system. This type of information can only be obtained by careful and thorough monitoring of creation/restoration efforts.

Fish and birds have been the most commonly monitored animal groups, with little information available on use of created/restored riparian ecosystems by mammals, reptiles, or amphibians. Richness of riparian vegetation and its close proximity to water are conducive to extensive use by mammals, particularly in arid regions, and should be investigated more during creation/restoration efforts.

Much of the information on nongame wildlife associated with wetland and riparian ecosystems has accumulated because of specific research interests in a species or a taxonomic group, or to test hypotheses relating to ecological questions (Fredrickson and Reid 1986). Such published information on nongame species often has high value for management, but the syntheses needed by land managers generally are lacking. Another important deficiency for wetland managers and administrators is the lack of information that identifies wetland management values for nongame wildlife that are not obligate wetland species. For example, bats and swallows feed on insects emerging from wetlands, raptors prey on wetland wildlife, and many seed-eating songbirds forage in wetlands. These vertebrates are not traditionally recognized as wetland species, yet wetlands play an important role in providing nutritional needs in their annual cycle.

Results of creation/restoration efforts frequently include only 1-2 years of data. Anderson and Ohmart (1982) stated that 2 years of data from their study of riparian ecosystem creation/restoration along the lower Colorado River was not enough time from which to draw any conclusions beyond that time or beyond the range of variables studied. They cautioned against using findings from their report for making predictions about plant growth and mortality after 4-10 years and stated that the report should be considered preliminary until the site was at least 15-20 years old. Documentation of creation/restoration efforts over extended periods is needed to project changes over time, improve the success rate of future projects, and provide scientific evidence of the success or failure of restoring riparian ecosystem functions.

Reasons for restoring wetlands must be clearly articulated, and success must be demonstrated to ensure future funding of endeavors (Hey 1988). Clearly, success of a particular project cannot be properly evaluated without detailed baseline data, careful and thorough monitoring, and an analysis of the data obtained over a long period of time. The three case studies discussed in the previous section exemplify efforts to achieve some of these goals. Success determinations would benefit from an investigation of various functions of riparian wetlands (including wildlife and fish habitat, hydrologic flow, erosion control, water quality improvement, and recreational use).

An important aspect of riparian ecosystem creation/restoration efforts is the documentation of monitoring results and making the information available to agencies and scientists (Platts et al. 1987b). Miller (1988) recommended that monitoring each site with standardized tests and setting expectation levels that indicate success be a standardized part of the permitting process. She also recommended that Federal, State, and local agencies set the same criteria.

In publishing results of riparian ecosystem creation/restoration efforts, consistent use of a wetland classification system, such as Cowardin et al. (1979), would aid in project comparisons, along with detailed descriptions of the project sites. Ischinger and Schneller-McDonald (1988) recommended that riparian ecologists adopt nationally accepted definitions of hydric soils and wetland plants to facilitate classification systems consistent with nationally recognized or statutory definitions.

In conclusion, the literature on riparian ecosystem creation/restoration in the WCR Data Base appears to stress three major needs: (1) protecting remaining natural, undegraded riparian ecosystems; (2) describing, creating/restoring, and monitoring riparian functions; and (3) increasing the emphasis on documenting creation/restoration efforts and publishing this information. The knowledge base of riparian ecosystem creation/restoration efforts needs to be increased if decisionmakers, planners, and managers are to have the necessary data to make informed decisions concerning protecting existing riparian ecosystems and to use creation or restoration to compensate for unavoidable loss of this valuable resource.

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15. Supplementary Notes

16. Abstract (Limit: 200 words)

Compared to other wetland types (e.g., coastal wetlands), projects and techniques involving creation or restoration of riparian ecosystems are not well documented. To provide a source of currently available literature, riparian ecosystem information from 92 records (primarily published papers or reports) in the U.S. Fish and Wildlife Service's Wetland Creation/Restoration (WCR) Data Base was used to develop a literature summary of creation and restoration of riparian ecosystems. The summary provides an overview of the status of riparian ecosystems in the U.S., a discussion of several riparian functions, and a review of some techniques used for planning, implementing, monitoring, and measuring project success of riparian ecosystem creation/restoration efforts. Case studies of various riparian ecosystem creation or restoration projects are used to demonstrate these techniques and to report some results of their use. Several well-documented case studies are discussed in detail to illustrate more extensive efforts to plan, implement, or monitor riparian ecosystem creation/restoration projects.

17. Document Analysis a. Descriptors

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