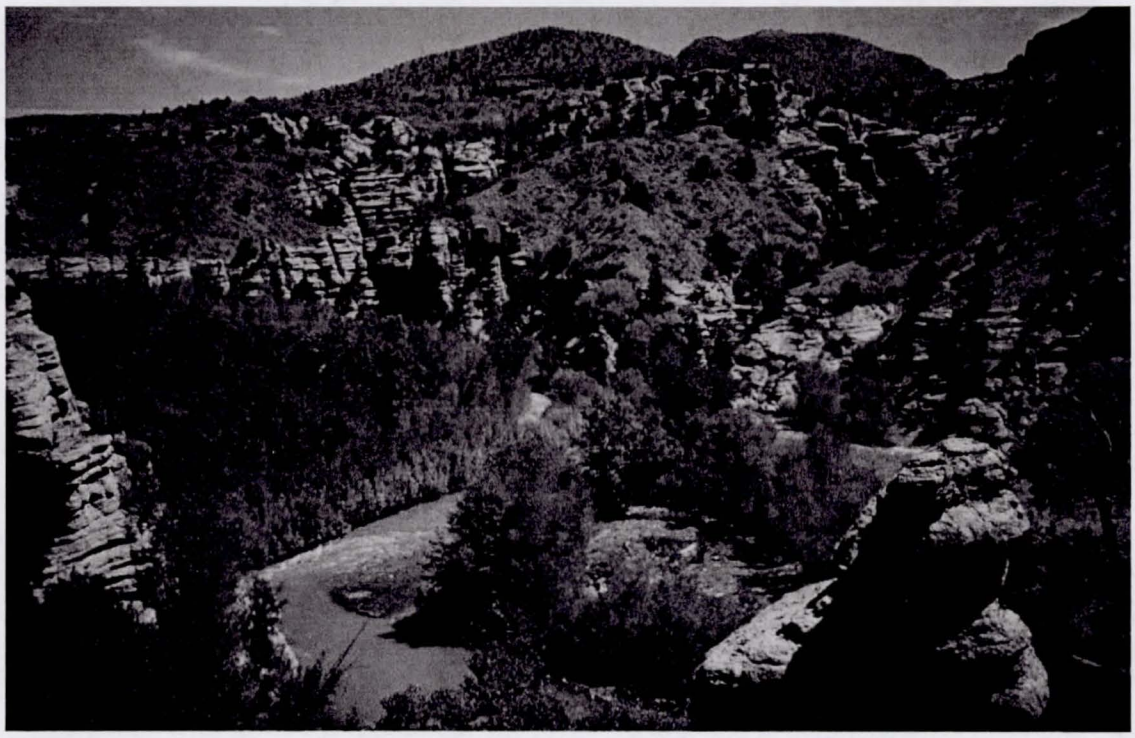
Riparian Ecosystem Restoration in the Gila River Basin: Opportunities and Constraints

Workshop Proceedings

April 8-9, 1999 Tucson, AZ



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Blue River in Apache National Forest, Arizona (Photo by P.B. Shafroth)

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Introduction

Patrick B. Shafroth, USGS, Midcontinent Ecological Science Center, Ft. Collins

The primary goal of the Gila River Riparian Restoration Forum was to provide information to representatives of various federal, state, tribal, local government, and non-governmental organizations with an interest in riparian ecosystem restoration in the Gila River basin, so that they may more effectively plan, implement, and manage riparian restoration projects in this region. In addition, this workshop was designed to promote interaction among attendees to enhance the sharing of information and ideas on riparian restoration. I am happy to say that these goals were largely achieved through the contributions of an excellent line-up of expert speakers and thoughtful group discussions involving all workshop participants. This proceedings is intended to both document much of the content of the workshop and to serve as a benchmark for future conferences and workshops on this topic.

The group of expert speakers covered a broad array of restoration topics, giving participants a good overview of important considerations and approaches. For example, general topics covered during the first day and included as extended abstracts in this volume, were pre-project considerations by Mark Briggs, the importance of restoring natural processes by Julie Stromberg and Matt Chew, geomorphologic considerations by Waite Osterkamp, site assessment by Lynette Mason and Janet Johnson, site prioritization by Don Falk et al., and monitoring by Mark Young and Rex Wahl.

Other presentations focused on specific restoration approaches such as saltcedar removal by K.C. McDaniel and John Taylor, small watershed management by Dave Gori, site manipulations that promote semi-natural tree regeneration by Gregor Auble, and pole planting and other techniques used on the Lower Colorado River by John Swett. These considerations and approaches are synthesized and summarized at the end of this document by Duncan Patten.

The second day's sessions were dedicated to formulating and discussing restoration plans for three very different riparian sites within the Gila

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Opening Workshop Remarks

"Twenty-five years ago, I was a student here at the University of Arizona in the School of Renewable Natural Resources. Then the call was to stop the runaway train. Today, the call is to back that train up, to restore these systems that have been degraded.

I work at one of the management bureaus in the Department of Interior. As such, I went to the Science Bureau, the U.S. Geological Survey, Biological Resources Division and asked them to provide me insight as to what the science side of the Interior Department sees restoration as being. As a result of those discussions, we made the decision to sponsor this workshop.

The intent of this workshop is to develop an understanding of what "restoration" means to those of us who work in the Gila River basin. My hope is that over the next two days we can develop a common set of definitions for restoration, better understand what works and what doesn't, come to understand what are reasonable expectations for restoration, and maybe most importantly, where do we start?"

Joe Smith, U.S. Bureau of Reclamation, Phoenix Area Office

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basin, following a presentation by Mark Briggs on the necessary steps in doing a restoration project. One site was a high elevation riparian meadow on the White Mountain Apache Reservation, which had been degraded by past land use activities by Jonathan Long and Candy Lupe. Another was The Nature Conservancy's Bingham Cienega Preserve along the middle San Pedro River, where efforts are focused on restoring lands formerly used for agriculture described by Daniel Baker. Finally, restoration prospects for the highly urbanized and dewatered Santa Cruz River in and near Tucson were evaluated and discussed by Nanette Gerstenberger.

The Gila River Riparian Restoration Workshop can be thought of as a milestone in the evolution of riparian ecosystem restoration. In the 1980s, "riparian restoration" generally consisted of planting native species, primarily cottonwood and willow, on flood plain surfaces or terraces where trees had been previously cleared or were no longer regenerating (e.g., Pinkney 1992, Swenson and Mullins 1985). Research and development of restoration techniques focused on ways to increase the survival of planted material (Anderson 1989). By the 1990s, a substantial body of research on the natural processes that structure western riparian ecosystems had accumulated (c.f., Friedman et al. 1997, Braatne et al. 1996). In addition, a number of restoration planting projects were largely unsuccessful, sometimes in spite of detailed site evaluations and intensive management (Briggs et al. 1992). As a result, today's restoration practitioners are placing a much greater emphasis on the importance of natural processes and self-sustainability when assessing potential restoration sites and evaluating approaches. This shift from a focus on replacing elements of the ecosystem to a combination of replacing elements *and* processes was apparent in many of the presentations and discussions during the Gila River Riparian Restoration Workshop.

Land managers, planners, and scientists must continue to pay attention to improving, refining, and inventing restoration approaches to ensure the successful and long-term recovery of damaged riparian ecosystems. We hope that the inevitable advances and new insights that will emerge from the results of ongoing and future restoration efforts can be shared and discussed in other workshops like this one.

LITERATURE CITED

Anderson, B.W. 1989. Research as an integral part of revegetation projects. 413-419. IN D.L. Abell (technical coordinator) Proceedings of the California Riparian Systems Conference: Protection, management, and restoration for the 1990s. Sept. 22024. Davis. California. General Technical Report PSW-110. Pacific Southwest Forest and Range Experiment Station. Berkeley.

Braatne, J. H., S. B. Rood, and P. E. Heilman. 1996. Life history, ecology, and conservation of riparian cottonwoods in North America. p. 57-85. IN R. F. Stettler, H. D. Bradshaw, P. E. Heilman, and T. M. Hinckley (eds.) Biology of Populus and its implications for management and conservation. NRC Research Press, Ottawa.

Briggs, M. K., B. A. Roundy, and W. W. Shaw. 1994. Assessing the effectiveness of riparian revegetation in Arizona. Restoration and Management Notes 12:160-167.

Friedman, J.M., W.R. Osterkamp, and W.M. Lewis, Jr. 1996. Channel narrowing and vegetation development following a Great-Plains flood. Ecology 77:2167-2181.

Swenson, E.A. and C.L. Mullins. 1985. Revegetating riparian trees in southwestern floodplains. IN Riparian Ecosystems and Their Management: Reconciling Conflicting Uses (First North American Riparian Conference, April 16-18, 1985, Tucson, Arizona), coordinated by R.R. Johnson, C.D. Siebell, D.R. Patton, P.F. Ffolliot, and R.H. Hamre, 135-139. USDA Forest Service General Technical Report RM-120. Fort Collins, Colo.: Rocky Mountain Forest and Range Experiment Station

Benefitting from Past Experiences: Lessons Gained from the Experiences of Past Riparian Recovery Efforts

Mark Briggs, Sonoran Institute, Tucson

The ecologic condition of many riparian ecosystems in the southwestern United States has declined in recent decades, and many of these important ecosystems have disappeared completely. The rapid decline of these valuable ecosystems has made riparian conservation a focal issue for many federal, state, and private organizations. Nevertheless, progress toward checking the decline of riparian ecosystems has been marginal. This is due, in part, to the fact that the science of repairing damaged riverine systems is relatively young; we are still investigating fundamental questions on riparian ecosystem processes and impacts of human activities. In addition, the results of only a relatively small number of projects to improve the condition of damaged riparian areas have been evaluated for the benefit of future projects. Consequently, we have learned little from past recovery efforts and are just beginning to understand how to effectively repair ecologically damaged riparian areas.

To begin filling this gap in riparian conservation literature and learn from the plethora of past efforts to improve damaged riparian areas, two investigations were completed over the past ten years to evaluate the results of riparian recovery projects from the arid southwestern U.S. and northern México. The first investigation evaluated a group of 27 riparian restoration projects (mostly revegetation efforts) in Arizona (Briggs 1992). The second investigation evaluated the results of riparian recovery efforts along the lower Colorado River, from Parker Dam to and including the river's delta (Briggs and Cornelius 1998).

The evaluation investigations had two principal objectives:

- First, to evaluate the effectiveness of past riparian recovery efforts so lessons gained from these experiences can be applied to future ecological restoration activities;
- Second, to recommend courses of action for identifying areas of natural significance and strategies for maintaining their ecologic condition. To the extent possible, the riparian recovery projects were evaluated with the assistance and participation of the project managers who had designed and implemented them in the first place (In some cases, project managers had

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Generally, there are three possible end points for efforts undertaken to improve the condition of an ecosystem that is in less than pristine condition: restoration, rehabilitation, and replacement/ reallocation (Aronson et al. 1993; Bradshaw 1988).

Restoration is an attempt to create an ecosystem exactly like the one that was present prior to disturbance (often referred to as "pre-development conditions.").

Rehabilitation creates an ecosystem that is similar to (but not identical) to the ecosystem that was present prior to the disturbance.

Replacement or reallocation strategies generally do not attempt to restore an ecosystem to its pre-disturbance condition. Instead, the original ecosystem is replaced by a different one.

For the purposes of this paper, "recovery" is used to refer to all three objectives when the details of the improvement are not clear, referring generally to any type of project (restoration, rehabilitation, or replacement projects) that is undertaken to improve the condition of a ecologically damaged ecosystem. By using "recovery" in place of "restoration," "rehabilitation," or "replacement," the precise intent of the effort does not need to be known and is therefore not misrepresented.

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not visited the site since the completion of the recovery effort).

Ultimately, 39 riparian recovery sites were visited and evaluated and a significant amount of information was generated regarding project success, how the effectiveness of recovery efforts could be improved, and how lessons can be applied to future riparian recovery efforts. Out of the numerous lessons gained from the evaluation efforts, eight lessons were selected and are elaborated on below.

LESSON 1: DEVELOP PROJECT OBJECTIVES THAT ARE CLEAR AND SPECIFIC

Developing a sound and clear recovery project objective is one of the key ingredients of success. The objective of the recovery effort is the linchpin on which many of the project's critical components are attached (the personnel needed, the strategies that are ultimately employed, the time frame for project completion, budget). It is therefore critical for project personnel to take the time at the onset to develop an objective that is thoughtful, realistic (recognizes the social, political, and ecological context) and viable in the long-term. An ill- defined objective can significantly hinder the effectiveness of the restoration effort and may even prevent the project from being completed (Briggs 1996). A clear and concise project objective makes possible the evaluation of project results, which, in turn, can benefit both the success of the project itself as well as provide critical information for future restoration efforts.

To offer an example of a project objective that was not well-defined, several revegetation efforts along the lower Colorado River were completed "to improve wildlife habitat." Although the objective was developed at the onset of the recovery effort, it lacked the detail needed to fully understand the project's intention. For what species of wildlife was the habitat improvement intended? What type of habitat is being considered? What characteristics of vegetation density and vertical complexity are required to provide habitat (or improvement of habitat) for the target wildlife species? The answers to these and other types of questions need to be addressed as part of developing a thoughtful and clear objective for the project.

Generally, there are at least six questions that should be addressed en route to developing a sound recovery objective:

- How does the current ecologic condition of the site affect what can or cannot be accomplished?
- To what extent have the site's ecologic conditions changed since pre-development times?
- What are the causes for the ecologic changes that have occurred?
- What political influences are driving the initiation of the recovery effort (e.g., issues of threatened and endangered species, water quality concerns, mitigation for perturbations elsewhere in the watershed)?
- What level of funding, personnel, and logistical support can be anticipated for the recovery effort?
- If appropriate to the site's socio-political landscape, what participation and commitment can be expected from riverside community citizens?

LESSON 2: UNDERSTAND THE CURRENT ECOLOGICAL CONDITION OF THE SITE

A recovery effort that is based on a sound understanding of current ecologic conditions is more likely to realize its overall objective than a project that is implemented without such an understanding (Anderson 1989; Riley 1998). Depth to saturated soils, streamflow characteristics, channel morphologic conditions, and soil salinity are four critical elements that need to be evaluated to understand current ecologic conditions and the extent that they may have changed from pre-development times (Briggs 1996). Some thoughts on how to go about developing a better understanding of pre-development conditions are presented in "Steps Toward Developing a Realistic Riparian Recovery Objective," in this proceedings.

Depth to Saturated Soils

Particularly in arid and semi-arid climates, depth to saturated soils and the extent that it

varies during the year is critical for understanding the water that is available for plant growth. Knowing this information is critical to identifying the types of vegetation that are capable of surviving at the site in the long-term.

Unfortunately, many past riparian recovery efforts were designed and implemented without a clear understanding of current groundwater conditions, nor of how these conditions had changed since pre-development times. Several recovery efforts along the lower Gila River, for example, attempted to re-establish cottonwoods (*Populus fremontii*) in areas where the depth to saturated soils was consistently over three meters Although cottonwoods are native and were extensively established along the Gila River floodplain during pre-development times, these shallow-rooted species have difficulty regenerating in many parts of this region as both soil salinity and depth to saturated soils have increased to unacceptable levels.

If such issues cannot be directly addressed and revegetation is still the preferred recovery strategy, it may be wise to use plant species that are better adapted to current site ecologic conditions. In the Gila River example, revegetating with trees such as mesquite (*Prosopis velutina*) and netleaf hackberry (*Celtis reticulata*) may have been more effective, as these native species can tolerate drier and saltier conditions.

Streamflow

Streamflow data are essential for determining the condition of a degraded riparian area and how it has changed. Knowledge of mean discharge, for example, will help project managers predict the amount of water that will be available for plant use; flood-frequency data combined with channel morphology information can give ecosystem managers a good indication of where vegetation should be placed. Discharge data can be used to estimate sediment yield, analyze the frequency of various flood events, and characterize flow regime in terms of average discharge, or range or variability of discharge (Lewin 1978; Richter et al. 1996).

Project managers are frequently asked to evaluate riparian ecosystems along drainage-ways where even the most rudimentary hydro-logic data is lacking. In such situations, estimates are often made by transferring information from gauged sites to ungauged sites through regional relations between flow characteristics and the physical and climatic characteristics of the basins. Unfortunately, flows in arid and semi-arid areas are only poorly related to the size of the basin and other basin characteristics (Wahl 1977). Therefore, many standard measurement techniques cannot be used along ephemeral and intermittent streams in arid and semi-arid parts of the world. In such situations, ecosystem managers, may have to rely on channel process information without relying on direct measurement of streamflow (Moody and Odem 1999).

Relations between stream channel geometry and flow offer a quick and inexpensive alternative method for estimating streamflow of ungauged streams. Streamflow characteristics can be extrapolated from channel geometry characteristics because the size of an alluvial channel is indicative of the water conveyed through that channel, while the shape of the channel is for the most part determined by the sediment transported by the stream (Hedman and Osterkamp 1982). This method is easily applied, requiring only data that describe the channel geometry and the particle size distributions of the material forming the channel perimeter. These data are then used in equations that were developed by Hedman and Osterkamp (1982) to determine mean annual runoff.

Soil Chemistry

Evaluating soil chemistry prior to revegetation has been particularly critical for riparian recovery efforts along the lower Colorado River, where soil salinity levels have increased significantly due to the lack of consistent, cleansing spring flooding (Anderson 1989). Many native southwestern riparian plants are intolerant to salt and the amount of salt in the soil is therefore a key factor for determining the effectiveness of riparian revegetation (Pinkney 1992). At a riparian revegetation project along the Pecos River in New Mexico, for example, cottonwood and willows did not establish, pri-

marily because groundwater and soils were characterized by salinity levels that exceeded 6,000 ppm (Swenson and Mullins 1985). The experiences of some riparian revegetation efforts indicate that flood irrigating prior to planting may help to remove salts from soils to concentrations acceptable for at least some native riparian plant species.

Anderson (1989) performs soil salinity analysis as a routine part of developing a riparian revegetation design. He begins with a preliminary soil sampling and analysis to avoid performing a more intensive soil analysis in areas where salt -affected soils are not a problem or where soil salinity varies little at the riparian site. The goal of the analysis is to identify (and then stay away from) areas characterized by high concentrations of salinity (Anderson 1989; Jackson et al. 1990).

Channel Morphology

Including the drainageway that passes through the degraded riparian ecosystem in the evaluation process is an integral part to understanding the riverine environment and what can be realistically done to bring back ecologically damaged areas. The focus here is on better understanding the stability of unconfined alluvial channels—channels fully bounded by sediment derived from prevailing conditions of water-sediment discharge. Unlike bedrock channels, which are confined by rock outcrops and change slowly over a long period of time (hundreds of years), alluvial channels are controlled by streamflow and are prone to changes over much shorter periods of time. Such changes may become dramatic when an alluvial channel falls out of equilibrium, potentially reaching the point of significantly affecting the results of streamside recovery efforts.

Several studies indicate that channel instability can degrade associated riparian ecosystems in two general ways. First, streamside vegetation can be destroyed directly through bank erosion and resultant loss of channel bank and flood plain integrity. Second, streamside vegetation can be lost via the subsequent dewatering of the riparian zone following channel incision, which may leave surviving vegetation dependent solely upon precipitation for moisture (Zimmerman 1969; Glinski 1977; McBride and Strahan 1981; Griggs 1984; Kondolf and Curry 1984; Minckley and Clark 1984). Literature abounds on channel morphology and how to evaluate and under-stand current channel conditions (Leopold 1951; Wolman and Leopold 1957; Heede, 1981; Osterkamp and Hupp 1984; Harrelson et al. 1994). The main point here is that project managers need to take the time to understand channel morphologic conditions, which can only be accomplished from a watershed perspective that takes into consideration conditions upstream and downstream of the site, tributary influences, and the condition of upland areas.

LESSON 3: IDENTIFY AND ADDRESS CAUSES OF ECOLOGIC DECLINE

When developing strategies for improving the condition of a degraded riparian area, we are often guilty of jumping to conclusions about the causes of degradation, how we are going to fix them, and what the end point of that fix should be. One of the most critical lessons learned from the experiences of past riparian recovery efforts is the importance of evaluating site conditions to identify the causes of de-gradation. Only after these are identified can recovery strategies be developed that will directly address the causes, not just the symptoms, of degradation. Strategies that address the causes of riparian decline are much more likely to be successful than strategies designed without understanding the reasons behind site degradation. Understanding the causes of site deterioration should, therefore, be the priority and one of the first steps in developing a recovery plan.

However, identifying the causes of ecological decline is not always obvious, requiring an understanding of how the often complex and interrelated causes of site ecologic decline are affecting the riparian area. This, in turn, requires that restoration project managers be able to discern between natural and unnatural variability in site conditions. The loss of significant vegetation from a riparian site, for example, may be due to the effects of a large magnitude flood (considered a natural part of river and

riparian ecosystems) or groundwater decline (considered unnatural if due to overpumping). Essentially, one of the first questions that should be posed is— Is the site actually damaged? And, if so, what are the causes of damage?

An important lesson learned from past riparian recovery efforts is that the identification of the causes of site decline needs to be done from a perspective that takes into consideration the uplands, upstream and downstream reaches, and tributaries (see also Lesson Five, below).

To identify causes of site decline, the evaluation process should also be broadened from a temporal perspective. Collecting information describing past conditions will provide a picture of how the riparian area has changed and some of the potential reasons for the changes.

LESSON 4: FOSTERING PROCESSES OF NATURAL REGENERATION CAN PRODUCE SIGNIFICANT RESULTS

Despite some notable riparian revegetation success stories, it is obvious that the results of most revegetation efforts pale in comparison to results achieved via natural regeneration. Of the recovery efforts that were evaluated along the lower Colorado River, the largest affected was roughly 60 ha. In comparison, three areas along the same reach were identified as having experienced significant natural regeneration without any human intervention: confluence of the Colorado River and Gila River (85 ha), Cienega de Santa Clara (20,000 ha), and the Rio Hardy (24,000 ha).

Although such direct comparisons may be unfair, they do highlight the need to create opportunities for natural regeneration in recovery efforts. Fostering processes of natural regeneration can not only produce significant results, but are usually more cost-effective. The areas of natural significance highlighted above, for example, were established and have been maintained naturally, without cost.

LESSON 5: DEVELOP THE RECOVERY EFFORT FROM A WATERSHED PERSPECTIVE

More than any other type of ecosystem, the structure and processes of lotic ecosystems are determined by their connection with adjacent ecosystems (Osterkamp 1978; Hupp 1985; Gregory et al. 1991). A disturbance in any part of a watershed will create disequilibrium that will be felt through rippling effects by many ecosystems within the watershed. Since riparian ecosystems are in the bottomlands of a watershed, changes in the way that sediment and water run off of surrounding lands impact them most. Riparian ecosystems are affected by perturbations along upstream and downstream reaches, tributaries, and surrounding uplands. Land use activities in the upper watershed, such as timber harvesting, will alter sediment and water runoff characteristics, possibly influencing the condition of the watershed's riparian ecosystems for many years (a good example is the impacts that the deforestation of the Pacific northwest has had on salmon).

Evaluating only isolated components of a watershed (e.g., a specific stream reach) will be ecologically incomplete, often failing to provide the information needed to fully understand why the riparian ecosystem has become degraded. Ecosystem managers must therefore avoid the myopic approach of developing recovery strategies that are based solely on an evaluation of the immediate degraded riparian site. In addition, it is likely that recovery based on such a narrow evaluation will not be very effective because the factors that initially caused degradation may continue to affect the site. The evaluation process therefore should include a significant amount of the riparian ecosystem's watershed, taking into consideration the condition of surrounding uplands, upstream and downstream reaches, and tributaries.

LESSON 6: POST-PROJECT CONSIDERATIONS ARE CRITICAL TO THE EFFECTIVENESS OF THE RESTORATION EFFORT

In some cases, recovery projects were designed and implemented with little thought as to how the project was going to be maintained, managed, and evaluated after it was completed. Such post-project considerations are just as important as the actual project implementation

and many recovery efforts have gone astray due to the lack of attention given to follow-up activities. It is therefore critical that recovery project managers make certain that budget and personnel are provided to allow post-project considerations to be carried out.

The following considerations should be included in every recovery plan:

- Monitoring and evaluation
- Maintenance
- Changes in surrounding land uses
- Site management and tenure

LESSON 7: PRIORITIZING PROJECTS/SITES IS ESSENTIAL FOR EFFECTIVELY ALLOCATING RESTORATION RESOURCES

In this era where areas that are ecologically damaged are abundant and the resources and personnel available to treat them are not, it is critical that resource managers have on-hand a system for prioritizing potential project locations. Essentially, where can resources and personnel be most effectively used to address issues of ecologic decline?

This is an important question that can quickly lead to several complex issues. For example, would resources be better spent on protecting areas that are still in good condition rather than on improving the condition of ecologically damaged areas? If the focus is on implementing efforts to improve damaged sites, should the priority be on areas that have experienced significant ecological change or areas that are only slightly damaged? What issues other than ecologic condition should be considered in determining priorities? And, how can available qualitative and quantitative information be most effectively used to provide meaningful prioritization insights and foster debate on natural resource and conservation issues?

A variety of prioritization strategies have been developed over the years for a variety of different reasons. Some strategies were developed to identify priority sites for restoration, others to pinpoint areas to focus conservation efforts, still others were completed to help coordinate management options. Some of these strategies were performed from a watershed perspective, others focused on specific river reaches. It is important for resource managers to consider some of these past prioritization schemes to determine if they could be effectively employed in their own arena (see the summary of "The Riparian Restoration Ranking (R3) System User's Manual" by Don Falk in this volume).

LESSON 8: INVOLVING COMMUNITIES CAN BE CRITICAL TO SUCCESS

Many of the riparian recovery efforts that were evaluated were completed in areas adjacent to land owned or managed by private citizens, yet very few of these efforts sought community participation. Involving local communities in recovery efforts can mean the difference between long-term sustainable success and failure.

Riverside communities have a large stake in the ecological condition of the river by virtue of the real and potential economic, social, and environmental values it provides. They may not have, however, the appropriate opportunity for input into decisions that affect their lives even more directly than those living afar. Bringing communities together and providing a workshop to discuss common problems and how they can be addressed can be mutually beneficial to both the river and neighboring towns and communities.

This approach generally is accomplished by providing opportunities for neighboring communities and land owners to participate meaningfully in decision-making processes that concern the land and water they are fortunate to live next to, and by structuring management policies so that financial benefits are accrued by communities that accept a resource conservation obligation. Simply put, there is often significant common ground between the needs and aspirations of riverside communities and the goals of river/riparian recovery efforts (e.g., the desire for clean water, protected natural areas, aesthetic beauty, etc.). It is this common ground that needs to be considered and promoted as part of gaining the involvement of riverside citizens in river recovery projects.

LITERATURE CITED

Anderson, B.W. 1989. Research as an integral part of revegetation projects, p.413-419. IN D.L. Abell (technical coordinator) Proceedings of the California Riparian Systems Conference: protection, management, and restoration for the 1990s; September 22-24, Davis, California. General Technical Report PSW-110. U.S. Department of Agriculture, Pacific Southwest Forest and Range Experiment Station, Berkeley.

Briggs, M. 1996. Riparian ecosystem recovery in arid lands: strategies and references. University of Arizona Press, Tucson.

Glinski, R.L. 1977. Regeneration and distribution of sycamore and cottonwood trees along Sonoita Creek, Santa Cruz County, Arizona, p. 116-123. IN Johnson, R.R. and D.A. Jones, (eds.) Importance, preservation, and management of Riparian habitat: A symposium, U.S. Department of Agriculture Forest Service General Technical Report RM-43. Rocky Mountain Forest and Range Experimental Station, Fort Collins.

Gregory, S.V., F.J. Swanson, W.A. McKee, and K.W. Cummins. 1991. An ecosystem perspective of riparian zones. BioScience 41:540-551.

Griggs, G.B. 1984. Flood control and riparian system destruction: Lower San Lorenzo River, Santa Cruz County, California, p. 142-150. IN R.E. Warner and K.M. Hendrix (eds.), California riparian systems - ecology, conservation, and productive management, University of California Press, Berkeley and Los Angeles

Harrelson, C.C., C.L. Rawlins, and J.P. Potyondy. 1994. Stream channel reference sites: An illustrated guide to field technique. U.S. Department of Agriculture, Rocky Mountain Forest and Range Experiment Station, General Technical Report RM-245, 61 pp.

Hedman, E.R. and W.R. Osterkamp. 1982. Streamflow characteristics related to channel geometry of streams in western United States. U.S. Geological Survey Water-Supply Paper 2193. 17p.

Heede, B.H. 1981. Rehabilitation of disturbed watersheds through vegetation treatment and physical structures, p. 257-260. In: Baumgartner, David. (ed.), Interior west watershed management. Washington State University, Spokane. 288 pp.

Jackson, J., J.T. Ball, and M.R. Rose. 1990. Assessment of the salinity tolerance of eight Sonoran Desert riparian trees and shrubs. Final Report prepared by the Desert Research Institute, University of Nevada System, Biological Sciences Center, Reno.

Kondolf, G.M., and R.R. Curry. 1984. The role of riparian vegetation in channel bank stability: Carmel River, California, 124-134. IN R.E. Warner and K.M. Hendrix (eds.) California riparian systems - ecology, conservation, and productive management. University of California Press, Berkeley and Los Angeles.

Leopold, L.B. 1951. Rainfall frequencies: an aspect of climatic variation. Transactions of the American Geophysical Union 32:342-352.

Lewin, J. 1978. Floodplain geomorphology. Progress in Physical Geography 2:408-437.

McBride, J.R., and J. Strahan. 1984. Establishment and survival of woody riparian species on gravel bars of an intermittent stream. The American Midland Naturalist 112:235-245.

Minckley, W.L., and T.O. Clark. 1984. Formation and destruction of a Gila River mesquite bosque community. Desert Plants 6:23-30.

Moody, T.O. and W. Odem. 1999. Regional relationships for bankfull stage in natural channels of central and southern Arizona. USDA Forest Service, Southwestern Region, 517 Gold Avenue, SW, Albuquerque.

Osterkamp, W.R. and C.R. Hupp. 1984. Geomorphic and vegetative characteristics along three northern Virginia streams. Geological Society of America Bulletin 5:1093-1101.

Pinkney, F.C. 1992. Revegetation and enhancement of riparian communities along the Lower Colorado River. Denver: USDI Bureau of Reclamation, Ecological Resources Branch.

Richter, B., J.V. Baumgartner, J. Powell, and D.P. Braun. 1996. A method for assessing hydrologic alteration within ecosystems. Conservation Biology 10(4):1163-1174.

Riley, A. L. 1998. Restoring streams in cities: A guide for planners, policy makers, and citizens. Island Press, Washington D.C.

Swenson, E.A. and C.L. Mullins. 1985. Revegetating riparian trees in southwestern floodplains. IN Riparian ecosystems and their management: reconciling conflicting uses (First North American Riparian Conference, April 16-18, 1985, Tucson, Arizona), coordinated by R.R. Johnson, C.D. Siebell, D.R. Patton, P.F. Ffolliot, and R.H. Hamre, 135-139. USDA Forest Service General Technical Report RM-120. Fort Collins, Colo.: Rocky Mountain Forest and Range Experiment Station.

Wahl, K.L. 1977. Accuracy of channel measurements and the implications in estimating streamflow characteristics. Journal of Research U.S. Geological Survey 5:811-814.

Wolman, M.G., and L.B. Leopold. 1957. River flood plains: some observations on their formation, p.87-107. Geological Survey Professional Paper 282-C, United States Printing Office, Washington.

Zimmerman, R.C. 1969. Plant ecology of an arid basin, Tres Alamos-Redington area, southeastern Arizona. U.S. Geological Survey Professional Paper 485-D, 51p.

A relatively undisturbed section of the White River. Photo: B. Tellman

Restoration of Riparian Ecosystems in the Arid Southwest: Challenges and Opportunities

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WHAT CONDITIONS DO WE WANT TO RESTORE?

One of the goals of ecological restoration is to restore the structure and function of a site to that of its historical, natural condition or of indigenous reference sites. In other words, the goal is to restore ecosystem integrity. Woodley (1993) states that: "Ecological integrity is defined as a state of ecosystem development that is optimized for its geographic location, including energy input, available water, nutrients and colonization history. ... It implies that ecosystem structures and functions are unimpaired by human-caused stresses and that native species are present at viable population levels." Given my background, I take a plant-centered approach to restoration of site quality or biotic integrity, fully recognizing that healthy plant communities depend on physical integrity. To me, restoring structure means restoring a wide array of plant species and functional groups, restoring viable age structures for the dominant species, restoring vertical complexity, and restoring a mosaic of vegetation patches in the flood plain. Restoring function means, among other things, restoring bioproductivity, and restoring the ability of the plant communities to capture and store nutrients, build soils, stabilize stream banks, and create habitat for animals. As well, the plant community should be self-sustaining and resistant or resilient to various types of natural disturbances.

To a large degree, the question *"What do we want to restore?"* is the flip-side of *"What are the symptoms of degradation?"* Within Southwest riparian ecosystems, we find a continuum of degradation. We have some healthy reference areas, but it is difficult to find any that have not been altered by humans in some fashion. The symptoms of degradation vary depending on one's way-of-seeing and area of expertise. To a fluvial geomorphologist, prime indicators of degradation may be reduced stream meandering, presence of incised channels, or, in other settings, presence of wide, shallow stream channels. To a hydrologist, these indicators may include declining ground water levels or stream flow patterns that deviate from natural patterns. A plant ecologist may look to see whether a site has little capacity for self-repair or revegetation after flood disturbance, or if species-rich communities have been replaced by homogenous thickets of tamarisk (*Tamarisk ramosissima*), giant reed (*Arundo donax*), Bermuda grass (*Cynodon dactylon*), or other exotic species. A wildlife biologist may test for declining diversity of bird species, or population declines of riparian specialist species such as yellow-billed cuckoos or Southwestern willow flycatchers. To a range ecologist, symptoms of degradation may include soil compaction, stream channel downcutting, lack of tree regeneration, and spread of unpalatable plant species. A loss of biotic interactions such as a loss of pollinators, a breakdown of plant-disperser interactions, or a loss of plant-fungi mycorrhizal relationships are yet other types of indicators of degradation.

HOW DO WE RESTORE DEGRADED ECOSYSTEMS?

Restoration of Physical Elements and Processes

Hydrologic regimes and fluvial geomorphic processes are prime determinants of riparian community structure. To restore a diversity of plant species, growth forms, and age classes, we need to restore the diversity of fluvial processes, such as movement of channels, deposition of alluvial sediments, erosion of aggraded flood plains, that allow a diverse assemblage of plants to co-exist. To restore bioproductivity and

maintain plant species with shallow roots and high water needs, we have to ensure the presence of the necessary hydrogeomorphic elements—notably water flows, sediments and nutrients. We need to restore flows of water, sediment, and nutrients not only in sufficient quantities but with appropriate temporal patterns.

Flood Flows and River Dynamism.

The ultimate strategy for restoring natural processes is to remove all impediments to the natural flow regime, which in many cases means removing dams. This type of approach falls within the realm of passive restoration: one removes stressors, restores natural conditions and processes, and then allows the biotic communities to recover of their own accord (Middleton 1999).

Dams are being removed in the American West for the purpose of restoring habitat, and most often for endangered fish species. Working within drainage basins, some groups have contrasted the relative costs and benefits of a suite of dams with respect to economics and ecology (Shuman 1995; Born et al. 1998). Issues of dam removal and decommissioning in the Southwest should be systematically explored . Although there may only a few dams that qualify for removal, that should not dissuade us from pursuing this strategy.

We also can make compromises with respect to river management. Despite demands on water supply or power supply, we can find creative ways to work within the political and institutional constraints to rehabilitate, if not fully restore below-dam ecosystems. For example, we know that the timing, magnitude, frequency and duration of flows are all important influences on riparian vegetation. We can rehabilitate riparian ecosystems by naturalizing flows so as to mimic the natural hydrograph, or flow pattern, of the river. This is being done on the St. Mary and Oldman Rivers, in Alberta, Canada (Rood et al. 1995; Rood et al. 1998, Mahoney and Rood 1998), the Truckee River in Nevada (Gourley 1997), and the Bill Williams River in western Arizona (Shafroth et al. 1998; Shafroth 1999). Various flow release strategies that can be used to manage for cottonwoods and willows, and against tamarisk, on our regulated rivers are:

- When releasing winter/spring regeneration floods, limit the summer duration of the flood flows (Stromberg 1997).
- Release post-germination summer floods to increase the relative mortality of tamarisk seedlings (Gladwin and Roelle 1998).
- Maintain high summer base flows and water tables, to give a competitive edge to the native species.

Additional measures such as clearing of vegetation with bulldozers may be necessary to mimic the functions that have been lost by truncating the flow peaks. These 'active' restoration approaches, wherein one intervenes with some type of engineering approach or physical action, can serve to mimic natural processes and conditions at sites where natural processes can not be fully restored (Friedman et al. 1995).

It is impossible to manage directly for every single species in an ecosystem. We can, however, focus on a subset of species that we treat as indicators of intact physical processes (Lambeck 1997). We increases our odds of meeting the needs of a larger number of native species and providing sustainable ecosystem improvement if we take an ecosystem approach that accounts for natural cycles of disturbance, stream hydrology, and fluvial geomorphology (Bayley 1991; Stanford et al. 1996). With planning, water managers could be prepared in wet years to release flows routinely in ways that mimic the natural hydrograph and favor the native species that are adapted to the natural flow pattern. We also may be able to salvage small, functional rivers out of large, heavily regulated and diverted rivers such as the Lower Colorado and Rio Grande. Even if much of the water is diverted from the river, one can theoretically design a flood flow regime that is in scale with the new base flow level, with respect to regional flood and overall flow patterns. A related option for large river restoration is to construct one or more side channels (Schropp and Bakker 1998).

Water Quantities

Although stream water is fully allocated and even over-allocated in parts of the arid Southwest, there are many opportunities for restoring perennial flows and raising ground water levels in dewatered river reaches. Many cities are presently releasing their effluent directly into stream channels. At sites where the alluvial aquifer has not been depleted, the net result has been restoration or rehabilitation of large expanses of riparian vegetation. Below the 91st Avenue water treatment plant in Phoenix, Arizona, the channel of the Salt River is lined by herbaceous plants and young stands of cottonwoods, willows, and tamarisk trees. Vegetation extends across the wide flood plain, sustained by ground water that is recharged by effluent and agricultural return flows. Along the Santa Cruz River near Nogales, Arizona, cottonwood and willow forest ecosystems similarly have redeveloped as an unintended consequence of the release of treated municipal wastewater to the dry river channel (Stromberg et al. 1993).

There also are opportunities to enhance or restore riparian vegetation by recharging ground water into appropriate sites. Through water-banking, some of the Colorado River allocation of Arizona is recharged or "banked" in aquifers. In the arid Southwest, where open water evaporation rates exceed 2.7 m per year, aquifer recharge is a more viable and desirable method of water storage than storage in surface impoundments. A recent modeling showed that we can accomplish the dual goals of ground water recharge and riparian restoration. Extensive riparian forests could be reestablished in a dewatered reach of the Agua Fria River below the New Waddell Dam in central Arizona, if Central Arizona Project water was released from the dam (Springer et al. 1999). Planning efforts may be able to identify recharge sites that best fit our needs with respect to region-wide riparian restoration.

Watersheds

Dams and diversions are certainly not the only factors to be addressed when restoring hydrogeomorphic conditions and processes. We also must restore quality to upland plant communities. Watershed restoration will require a mix of passive measures, such as restoring natural fire regimes and grazing regimes, and active measures. For example, controlled burns may be useful for restoring structure to upland forests. Within the riparian corridor itself, small check dams can allow for more infiltration of water into the aquifers, thereby helping to sustain base flows year round while also reducing the frequency of catastrophic floods.

Channel-Floodplain Connectivity

Riparian ecosystems can be restored or improved along some rivers by removing the physical barriers that separate a channel from its flood plain. Along the Colorado River, for example, there are opportunities to remove the dikes and levees and restore some degree of channel-flood plain connectivity. By allowing water to periodically flow onto the flood plain, we provide the input of water, nutrients, sediments, and plant propagules to sustain the productivity and diversity of the riparian forest. Small flood releases along the Rio Grande (New Mexico), although too small to serve as recruitment flows, have reconnected the floodplain vegetation with the river water and served to partially restore riverine functioning in cottonwood forests (Molles et al. 1998).

Integration of Natural and Managed Ecosystems

Not all of our flood plain lands can be managed as ecological preserves. On our heavily used flood plains–such as those used for agriculture or urban centers–there are many benefits to be had by intermingling direct human uses with restoration of native riparian vegetation. For example, riparian forests could be restored to strips between agricultural fields, similar to the hedgerows used in Europe and elsewhere (Petit and Usher 1998). In the lower Colorado River flood plain, agricultural return flows have been used to increased the survivor-ship of riparian trees and shrubs planted as part of revegetation efforts (Briggs and Cornelius 1998), and such efforts could be expanded. Such efforts can move us farther towards sustainable agricultural practices, provide us with services such as crop pollination and consumption of

crop pests, and help us to meet riparian restoration goals.

Restoration of Animal Populations and Processes

Just as it is important to restore the hydrogeomorphic regimes to which native riparian species are adapted, it also is important to maintain biotic interactions, such as herbivory, within evolved tolerance ranges. Herbivores exert strong selective pressure on plant species. Alteration of herbivore grazing patterns or grazing intensity selects for a different assemblage of plant species. Heavily grazed plant communities, more often than not, do not provide us with a wide range of desired functions and services.

Ungulate Grazing

Will livestock exclusion restore riparian health? Sometimes, eliminating a stressor is all that is needed to enable natural recovery. Livestock removal (or reductions of higher-than-typical populations of elk and deer) can result in dramatic and rapid recovery of some elements of the riparian ecosystem, particularly where the ecosystem has not been degraded by other factors. Along the free-flowing upper San Pedro River, Arizona, cattle exclusion was followed by rapid channel narrowing and vegetative regrowth. New stands of cottonwood and willows and herbaceous plants developed in the wide, open stream banks, and song-bird populations increased (Krueper 1992). In other cases, the legacies of past severe overgrazing, or the presence of ongoing stressors, present more intractable restoration challenges. Natural recovery after cattle exclusion can be slow and problematic on severely overgrazed sites.

Other important questions remain. Can we manage for economically viable livestock grazing and riparian ecosystem health on the same parcel of land? This compromise is perhaps best met by reducing stocking rates rather than by imposing rest and rotation schemes (Holechek 1998). I suggest that we set livestock stocking rates based on the amount of forage available during dry years, rather than during average rainfall years (the typical practice). Ecological damage often occurs when there is a combination of stressors, such as drought and herbivory. Realistically, this may mean that livestock grazing is not economically viable in the hot deserts of the Southwest.

We also sorely need to increase our knowledge base in this area. There are few solid studies that demonstrate the consequences of grazing management schemes on *arid*-region riparian vegetation. Tolerance of, and recovery from grazing, is a much different ecological story in hot, arid regions than in mesic regions (Belsky et al. 1999).

We also need studies that allow us to separate the effects of grazing management changes from climate changes. In the past few decades, the Sonoran Desert has been wetter-than-normal (Swetnam and Betancourt 1998), and conditions have been favorable for Fremont cottonwood and Goodding willow regeneration (Stromberg 1998). We must be careful not to take management credit for ecological changes —such as large pulses of cottonwood and willow regeneration—that may simply be due to

Cattle have caused erosion and loss of vegetation along this path down to the Little Colorado River. Photo: B. Tellman

weather patterns.

At the very least, it is essential to maintain a sizeable number of ungrazed reference allotments at different elevation and in different geomorphic settings. This will provide us with a series of benchmark or reference sites against which we can compare the condition or integrity of grazed watersheds (Brinson and Rheinhardt 1996) and help to insure that we maintain a large diversity of high-quality riparian sites across the landscape.

Keystone Species

Reintroduction of missing or extirpated keystone species such as beaver can be an effective restoration tool. Beaver are considered to be a keystone species in riparian ecosystems because of the extent to which they modify local hydrology, stream geomorphology, and habitat conditions for plants and animals. Dams built by beavers serve to raise ground water levels, minimize seasonal variations in surface and ground water levels, and expand the areas of the flood plain and channel inundated by shallow water. There is a need, however, for scientific study of the effects of beaver on arid region riparian ecosystems (Naiman and Rogers 1997).

Prior to reintroducing beaver, one should assess site conditions to insure that the habitat and food supply are suitable. As with other natural forces such as floods, beavers can be problematic and cause further loss of quality at degraded sites. For example, if preferred food sources such as cattails (*Typha domingensis*) are sparse as a result of stream dewatering, beaver may be forced to feed heavily on cottonwoods and willows; if these are in short supply, due to river regulation for example, the net effect can be further reduction in site quality.

Restoration of plants and fungi

Restoration Plantings

A decade or so ago in the US Southwest, "riparian restoration" was synonymous with "cottonwood pole planting." We have learned, however, that planting is a successful restoration tool only if accompanied by other actions, i.e., only if the root causes of the absence or scarcity of the native species are addressed (Briggs 1996). There are times and places where it is necessary to plant native plant species to achieve restoration success or at least hasten recovery. For example, planting or seeding are essential if local seed sources have been depleted in number or in genetic diversity (Hill and Platts 1998).

We need to remind ourselves, periodically, of the biological complexity of riparian corridors. It is a daunting task to attempt to restore hundreds of species through direct plantings. Use of donor seed banks is a promising technique to restore some of this biodiversity to degraded sites. Donor soils have been obtained from high-integrity reference ecosystems to restore biodiversity to various types of degraded or newly created wetlands (Brown and Bedford 1997). Seed banks also can constitute a source of "hidden biodiversity," wherein the seeds at a degraded site are "waiting" below-ground for the return of suitable conditions.

Soil fungi are another important, but often overlooked, component of riparian ecosystems. Many human actions that affect soils, such as various agricultural practices, can deplete populations of mycorrhizal fungi. Reintroduction of mycorrhizal inoculum can improve the chances of restoration success on the many abandoned agricultural fields that line our arid-region rivers.

Exotic Species

Exotic species—those that have been introduced accidentally or intentionally by humans to a region in which they did not evolve—pose a definite challenge to riparian restorationists. There are hundreds of exotic plant species that have become naturalized in riparian corridors. A small percentage of these have become management issues due to their prevalence, negative influences on the ecosystem, or inability to totally mimic the functions of displaced natives. Generally, removal of exotics is an effective restoration strategy only if part of a larger plan that includes restoration of processes and conditions (but see Barrows 1998). We need to ask, is the exotic the cause of degradation or a symptom? Often, the abundance of riparian exotics is one symptom or facet of a complex, systemic resource allocation problem.

Without addressing the root causes of degradation that have led to the loss of the native species, there is a risk that traditional control measures—such as herbicides and biocontrol insects—will serve only to worsen the situation. In other words, some plants may be better than none (Anderson 1998).

Restoring natural processes and removing stressors, and then stepping back, can be an effective strategy for restoring native riparian species to some exotic-dominated sites. By restoring more natural stream flows and herbivory patterns, for example, we can tip the ecological balance in favor of the native species (Poff et al. 1997). The middle San Pedro River provides an interesting case study of such natural recovery (Stromberg 1998).

Once a firm commitment has been made to naturalize processes, we may be able to expedite recovery of the natives by removing the exotics mechanically. A success story using this approach can be found on a reach of the Rio Grande River in New Mexico. To restore the site, managers of the Refuge have mimicked the effects of large floods by using bulldozers, herbicides, and fire to clear the extensive stands of tamarisk at a cost of from $750 to $1,300 per hectare (Taylor and McDaniel 1998). Tamarisk clearing was essential, but it is the appropriate timing and quantity of water flows that will drive the system toward an increasingly native composition. Similar restoration efforts are being made at sites along the Lower Colorado River.

CLOSING WORDS

We close with a plea to all those involved in restoration attempts to document, publish, and share their results. Only from an extensive and shared knowledge base can we stop repeating the mistakes of the past and move towards a more desirable future.

LITERATURE CITED

Anderson, B. 1998. The case for salt cedar. Restoration and Management Notes 16: 130-134.

Barrows, C. 1998. The case for wholesale removal. Restoration and Management Notes 16: 135-139.

Bayley, P.B. 1991. The flood-pulse advantage and the restoration of river-floodplain systems. Regulated Rivers: Research and Management 6: 75-86.

Belsky, A. J., A. Matzke, and S. Uselman. 1999. Survey of livestock influences on stream and riparian ecosystems in the western United States. Journal of Soil and Water Conservation 54: 419-431.

Born, S. M., K. D. Genskow, T. L. Filbert, N. Hernandez-Mora, M. L. Keefer, and K. A. White. 1998. Socioeconomic and institutional dimensions of dam removals: The Wisconsin experience. Environmental Management 22: 359-370.

Briggs, M. K. and S. Cornelius. 1998. Opportunities for ecological improvement along the lower Colorado River and delta. Wetlands 18: 513-529.

Briggs, M. K. 1996. Riparian ecosystem recovery in arid lands. Tucson: University of Arizona Press.

Brinson, M. M. and R. Rheinhardt. 1996. The role of reference wetlands in functional assessment and mitigation. Ecological Applications 6: 69-76.

Brown, S.C. and B. L. Bedford. 1997. Restoration of wetland vegetation with transplanted wetland soil: An experimental study. Wetlands 17: 424-437.

Friedman, J. M., M. L. Scott, and W. M. Lewis. 1995. Restoration of riparian forest using irrigation, artificial disturbance, and natural seedfall. Environmental Management 19: 547-557.

Gladwin, D. N. and J. E. Roelle. 1998. Survival of plains cottonwood (*Populus deltoides* subsp. *monilifera*) and saltcedar (*Tamarix ramosissima*) seedlings in response to flooding. Wetlands 18: 669-674.

Gourley, C.R. 1997. Restoration of the lower Truckee River ecosystem: Challenges and opportunities. Paper presented at Wallace Stegner Conference: "To Cherish and Renew": Restoring Western Ecosystems and Communities.

Hill, M. T. and W. S. Platts. 1998. Ecosystem restoration: A case study in the Owens River Gorge, California. Fisheries 23: 18-27.

Holechek, J., R. D. Pieper, and C. H. Herbel. 1998. Range management: principles and practices. Prentice Hall, New Jersey.

Lambeck, R. J. 1997. Focal species: A multi-species umbrella for nature conservation. Conservation Biology 11: 849-856.

Krueper, D. J. 1992. Effects of land use practices on Western riparian ecosystems. USDA Forest Service General Technical Report RM-229: 321-330.

Mahoney, J. M. and S. B. Rood. 1998. Streamflow requirements for cottonwood seedling recruitment—an integrative model. Wetlands 18: 634-645.

Middleton, B. 1999. Wetland restoration: Flood pulsing and disturbance dynamics. New York: John Wiley and Sons.

Molles, M.C., C.S. Crawford, L.M. Ellis, H.M. Valett and C.N. Dahm. 1998. Managed flooding for riparian ecosystem restoration - Managed flooding reorganizes riparian forest ecosystems along the middle Rio Grande in New Mexico. BioScience 48: 749-756.

Naiman R. J. and K. H. Rogers. 1997. Large animals and system level characteristics in river corridors. BioScience 47: 521-529.

Petit, S. and M. B. Usher. 1998. Biodiversity in agricultural landscapes: The ground beetle communities of woody uncultivated habitats. Biodiversity and Conservation 7: 1549-1561.

Poff, N. L., J. D. Allan, M. B. Bain, J. R. Karr, K. L. Prestegaard, B. D. Richter, and J. C. Stromberg. 1997. The natural flow regime: A paradigm for river conservation and restoration. BioScience 47: 769-784.

Rood S. B, A. R. Kalischuk, and J. M. Mahoney. 1998. Initial cottonwood seedling recruitment following the flood of the century of the Oldman River, Alberta, Canada. Wetlands 18: 557-570.

Rood, S. B., J. M. Mahoney, D. E. Reid, and L. Zilm. 1995. Instream flows and the decline of riparian cottonwoods along the St. Mary River, Alberta. Canadian Journal of Botany 73: 1250-1260.

Schropp, M. H. and C. Bakker. 1998. Secondary channels as a basis for the ecological rehabilitation of Dutch rivers. Aquatic Conservation- Marine and Freshwater Ecosystems 8: 53-59.

Shafroth, P. B. 1999. Downstream effects of dams on riparian vegetation: Bill Williams River, Arizona. PhD Dissertation, Arizona State University, Tempe.

Shafroth, P. B., G. T. Auble, J. C. Stromberg, and D. T. Patten. 1998. Establishment of woody riparian vegetation in relation to annual patterns of streamflow, Bill Williams River, Arizona. Wetlands: 18: 577-590.

Shuman, J. R. 1995. Environmental considerations for assessing dam removal alternatives for river restoration. Regulated Rivers- Research and Management 11: 249-261.

Springer, A. E., J. M. Wright, P. B. Shafroth, J. C. Stromberg, and D. T. Patten. 1999. Coupling ground-water and riparian vegetation models to simulate riparian vegetation changes due to a reservoir release. Water Resources Research, in review.

Stanford, J. A., J. V. Ward, W. J. Liss, C. A. Frissell, R. N. Williams, J. A. Lichatowich, and C. C. Coutant. 1996. A general protocol for restoration of regulated rivers. Regulated Rivers: Research and Management 12: 391-41.

Stromberg, J. 1998. Dynamics of Fremont cottonwood (*Populus fremontii*) and saltcedar (*Tamarix chinensis*) populations along the San Pedro River, Arizona. Journal of Arid Environments 40: 133-155.

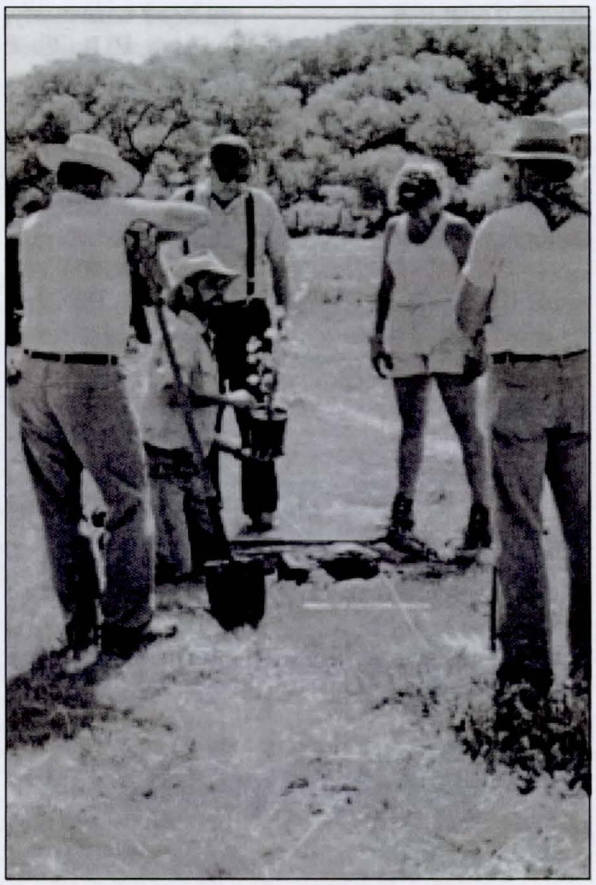
Stromberg, J. C. 1997. Growth and survivorship of Fremont cottonwood, Goodding willow, and salt cedar seedlings after large floods in central Arizona. Great Basin Naturalist 57: 198-208.

Stromberg, J. C., M. R. Sommerfeld, D. T. Patten, J. Fry, C. Kramer, F. Amalfi, and C. Christian.1993. Release of effluent into the Upper Santa Cruz River, Southern Arizona: Ecological considerations. Pages 81-92 IN M. G. Wallace, Editor. Proceedings of the Symposium on Effluent Use Management. American Water Resources Association, Tucson, Arizona.

Swetnam, T. W. and J. L. Betancourt. 1998. Mesoscale disturbance and ecological response to decadal climatic variability in the American Southwest. Journal of Climate 11: 3128-3147.

Taylor J.P. and K. C. McDaniel. 1998. Restoration of saltcedar (*Tamarix* sp.)-infested floodplains on the Bosque del Apache National Wildlife Refuge. Weed Technology 12: 345-352.

Woodley, S. 1993. Monitoring and measuring ecosystem integrity in Canadian National Parks. 155-176 IN Woodley, S., J. Kay, and G. Francis. Ecological integrity and the management of ecosystems. St. Lucie Press.



Volunteers planting cottonwoods.
Photo: Ron Tiller

Fluvial-Geomorphic Considerations in Riparian-Zone Restoration Efforts

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The concept and practice of riparian-zone restoration has been advanced primarily by ecologists for ecologists (e.g. Briggs 1996). Restoration, however, is the act of re-establishing or reverting toward a previous condition or position, and when applied to natural systems must include considerations of interactions between them (e.g. Gordon et al. 1992; Tellman et at. 1993).

HYDROGEOMORPHIC DYNAMICS

Any restoration activity should be attempted with recognition that bottomland species are endemic to an area because they are adjusted to natural conditions of hydrogeomorphic dynamics. The degree to which pre-development hydrologic and geomorphic processes can be restored is a measure of the potential for successful re-introduction of indigenous biota. Owing, for example, to spawning and seed-dispersal patterns, soil- and water-quality tolerances, and competition for water, nutrients, and light, many fauna and flora cannot survive in bottomland ecosystems unless floods effectively move bed material, erode bank sediment, cause bar and overbank deposition of silt and sand, and remove decaying organic litter. Unless these processes of fluvial dynamics are replicated by flows and floods typical of pre-development conditions, riparian-zone restoration cannot be total.

Especially when ecological restoration is desired within bottomland areas of active, unregulated streams, goals of achieving diverse habitat must be consistent with the ongoing change typical of an active fluvial system. This change, the result of varying fluxes of water and sediment, is expressed as constantly changing geomorphic features—stream channels, bars, flood plain, and terraces—and thus constantly changing but disparate habitat types. Where streamflow is regulated or otherwise altered and sediment is stored in upstream reservoirs, successful riparian-zone restoration may be most likely if variable streamflow and pre-regulation discharge of sediment can be re-established to restore processes of landform dynamics (Stanford et al. 1996). Efforts in the first instance, where fluxes of water and sediment have not been disrupted, may reasonably be applied to achieve full restoration. Where regulation, streamflow diversion or augmentation, groundwater pumping, or alteration of the physical bottomland characteristics preclude reinstating pre-development inputs of water and sediment, only partial restoration may be feasible and objectives should be stated accordingly.

EXAMPLES OF RESTORATION EFFORTS

Restoration is feasible only within the physical limits imposed on a watershed. Examples of restoration efforts applied to altered fluvial systems include streams flowing westward to the Mississippi River in western Tennessee, and upper reaches of the Little Colorado River in eastern Arizona. Both examples represent changes due to social, political, and economic conditions that probably preclude complete renovation of the hydrologic, geomorphic, and ecological characteristics of the bottomlands.

Most major stream channels of western Tennessee, which prior to development meandered on sandy beds a small depth below forested flood-plain areas, have been cleared of vegetation, dredged, and straightened repeatedly during the last century in attempts to reduce flood frequency. The deepening and gradient increases have caused increased stream power and thus pronounced stream incision accompanied by adjustments in riparian-zone vegetative patterns and various forms of bank failure, channel erosion, and loss of farmland (Simon and Hupp 1987). Changes in land use and status

during the last century make it impractical to re-impose the original positions (especially sinuosity) of the channels, and restoration programs must be designed to restore stream-channel stability within a condition of permanently incised and straightened channel patterns. Restoration of pre-development plant species may be possible, but the areal extent of the forested riparian zone will remain small, an inset within the channel incision.

Two reservoirs, Lyman and Zion, store water and sediment of the Little Colorado River, in northeastern Arizona. Downstream from Zion Reservoir, which was constructed in the early part of the century and quickly filled with sediment, the channel of the river is generally dry. Infrequent, sediment-deficient flows, however, have cut as much as eight meters into the easily eroded bottomland deposits of the area. The incision has caused the drainage of shallow ground water and, possibly exacerbated by land-use practices and regional extractions of the deep groundwater resources, conversion of riparian-zone vegetation from phreatophytes to xerophytes; channel vegetation is dominated by saltcedar. Restoration efforts are centering on augmentation of streamflow, the elimination of Zion Dam, evacuation of sediment presently stored in the reservoir, and deposition of entrained sediment downchannel to reverse the incision process and re-establish a shallow groundwater reservoir. If restoration activities of the physical system prove successful, attempts will be made to re-introduce native plant species of the pre-development period.

LITERATURE CITED

Briggs, M.K. 1996. Riparian ecosystem recovery in arid lands. The University of Arizona Press. Tucson. 159 p.

Gordon, N.D., T.A. McMahon, and B.L. Finlayson. Stream Hydrology—An introduction for ecologists. John Wiley and Sons. Chichester. 526 p.

Simon, Andrew and C.R. Hupp. 1987. Geomorphic and vegetative recovery processes along modified Tennessee streams: An interdisciplinary approach to distributed fluvial systems. Forest Hydrology and Watershed Management. International Association of Hydrological Sciences Publication 167. 251-262.

Stanford, J.A., et al. A general protocol for restoration of regulated rivers. Regulated Rivers Research and Management. v. 12 391-413.

Tellman, Barbara, H.J. Cortner, M.G. Wallace and L.F. DeBano (Technical Coordinators) 1993. Riparian management: Common threads and shared interests. Conference Proceedings. Rocky Mountain Forest and Range Experiment Station. General Technical Report RM-226. Ft. Collins.

Tonto National Forest Stream Assessment Method[1]

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INTRODUCTION

Nowhere is there more recognition of the ecological importance of riparian areas than in the arid southwestern region of the United States. Representing less than one percent of the total land base, conflicts involving riparian areas dominate public land management efforts. Livestock grazing, increasing elk use, recreation impacts, surface water diversion, groundwater pumping, mining, highway construction, and continued listing as threatened or endangered of many native fish and wildlife species associated with riparian areas present increasingly complex land management choices, and have resulted in widespread controversy and legal challenges.

A key component necessary for effective management and restoration of riparian areas is a systematic approach to inventory, classification, monitoring, and assessment. In other geographic regions of the western United States, there has been a general acceptance and standardization of inventory and classification methods. In the Southwest, however, there is a perception that riparian ecosystems, the processes that shape them, and their history of degradation, are unique and do not fit within any existing classifications.

A systematic approach to analysis is essential to program development and institutionalizing riparian area considerations into any decision making process. Lack of such an approach has contributed to minimal program development and agency support in the Southwestern Region of the Forest Service. Our approach is based primarily on an assessment of parameters that affect a stream channel's physical stability. Rosgen's (1999) definition of stream stability is "...the ability of a stream to transport the water and sediment of its watershed while maintaining its dimension, pattern, and profile over time and in the current climate, without aggrading or degrading."

METHOD OF ASSESSMENT

The initial step is to stratify stream reaches by delineating valley segments on the basis of valley width and slope (Maxwell et al 1995). Data are collected to provide a descriptive characterization of the fluvial surfaces within the valley segment and the vegetation associated with each surface. A cross section of the valley bottom is sketched. Width and depth to the bottom of the stream channel are estimated. Dominant tree, shrub, and herbaceous species are listed for each surface. Vegetative cover is estimated by species and size class. Stream reaches within valley segments are verified in the field and sampled at representative sites. Stream channel cross sections, including channel slope, and pebble counts are completed. The reach is then classified according to Rosgen's (1996) stream classification method. Regional curves (Moody and Odem 1999) are used to help locate bankfull features, that are often not apparent on degraded streams.

The following parameters are then evaluated for each reach: depositional pattern, riparian health (Thompson et al. 1998), width/depth ratio, channel stability (Pfankuch 1975), and bank erosion hazard index (Rosgen 1996). These parameters aid in assessing the overall stability of a stream as described by Rosgen in the above definition. Each of the five parameters is rated as stable, impaired, or unstable and tallied for an overall rating. Professional judgement also plays a role in the overall rating. A "Proper Functioning Condition" scorecard (Barrett 1993) is completed at the end of each field

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1 Also published in Olsen, D. S. and J. P. Potyondy (editors). 1999. Proceedings Specialty Conference Wildland Hydrology, June 30-July 2, 1999, Bozeman, Montana. Wildland Hydrology, American Water Resources Association, Herndon, Virginia, TPS-99-3, 536 pp.

visit.

Depositional patterns (Rosgen 1996) are used to indicate stream condition. Various patterns of bar formation display the effects of past land management and natural disturbances on sediment supply. Excessive sediment deposition is related to changes in the dimensions of the stream channel.

Stream bank stability and floodplain function are affected by the condition and abundance of riparian vegetation (riparian health) (Thompson et al 1998). Healthy riparian communities stabilize banks, build floodplains, dissipate energy of high flows, provide wildlife habitat, and facilitate groundwater recharge and discharge. Degraded riparian vegetation impairs these functions and reduces stream stability.

Stream channel width/depth ratio is a key channel morphology parameter used to indicate trend in channel stability. This ratio is key to understanding the distribution of energy in a channel and the ability of various discharges to move sediment (Rosgen 1996). Ranges of width/depth ratio values for each stream type compiled from the Tonto National Forest's stream data base, supplemented by Rosgen's data, provide a basis for evaluating the condition of an individual stream's width/depth ratio.

Pfankuch's channel stability rating (1975) has been a widely used method to evaluate the ability of a channel to resist sediment detachment from the bed and banks. Since all channel types do not have the same inherent stability, Rosgen's conversion table that modifies the Pfankuch stability rating based on stream type is used.

Streambank erosion is a natural process, but management practices can accelerate erosion. Rosgen developed the Bank Erosion Hazard Index (BEHI) as an indicator of bank erosion potential based on numerical characterization of various streambank conditions. These conditions are rated individually and summed for an overall rating of bank erosion hazard.

CONCLUSION

Riparian areas in the Southwest are characterized by their limited size and high productivity. The Tonto National Forest includes approximately three million acres, of which one percent, or 30,000 acres, are riparian areas. This includes approximately 1,400 stream miles. Data has been collected on some 160 reaches or approximately 160 miles of stream. Most of the assessments are done by the Forest Service's riparian ecologist and hydrologist. The Tonto National Forest Stream Assessment Method was developed in 1996 and subsequently revised several times. The data collected provides the inventory for the forest-level data base.

Approximately half of channel cross section sites are permanently located, providing monitoring data and trend. Data are used primarily for project level analysis. Recently, the data was used to assess watershed condition in a forest-level biological assessment prompted by a lawsuit involving livestock grazing and threatened and endangered species.

LITERATURE CITED

Barrett, Hugh, Jim Cagney, Ron Clark, Jim Fogg, Karl Gebhardt, Paul L. Hansen, Brenda Mitchell, Don Prichard and Dan Tippy. 1993 (Revised 1995). Riparian area management: Process for assessing proper functioning condition. Technical Ref. 1737-9, Bureau of Land Management, Denver, CO. 51 p.

Maxwell, James R., Clayton J. Edwards, Mark E. Jensen, Steven J. Paustian, Harry Parrott, and Donley M. Hill. 1995. A hierarchical framework of aquatic ecological units in North America (Nearctic Zone). General Technical Report NC-176. St. Paul MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 72 p.

Moody, Thomas O., Wilbert Odem. 1999. Regional relationships for bankfull stage in natural channels of Central and Southern Arizona. Northern Arizona University, Flagstaff, Arizona. 37 p.

Pfankuch, D. J. 1975. Stream reach inventory and channel stability evaluation. USDA Forest Service, R1-75-002. GPO #696-260/200, Washington, D.C. 26 p.

Rosgen, Dave. 1996. Applied River Morphology. Wildland Hydrology. Pagosa Springs.
Rosgen, Dave. 1999. personal communication, Wildland Hydrology. Pagosa Springs, CO.
Thompson, William H., Robert C. Ehrhart, Paul L. Hanson, Thomas G. Parker, and William C. Haglan. 1998. Assessing health of a riparian site. IN Proceedings AWRA speciality conference on rangeland management and water resources May 27-29, Reno American Water Resources Association, pp. 3-12.

An eroded headwater stream in the San Francisco Mountains. Photo: B. Tellman

The Riparian Restoration Ranking (R3) System: A Tool for Setting Priorities in a Resource-Limited World

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"Watershed maintenance and restoration are the oldest and highest callings of the Forest Service. The National Forests truly are the headwaters of the nation. Our agenda places a renewed emphasis on ensuring that our watersheds are protected and restored for the use and benefit of our citizens." Michael Dombeck, Chief, US Forest Service.

To address increasing needs for riparian restoration on public lands in the Southwestern United States, the Society for Ecological Restoration (SER) undertook a collaborative project with the Southwest Region of the USDA Forest Service ("the Region"), with the goal of strengthening efforts to restore riparian ecosystems in the highest priority watersheds. SER's collaborators in the project included the Sonoran Institute and the USGS-Biological Resources Division office at the University of Arizona. SER and its primary collaborators also assembled a regional team of experienced riparian ecologists and restoration practitioners. This Review Panel met several times during development of the R3 system, and contributed immeasurably to its quality. Collectively these public and private institutions are the "R3 Partners" who created this system.

Riparian areas constitute some of the most important ecosystems in the western United States. Known for their high biological diversity, productivity, and functional importance, riparian areas are truly "keystone ecosystems" almost everywhere they occur. More than 240,000 acres of riparian areas occur on National Forests in the southwestern United States. These areas are home to large numbers of rare, threatened, and endangered species, including at least 100 animal species and many rare plants. Despite their importance to ecology, water quality, water supply, and recreation, riparian areas have experienced heavy impacts from land use in recent years. A wide range of land use activities affect riparian ecosystems, including recreation, mining, grazing, commercial and residential development, and many others. The end result is that many riparian areas have become degraded, and thus less able to support the rich species assemblages and key ecological functions that they perform when healthy.

Ecological restoration is emerging as a key strategy to maintain the health of riparian ecosystems. Restoration involves returning an ecosystem to a healthy condition, preferably one that resembles closely its prior natural and healthy state. Restorationists recognize that it may not always be possible (or even desirable) to restore every aspect of an ecosystem to its original condition. However, by using *reference conditions* as a guide, land managers and restoration practitioners can develop a prescription that will bring the riparian ecosystem back within a normal range of conditions. Often, the dilemma facing land-management agencies is not whether they *want* to restore a particular ecosystem, but whether they have the resources available to do so. Given that there are increasing needs (but limited resources) for ecological restoration, land managers must therefore allocate their available resources carefully. The key tool available to a land manager for this process is a system of *setting priorities*.

The R3 System is designed as just such a system. *The purpose of the R3 System is to rank*

riparian areas and their associated water-sheds for restoration potential and difficulty, as a key step in establishing priorities. R3 accomplishes this by bringing together two kinds of information. First, the R3 user assembles pertinent information concerning the *ecological condition* of the riparian area and its watershed. Second, the user assembles information about *land use* in the same areas. A simple numerical scoring system is used to indicate how different the current watershed condition is from the reference condition, and the extent to which land use practices are affecting ecological condition. R3 then combines the scores into a numerical index, which the land manager can use to compare different watersheds for restoration priority and potential difficulty. The R3 System can be scored manually, or using a simple computer spreadsheet application developed specifically for this purpose. In this way, the main objective of the R3 System is fulfilled, which is to provide land managers an objective system for determining which riparian areas should be of the highest priority for restoration.

The R3 System is designed to have several important characteristics. First, it is based on *objective criteria* rather than reliance on subjective assessments. Second, R3 it can be implemented using *existing data*, recognizing that land managers frequently have to make decisions about priorities using available information, and without the luxury to conduct additional investigations. Third, *R3 works at multiple hydrologic scales* including the IVth-VIth watershed scales frequently used by the Forest Service and other agencies in watershed planning. Fourth, R3 *allows analysis at the forest, state, or regional level,* enabling its application by a variety of land managers within the region. Fifth, R3 *employs widely-available software*, so that its application will not require sophisticated computer facilities. And sixth, R3 *integrates riparian and watershed evaluation*, in the belief that riparian restoration will ultimately be most successful when it is coupled with sound watershed planning.

The R3 System is *not* designed to provide a detailed restoration prescription. Nor does it take the place of other considerations in the management of public lands, such as local social, political, and economic factors. Indeed, R3 is designed specifically to provide an *objective, information-based system* with which land managers may evaluate competing restoration priorities. No ranking system can take the place of sound and informed policy; the goal of R3 is to provide a sound objective and scientific basis for the implementation of land use and restoration policies.

The R3 ranking procedure includes collection and input of a variety of information about ecological condition, generally through the use of "composite variables" that represent the synthesis of any number of individual measurement variables. For example, Ecological Condition attributes include:

- E1 Increased Channel instability;
- E2. Altered streamflow characteristics;
- E3. Altered water quality;
- E4. Altered bottomland plant communities;
- E5. Altered aquatic fauna;
- E6. Altered obligate wetland or riparian Fauna;
- E7. Altered upland geophysical condition.

Each of these can be represented by a variety of measurement data available to the agency. The user scores the percent of the watershed land area, or linear stream miles, that have been altered from reference conditions. In the case of Land Use & Management, the composite variables include:

- L1. Non-Forest Service ownership;
- L2. Urbanization;
- L3. Grazing allotments;
- L4. High impact recreation;
- L5. Mining: Active claims or mineral;
- L6. Agriculture;
- L7. High intensity logging;
- L8. Road and utility corridor density;
- L9. Altered fire regime;
- L10. Groundwater withdrawal;
- L11. Recreation: Active floodplain impacts;
- L12. Mining: Active floodplain impacts;
- L13. Water impoundments and diversions;
- L14. Grazing in active floodplain;
- L15. Roads or buildings in an active floodplain.

The user scores these factors by estimating the percentage of watershed area or linear stream miles affected by these respective uses. The R3 system employs a "trending" calculation to take into account whether ecological conditions in the study area are declining or improving, and whether land uses are intensifying or ameliorating

FUTURE DIRECTIONS

The Region III office of the Forest Service has indicated plans to test, adopt and utilize the R3 system extensively. R3 is intended to be an iterative living system that will change and improve with successive users. Please forward your interest in testing the R3 system and any comments on its application and utility to the authors or:

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ACKNOWLEDGMENTS

The R3 System has been a collaborative effort involving the knowledge and dedication of many people and institutions. The Project Leaders wish especially to acknowledge the contributions of the Doug Shaw and Reggie Fletcher (*USDA Forest Service, Region III*), Greg Miller (*Carson National Forest*), Carl Edminster (*USDA Forest Service, Rocky Mountain Research Station*), Mima Falk, Bob Le Fevre, Tom Skinner (*Coronado National Forest*), and the *R3 Review Panel Members*. The Project Leaders also thank our respective home institutions (Society for Ecological Restoration, Sonoran Institute, USGS-Biological Resources Division) for making the restoration of riparian areas a significant priority.

Note: Free copies of the R3 Manual may be obtained from Reggie Fletcher at the U.S. Forest Service at the above address.

Field of planted cottonwoods in the second year.
Photo: Ron Tiller

Restoration Monitoring

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INTRODUCTION

Monitoring is an essential part of any habitat restoration project, especially those undertaken as regulatory compliance or mitigation (e.g. wetland habitat restoration). Monitoring is a means of assessing the attainment of a goal, or measuring progress toward a goal. Monitoring may also detect failures in implementation, allowing quick corrective action. Monitoring is often required in mitigation cases. Properly designed and executed, monitoring can save time and money.

The first requirement of a monitoring plan is a clear statement of the desired condition. The ideal monitoring plan will identify the monitoring target or targets (parameters to be measured), the monitoring period and frequency, the methods of measurement, and the mileposts to be met or the range of acceptable variation in the parameter to be monitored.

This paper draws from many sources, including the Federal, state and local resource agencies, research documents and papers, and from professional experience in preparing restoration and mitigation plans and monitoring reports. Our emphasis is on aquatic sites, which include wetlands, river and lakes, and upland wildlife sites. Our experience in de-signing and conducting monitoring plans is primarily associated with mitigation of transportation or development projects. Wetland and stream restorations have been our primary focus; however, the principles outlined here can be applied to any situation, since often restoration is tied to roadways, other construction projects, or consequences of urbanization. This paper is a brief overview of restoration monitoring planning, and does not cover specific details of field monitoring techniques. A few references on sampling methods are included in the bibliography.

Restoration monitoring takes into account both the physical site characteristics and the surrounding landscape (i.e., has the planned restoration adapted or fit into the landscape?). Monitoring is conducted to determine if the restoration site has been established in the landscape to recreate a naturally functioning habitat type.

A monitoring program is created as a secondary, but dependent and integral part of the restoration effort. The monitoring program is the mechanism that helps define what to measure in the landscape, what the results should be compared with after collected, what should be done if corrective measures need to be implemented, and what the measurement criteria are to determine if the performance standards have been met.

A good monitoring program begins by clearly defining project goals (i.e., what should be measured) during the initial planning phase of a restoration project. The monitoring program uses background data collected from the impact area and proposed restoration site. Also included are the proposed restoration goals and objectives to formulate performance standards and measurement criteria. The monitoring program should include:

- Define project goals;
- Determine what to measure/monitor;
- Determine appropriate schedule;
- Implement monitoring program;
- Report results;

Additional tasks may include

- Finding compatible reference sites;
- Conducting multiple season/year analyses; and
- Preparing maintenance or contingency measures implementation plan if the performance standards are not met.

Performance standards in the restoration plan should be easily measurable and tied to the landscape to allow relatively smooth monitoring. This may include:

- Examining percent cover;
- Survival rate; and

- Species richness and diversity of vegetation to verify that the structure of the landscape is suitable for targeted wildlife species identified in the restoration plan.

Long-term monitoring periods (e.g., five to ten years for a wetland mitigation site) may be spaced to bi- or tri-annual reviews, but should only be terminated when the goals and objectives are met. Funding for monitoring needs to be factored into the design cost to maintain consistency and build a solid research database.

DESIGN AND MONITORING PLAN

Monitoring determines if the desired planning goals and objectives have been met, and, if not, indicates what can be done to correct the restoration effort. Monitoring results build the current resource agency database to strengthen future restoration efforts by knowing specifically what has worked and what has not worked. Monitoring needs to be flexible to allow for contingency measures to occur. Contingency measures would provide post-construction modifications to the original design to correct for unforeseen (e.g., wildlife predation) or unusual (e.g., severe drought or rainfall) circumstances.

Monitoring is the inverse of the planning process effort. Planning formulates the objectives of the restoration plan, determines the function and then designs the structures to meet the function. Monitoring examines the site to determine if the structure has been adequately established in order to provide the habitat or landscape for the function, which, in turn, demonstrates that the objectives have been achieved.

Public Participation

If the project is controversial or is highly visible, a follow-up public meeting after design should be included in the plan to kick-off the monitoring. Sometimes interested groups (e.g., Audubon Society, neighborhood associations, etc.) can contribute informally to the monitoring program. For example, these groups may volunteer time to re-stake wind-thrown saplings, observe wildlife at off-hours, provide a presence to reduce vandalism, and take pride and ownership in a project through this kind of stewardship effort.

Monitoring Planning

Monitoring should relate to initial site conditions and identify habitat type or target species (flora or fauna) that the restoration is to replace (restore). This will give the focus of effort for both the restoration planning and the subsequent monitoring. The selected habitat type or target species will dictate the physical, chemical and biological needs for the restoration plan. Also, when a habitat type or target species have been identified, adequate funding to do the monitoring then can be budgeted into the construction appropriations for the anticipated monitoring period (e.g., forested restorations take longer to establish, so require longer monitoring periods).

However, typically there are only limited funds available to do the monitoring on multiple levels (i.e., physical, chemical and biological levels) so the monitoring program generally needs to focus on basic and readable characteristics in the landscape; that is: the physical structure of the landscape for providing a specific habitat or a particular need for a species characteristic of, or within the desired habitat type (e.g., amphibians in wetlands due to the general sensitivity to changes in water quality).

Monitoring programs can not be generic. Each project's monitoring effort should focus on how to identify and measure the specific environmental needs of species (flora and fauna) that are part of the goals and objectives.

Baseline

The plan begins with a pre-project baseline of the actual restoration site for comparison as monitoring progresses. Identifying the existing site conditions will provide a benchmark to see if the restoration has taken hold and is moving towards the desired goal. Typical elements to include in the baseline review are listed below.

- Size and location of site;
- Position in landscape (depression, stream, floodplain, terrace, and upland);
- Soil characteristics (texture and chemistry);

- Hydrologic regime (rainfall, surface/subsurface flow and water budget)
- Water quality (temperature, dissolved oxygen, pH, and alkalinity)
- Dominant plant community or species association (native and non-native)
- Fish and wildlife species (resident and migratory)
- Current and future land use

As monitoring progresses, the frequency of site reviews can be reassessed depending on results in comparison to the baseline.

Restoration Resources

Several resources can also be used in the formulation of the restoration plan, monitoring program and to determine if restoration goals have been met. These include previous studies and government standards. Government standards include Habitat Suitability Indices (HSI's) and Habitat Evaluation Procedures (HEP's) that identify necessary landscape elements and site characteristics that need to be present (e.g., river bed substrate, vegetation species density/diversity or aquatic regime) for stream rehabilitation or bank stabilization. After data is gathered on the physical structure of the site, the results can be compared to the requirements found in the literature for the restoration habitat type or target species. This may be simply measuring the desired attributes and comparing them with the project objectives (e.g., the objective was to establish cottonwood trees at a minimum density of 500 trees/ha. Five years after planting, the monitoring determined the cottonwood density to be 554 trees/ha. If the goal for the habitat type or target species "X" habitat were cottonwoods at 500 trees/ha, the restoration would have met the goal).

The most effective way to use monitoring is by contrasting the restoration site with an existing, comparable area, the reference site. If the reference site is doing well and the restoration site is not, then the monitoring effort is prompted to look for a cause. If the reference site is doing badly, however, then the monitoring effort would be directed to determine a reason and may attribute the cause to natural conditions, such as a drought.

Reference sites should be areas that have had a lack of, or minimum human disturbance to date and will be protected in the future. Care must be taken to select a typical reference rather than trying to achieve a unique or rare landscape condition for comparison to the restoration site. Selecting a reference site that is too unique may set performance standards that are unachievable or too costly for an average restoration project. Unique or rare habitats used for reference sites should be used, however, if warranted for restoration of threatened and endangered species habitat, and when sufficient funds are available for the project. The reference site may be in the same general area as the restoration project or in another watershed in the same geographic region. Typically, a restoration project will not be able to achieve the goals in a reasonable time, since restorations often include goals that require decades or more to be realized (e.g., forested riverine site can take 50+ years). So, the monitoring should be aimed at the "building blocks" of the restoration—is there the right mix of physical, chemical and biological conditions to meet the goal for the habitat type? We look at this by seeing if the landscape is healthy: do we have young plants of the target community? Do we have early successional plants leading to the desired climax stage?

Monitoring Structure

In general, we monitor the structure of the restoration by examining the vegetation (aquatic or terrestrial) or by indicators of vegetation. This would mean sampling the landscape to see if the restoration site is the same as planned (e.g., did some wash away, did plants not grow, is some of the wetland site dry?), and is the site re-vegetated as designed (e.g., are the plants we wanted to grow flourishing?)? Depending on the project, site features tied to each objective need to be monitored independently. The breakdown should be tied to the critical vegetative structure needed to meet the project goals, but are generally divided into strata covering herbaceous (grasses and forbs), shrub and tree communities. In some cases, saplings, shrubs, cacti and vines (lianas) can be included as separate plant communities to measure.

With the herbaceous community, measuring percent cover is easiest. This can give answers for contingency measures for revegetation if specific plants species do not take hold, or whether the site is subject to predation. With trees and shrubs, measuring percent survival (individual) in the initial one to two years, and measuring cover thereafter works well, since most trees and shrubs have established.

Species that normally thrive in the desired habitat type should be selected as appropriate for the ecosystem that is being replicated. For example, look for amphibians in wetlands and lakes (due to the sensitive water quality needs) and butterflies for arid riparian areas (due to their relatively quick response (growth/extinction) to habitat changes).

Periodic photographs from fixed points provide quick comparative data on structure and cover. This may include an aerial photo beyond the standard ground level views. Supplemental photos can be taken to illustrate unique items, such as nesting areas, colonization by other species, etc.

Monitoring Intervals

Choice of monitoring intervals reflects project goals and objectives. Seasonal monitoring for the length of the monitoring period may be excessive. Spring and fall monitoring is generally sufficient during a project's initial years, though intervals may be lengthened or otherwise modified, as contingency measures require. Monitoring ceases when goals have been achieved and a sufficient period (e.g., a year or more) has elapsed after all artificial supports have been removed (e.g., watering, weeding and fertilizers).

Monitoring Results

Monitoring results should be recorded in brief reports that include:

- General site conditions;
- Comparisons with baseline condition;
- Contingency actions;
- Schedules for future monitoring;
- Data collected (as appendices).

Also included should be the lead review agency, agency distribution list and project sponsor contacts. A final report should be prepared at the end of the monitoring period, consolidating previous results and providing a synopsis of the overall restoration project. Monitoring results should be compared to other relevant studies. Results should include the Reference Site conditions that constitute uncontrollable environmental conditions. The Final Report should also identify any contingency measures that were employed. Copies of the report should be sent out to participating and/or permitting agencies for review and concurrence, with the project sponsor taking the lead role in consolidating comments.

MONITORING BENEFITS

Over the long term, effective monitoring expands databases, facilitates future restoration efforts and saves money. While project modifications are increasingly expensive as the planning/design process proceeds, they are less costly than those implemented after construction has begun. Contingency measures—necessitated by site-specific conditions or unforeseeable circumstances— may similarly be unavoidable but necessary costs to satisfy permit requirement and guarantee a successful project.

Monitoring birds along the Bill Williams River. Photo: B. Tellman

Large Scale Removal of Saltcedar Monocultures Prior to Restoration with Native Vegetation

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INTRODUCTION

Restoring southwestern riparian areas frequently entails preliminary control of exotic flora (Anderson and Ohmart 1982). On the Middle Rio Grande in central New Mexico, saltcedar, (*Tamarisk ramosissima* Ledeb), is a dominant exotic tree occurring in extensive monocultures. Where river flow regimes mimic natural hydrographs coinciding with seed rain for native species, exotic flora must be removed for native species regeneration to succeed (Taylor et al. 1999). Here we evaluate control efficacy and costs for two techniques used for large scale saltcedar control prior to native species reestablishment.

SALTCEDAR CONTROL

Two methods of saltcedar control appear to be effective prior to revegetation with native riparian species: mechanical control and herbicide/burn control. Mechanical saltcedar control using heavy equipment evolved from the use of plows pulled by bulldozers to sever underground root crowns in the 1950s (Horton 1960), to a three-step process of aerial stem removal, root plowing, and root raking now practiced extensively in the Middle Rio Grande Valley (Taylor and McDaniel 1998). This three-step mechanical control process has provided lasting control killing 95 percent of saltcedar plants when specific techniques are followed. Aerial herbicide applications have been effective in killing about 90 percent of saltcedar plants with either a 1.2 kg/ha rate of imazapyr or a 0.6 + 0.6 kg/ha mixture of imazapyr and glyphosate on the Pecos River in eastern New Mexico (Duncan and McDaniel 1998). When followed by prescribed broadcast burning, over 90 percent of the woody debris is removed (Taylor and McDaniel 1998).

Study Area and Methods

Ten, 2.5 ha adjacent plots were established within a saltcedar monoculture on the Bosque del Apache National Wildlife Refuge in summer 1994. The plots, measuring 82 x 305 meters, were delineated by 10m buffer roads constructed between each plot. Saltcedar within the study area was last burned by wildfire in 1986. An average of 7,100 plants/ha occurred on the site and average plant height was about .3 meters Cover averaged 56 percent. Two treatments, mechanical control and herbicide/burn control, were applied randomly to the plots resulting in five replications of each treatment.

An aerial herbicide application was made using a Cessna T188™ aircraft fitted with a streamline boom with nozzles (D8-SS) positioned 45° aft to deliver 65 L/ha total spray volume calibrated at 49 m/sec. The herbicide mixture included imazapyr plus glyphosate (0.6 + 0.6 kg ai/ha) in water with a 0.25 percent v/v non-ionic surfactant, and a 0.07 percent v/v drift control agent. Conditions during the early morning included 16-19°C air temperature, 65-92 percent relative humidity, and wind below one m/sec. Three years later in early October, 1997, dead standing saltcedar debris was ignited in a pre-scribed broadcast fire on each plot using a terra-torch carried in a pickup truck (Firecon, Inc., Ontario, OR). Conditions during prescribed burning included 28-32° C air temperature, 31-42 percent relative humidity, and wind speeds of 1-3 m/sec. Within 20-30 minutes nearly all aerial material was consumed by fire within each plot.

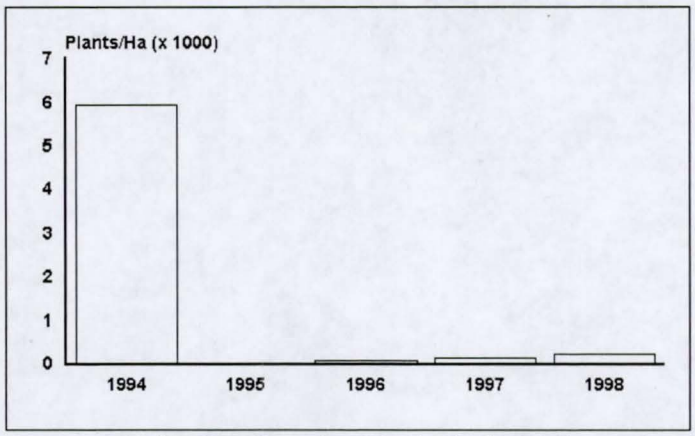


Figure 1. Saltcedar plant densities in herbicide/burn plots, Bosque del Apache, N.M.

Mechanical saltcedar control occurred between June and November, 1995. Initial clearing was accomplished using a D-7 class bulldozer mounted with a dirt blade. Debris was then stacked using a 1.9-m^3 capacity articulating loader fitted with a brush rake. Piles were burned prior to root plowing following techniques described by Horton (1960). Detached root crowns were raked from the ground using a hydraulic 6.4-m-wide root rake (Taylor and McDaniel 1998). Roots were then stacked using the articulated loader and burned. Saltcedar resprouting was extensive by 1997 and the process was repeated in late spring, 1998.

Saltcedar response to the treatments was monitored using belt transects (Burnham et al 1980). Four permanent transects, each 4 m x 50m, were established in each plot to determine saltcedar plant unit density and cover. Density and cover were determined prior to treatment application in 1994 and annually through 1998.

Results

In herbicide/burn treatment plots, discoloration occurred within one month following aerial herbicide application. Upon inspection the following spring, no green growth was noted and only 6 plants/ha were recorded during 1995 transect monitoring (Figure 1). Densities increased to 83 plants/ha in 1996, and by 1997 nearly doubled to 137 plants/ha. 1997 plant densities represented 97.7 percent control. Prescribed broadcast burning conducted in early fall of 1997 following transect monitoring, resulted in 99 percent fuel consumption. Adjacent saltcedar vegetation outside the study area was unaffected by prescribed burning activity. High fuel moistures and relative humidity within this adjacent vegetation provided safe burning conditions for the dead herbicide treated material. 1998 transects recorded 238 plants/ha comprising a three percent canopy cover (Figure 2). Overall control was estimated at 96 percent and treatment costs averaged $281/ha.

Saltcedar plant density in mechanically treated plots was 2,590 plants/ha following initial control in 1995 and canopy cover was reduced to three percent comprising many small re-sprouts (Figures 3 and 4). Plant densities did not increase in 1996 or 1997, but as individual plant resprouts matured, canopy cover increased dramatically to over 17 percent by 1997. The level of control was more variable among mechanically cleared plots ranging from 54 to 88 percent control. From a management point of view this level of control was not acceptable,

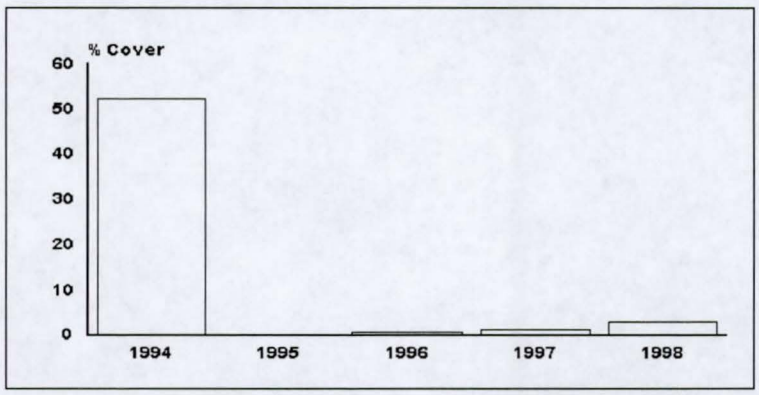


Figure 2. Saltcedar percent cover on herbicide/burn plots, Bosque del Apache, N.M.

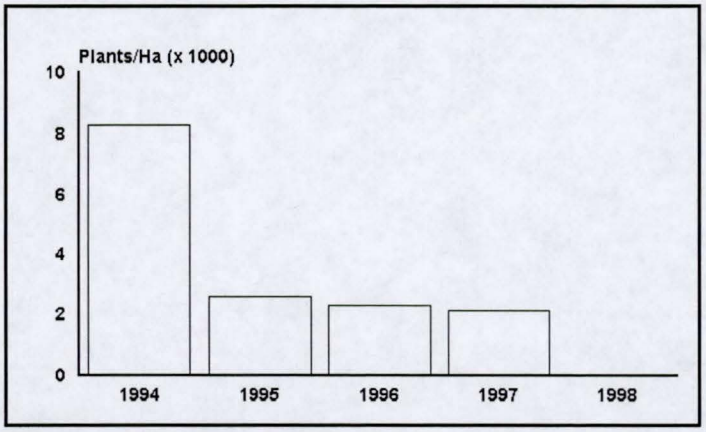


Figure 3. Saltcedar plant densities in mechanically cleared plots , Bosque del Apache, N.M.

thus prompting further mechanical control during summer, 1998. Low plant densities (11 plants/ha) were recorded during 1998 evaluations as a result. Total costs for mechanical saltcedar control averaged $1,469/ha.

DISCUSSION

Saltcedar control in many cases, is an essential element of riparian restoration. This study evaluated two approaches for large scale control, each focusing on destroying the root system of the plant. For optimum results, mechanical control should be conducted in dry areas during the hottest season of the year to facilitate root crown dessication when pulled to the surface during root raking operations. Unacceptable results from initial mechanical control efforts probably resulted from root plowing and raking occurring too late in the year when ambient temperatures were lower and soil moistures were higher. Ninety-nine percent control was achieved as a result of follow-up mechanical control when plowing and raking occurred in June, the hottest and driest time of the year.

Critical to successful saltcedar control using herbicides is adherence to specific site and environmental condition requirements. A late summer herbicide application will optimize herbicide translocation to saltcedar root systems as carbohydrates are stored in preparation for winter dormancy. Application during periods of low ambient temperature, high relative humidity and no wind optimizes foliage uptake of the herbicide particularly in dense even-aged saltcedar (Duncan and Mc Daniel 1998). By waiting at least two and preferably three years after herbicide application before burning dead material, optimum time has passed to assure herbicide activity has been completed. Dense uniform stands facilitate total fuel consumption during prescription broadcast burning.

Ultimate saltcedar control success should be flexible and managers should be prepared to employ a combination of techniques. Many factors can influence control technique selection including specific site conditions, equipment availability, and financial constraints. These conditions are frequently found in areas of high water table. Conversely, areas which have native vegetation components are poor choices for herbicide/ burn treatments due to the unselective nature of effective herbicides. Costs are obviously higher for mechanical control. Mechanical removal of aerial vegetation ($477/ha) is twice that of the entire herbicide/ burn control technique. An adaptation combining both techniques might include follow-up root plowing and raking necessary due to unacceptable resprout densities after a

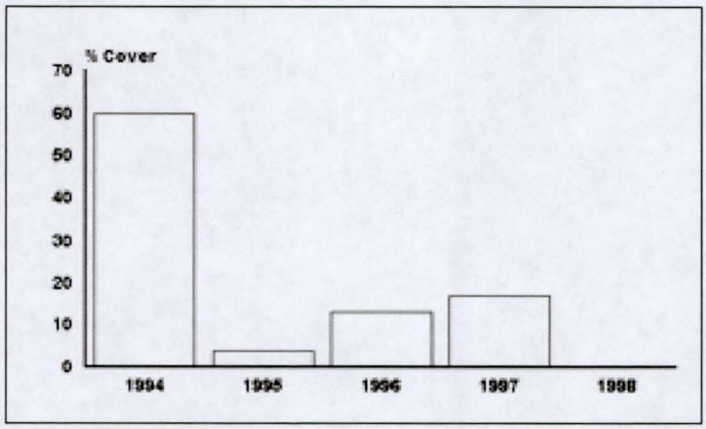


Figure 4. Saltcedar percent cover on mechanically cleared plots, Bosque del Apache, N.M.

herbicide/burn treatment. This approach still provides a savings over mechanical control alone.

LITERATURE CITED

Anderson, B.W. and R.D. Ohmart. 1982. Revegetation and wildlife enhancement along the Lower Colorado River. U.S. Department of the Interior, Bureau of Reclamation. Contract No. 7-07-30-V0009. 215 pages.

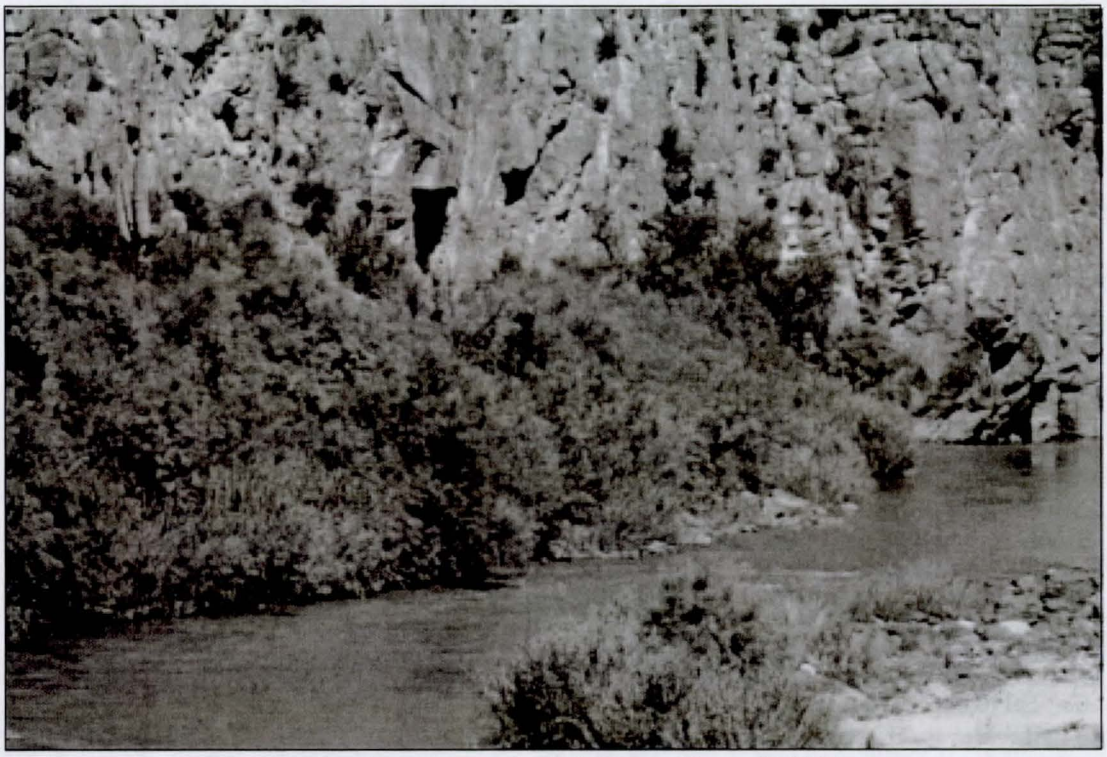
Duncan, K. W. and K. C. McDaniel. 1998. Saltcedar (*Tamarix* spp.) management with imazapyr. Weed Technology. 12: 337-344.

Horton, J. S. 1960. Use of a root plow in clearing tamarisk stands. U.S. Department of Agriculture, Rocky Mountain Forest and Range Experiment Station, Ft. Collins, CO, USA. Research Note 50.

Taylor, J.P. and K.C. McDaniel. 1998. Restoration of saltcedar- (*Tamarix* sp.)infested floodplains on the Bosque del Apache National Wildlife Refuge. Weed Technology. 12:345-352.

Taylor, J. P. and K. C. McDaniel. 1998b. Riparian management on the Bosque del Apache National Wildlife Refuge. NM Journal of Science. 38:219-232.

Taylor, J.P., Wester, D.B., and L.M. Smith. 1999. Soil disturbance, flood management, and riparian woody plant establishment in the Rio Grande floodplain. Wetlands 19:372-382.



A saltcedar forest along the Salt River. Photo: B. Tellman

Restoration of Native Riparian Plant Communities Along the Lower Colorado River

John Swett, Bureau of Reclamation, Boulder

Historically, the Lower Colorado River was a highly dynamic ecosystem subject to yearly flood events of varying magnitude. These annual disturbances created the conditions necessary for native riparian plants to regenerate. In the canyons along the river, flow rates were such that few, if any, plants were able to become established or able to survive for any length of time. However, once the water and sediment were released from the narrow canyons into one of the broad valleys, sediment deposition occurred. Mosaics of Fremont cottonwood (*Populus fremontii*), Goodding willow (*Salix gooddingii*), honey mesquite (*Prosopis glandulosa torreyana*), screwbean mesquite (*Prosopis pubescens*), quailbush (*Atriplex lentiformis*), and arrow-weed (*Tessaria sericea*) became established within these broad flood plains, where soil and water conditions allowed. Migration of the river channel created or reconnected backwaters and oxbows. These conditions created abundant and species-rich habitat that was especially important to both breeding and migrating neo-tropical avifauna.

Although man-caused changes to the Colorado River ecosystem began shortly after the United States acquired this region at the conclusion of the Mexican-American War in 1848, conditions changed drastically after the completion of Hoover Dam in 1935. Dams, agricultural development, and urbanization all contributed to the loss of native riparian habitat after 1935. The preclusion of annual scouring flood events prevented large-scale regeneration of native riparian species and, instead, favored the invasion of the exotic saltcedar (*Tamarix ramosissima*). An increase in saltcedar created more volatile fire conditions which, over time, has created large expanses consisting almost entirely of saltcedar. Increased soil salinity and fluctuating groundwater has also been detrimental to native riparian plant species.

A variety of restoration techniques have been attempted along the Lower Colorado River during the past twenty years. Initially, pole planting supported by drip irrigation was the preferred method for restoring cottonwood-willow stands. Although this technique has had some success in areas where the abiotic conditions are ideal, the majority of sites available along the Lower Colorado River floodplain are less than ideal. Flood irrigation of plantings is usually more appropriate in less than ideal conditions if water can be delivered in large enough quantities to leach salts from the soil and where soil texture is coarse enough to allow leaching to occur. New techniques, such as creating artificial flood events and artificially seeding mechanically scoured areas, are being tried in an effort to revegetate large blocks of habitat.

Riparian Restoration Using Physical Manipulation and Natural Seedfall

Gregor T. Auble, U.S. Geological Survey, Fort Collins

INTRODUCTION

In many arid landscapes, riparian sites are the only places wet enough to support trees. The vertical structure of trees and shrubs is critical to many riparian habitat and aesthetic values (Brinson et al. 1981). Thus, woody vegetation is often an important objective and success measure for riparian restoration. Effective restoration planning depends on some underlying model of how the ecosystem functions– what variables determine its condition, how it became degraded, and how it will respond to alternative management actions. Vegetation within a riparian system is dependent on site conditions and the processes that determine those conditions (Figure 1)

In a riparian system, the associated watercourse is an important determinant of site conditions. The river provides moisture that can serve as either a subsidy or a stress to vegetation. In most arid systems, the supplemental moisture supports vegetation that can not tolerate the more xeric upland landscape. Alternatively, excessive moisture may limit the distribution of some plant species through stresses associated with waterlogged and anoxic soils. The river may also serve as an important transport vector for sites in the riparian zone– dispersing seeds and carrying organic and inorganic materials to and from the site. Transport and flushing of salts is especially important where disconnection from the river may produce concentrations of salts from evapotranspiration.

The river episodically disturbs riparian sites by killing plants or removing biomass. Relations between streamflow and site conditions in the riparian zone are not constant. The river is also an agent of geomorphic change. Channel narrowing and widening, lateral migration and avulsion, and aggradation and degradation can alter the way streamflow affects conditions at any fixed site Herbivory, including sheep and cattle grazing, may strongly influence riparian vegetation at some sites. (Chaney et al. 1990, Green and Kauffman 1995). Finally, introduction of exotic species has fundamentally altered the mix of plant species at most southwestern riparian sites and may have defined fundamentally new trajectories of response to some combinations of physical site conditions.

Figure 1 is a template for understanding what the vegetation would be on an undegraded site, what has produced the degraded vegetation, and what vegetation a restored site might naturally support. This understanding is important in formulating restoration objectives. It does not dictate desired vegetation, but it does suggest what vegetation is most suitable to the physical environment of the site. It is generally expensive to force and maintain vegetation unsuitable to site conditions. In many cases, locally degraded riparian sites occur along rivers that have been fundamentally altered so that they no longer provide the appropriate physical site conditions for the original vegetation.

WOODY PIONEERS

Cottonwood and willow often dominate western riparian tree and shrub communities. These are pioneer species that tend to establish as seedlings on fluvial disturbance patches of freshly deposited or reworked alluvium. Seedling establishment requirements are relatively specific and well known. Seedlings require a continuously moist surface during the first week or more of growth (Moss 1938). Abundant seeds are released early each summer (Scott et al. 1993, Johnson 1994) and lose germinability within a few weeks (Moss 1938, Ware and Penfound 1949). Cottonwoods rarely recruit successfully from seed under an existing stand of trees (Johnson et al. 1976) or herbs (Friedman et al. 1995). By the end of the first growing season, seedlings are able to survive declines in

the water table of one meter or more (Fenner et al. 1984, Mahoney and Rood 1991, Segelquist et al. 1993). Drought mortality in arid regions, however, may impose an upper limit on height of seedling recruitment above the river or groundwater surface. If seedlings are to develop successfully into trees, seedling establishment sites need to be protected from subsequent intense disturbances that kill or remove seedlings (Stromberg et al. 1997).

The critical process question is how the river creates suitable establishment sites—in the natural, pre-degraded site; in the degraded site lacking desired regeneration; and in possible restored configurations at the site. We have tried to consider some of the ways in which rivers create these sites through geomorphic processes (Scott et al. 1996, Freidman et al. 1997, Auble and Scott 1998).

Figure 2 illustrates how processes of narrowing (Johnson 1994, Friedman et al. 1996), meandering (Bradley and Smith 1986, Johnson 1992, Johnson et al. 1976), and flooding (Scott et al. 1997, Auble and Scott 1998) create bare, moist sites that become safe enough from future disturbance to allow tree recruitment. These suitable sites differ from cases of no inter-annual flow or channel variability where seedlings are established each year in the same positions without ever surviving to become saplings (Figure 2). Often a laterally constrained and flood controlled river will not produce enough suitable regeneration sites to maintain the pre-modification extent of cottonwood and willow wood-land. Urban reaches where channel movement and overbank flooding are minimized because of associated property damages often fall into this class. (Auble et al. 1997).

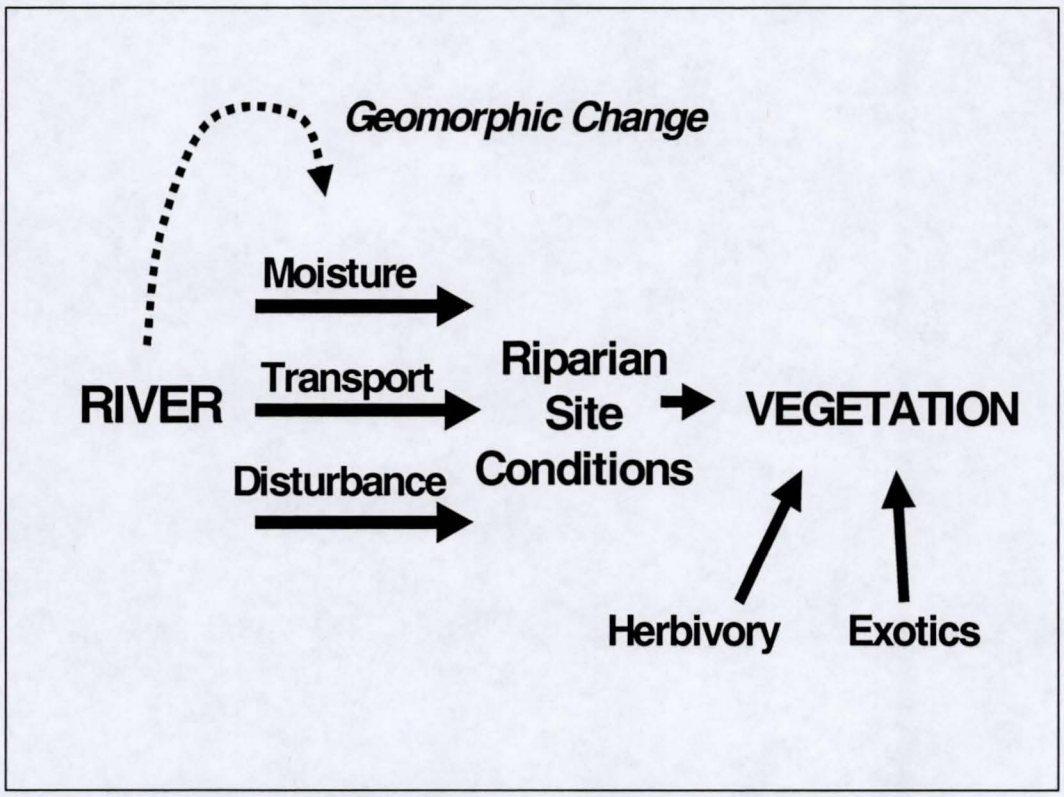


Figure 1. Principal determinants of riparian vegetation.

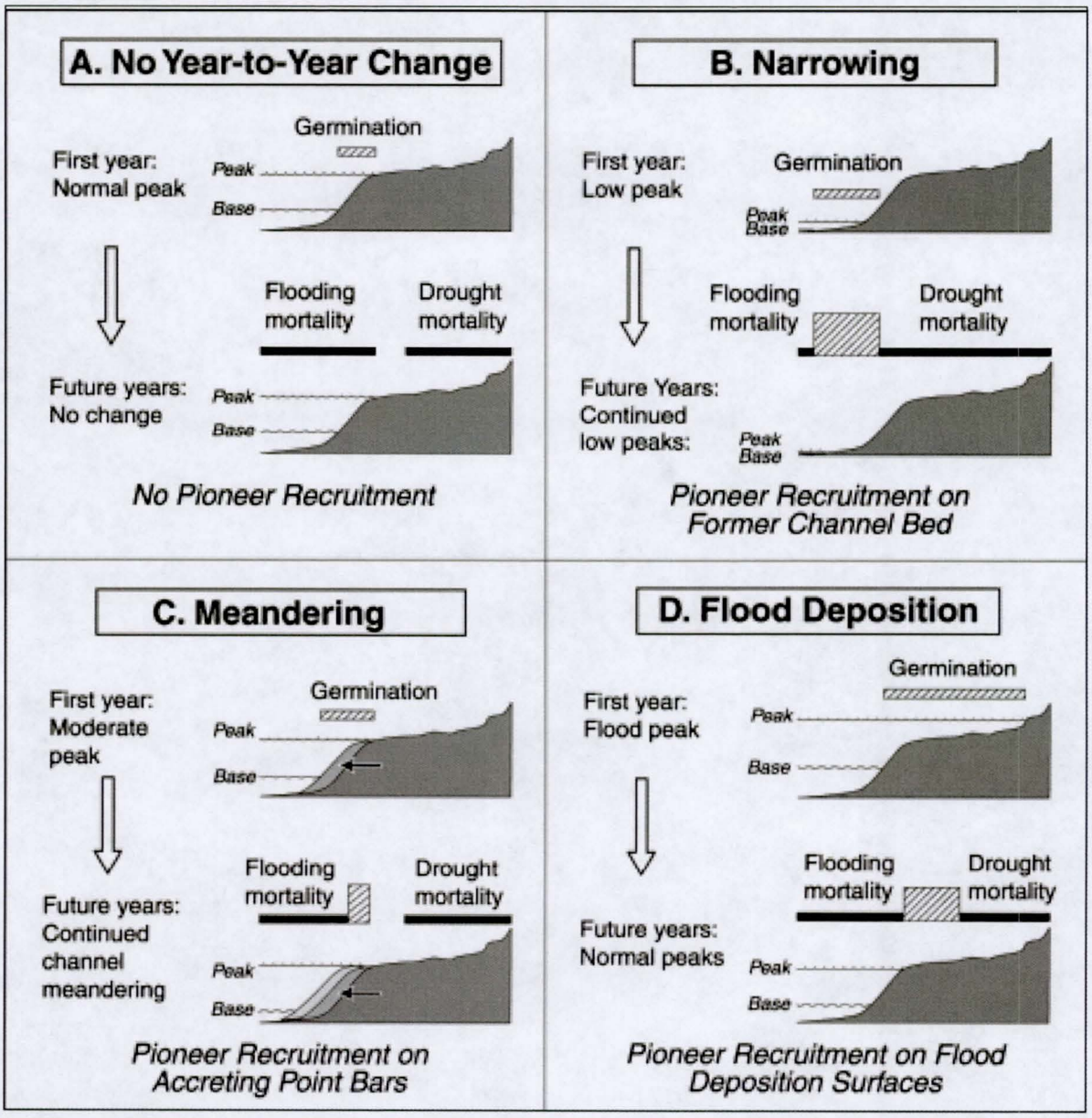


Figure 2. Geomorphic processes and the creation of suitable establishment sites for pioneer trees (from Auble and Scott 1998).

IMPLICATIONS FOR RESTORATION

In many degraded riparian systems, streamflow iterations or channel works have reduced the capacity of the river to create suitable regeneration sites for cottonwood and willow. There are two choices for restoration:

- Recast objectives to accept an altered extent of cottonwood and willow woodland sustainable by natural processes operating at an altered rate; or
- Intervene to achieve state objectives of the original woodland extent that is larger than is sustainable from natural processes operating at current rates. If a greater than sustainable extent of woodlands is desired, intervention may take a number of forms

varying widely in cost and effectiveness. One intervention strategy employs direct actions to plant and nurture the desired individuals on the site— mulching, seeding, pole planting, and irrigation. Another intervention strategy is to simulate the natural regeneration processes. In the case of woody riparian pioneers this means creating bare, moist sites during a relatively brief annual window of seed dispersal and germinability (Johnson 1965).

Friedman et al. (1995) examined this strategy in a small-scale experiment by applying combinations of scraping (bare), irrigation (moist), and supplemental seed to stream banks along a flow-stabilized and laterally constrained urban reach of Boulder Creek, CO. They achieved substantial seedling establishment from natural seedfall from a few mature trees on sites they had scrapped and irrigated. Roelle and Gladwin (*in press*) successfully applied this approach to restoration of an abandoned gravel pit by pro-viding a controlled drawdown that made bare surfaces of the pit moist during the period of natural seed dispersal.

Riparian restoration strategies that simulate the physical processes by which rivers create fluvial disturbance patches have potential advantages of cost and use of local genetic material. They are not, however, a panacea. The simple physical conditions produced by fluvial disturbance (bare and moist) may not be sufficient to produce natural regeneration. Natural regeneration may be limited by contaminants (e.g., abandoned mine tailings) or high salinity (dry terraces disconnected from the current river). Some sites may not have adequate natural seed sources. Manipulation of the physical conditions is most practical on sites that are most similar to natural disturbance patches: excavated depressions or relict disturbance features such as abandoned side channels. Manipulation may be infeasible on other sites such as high terraces. Finally, co-establishment of undesirable exotic plants may be difficult to control, as there is often overlap between the establishment requirements of these species and the native disturbance-dependent pioneers.

LITERATURE CITED

Auble, G. T., M. L. Scott, J. M. Friedman, J. Back, and V. J. Lee. 1997. Constraints on establishment of plains cottonwood in an urban riparian preserve. Wetlands 17:138-148.

Auble, G. T., and M. L. Scott. 1998. Fluvial disturbance patches and cottonwood recruitment along the upper Missouri River, Montana. Wetlands 18:546-556).

Bradley, C. E., and D. G. Smith. 1986. Plains cottonwood recruitment and survival on a prairie meandering river floodplain, Milk River, southern Alberta and northern Montana. Canadian Journal of Botany 64:1433-1442.

Brinson, M. M., B. L. Swift, R. C. Plantico, and J. S. Barclay. 1981. Riparian ecosystems: their ecology and status. U.S. Fish and Wildlife Service, Biological Service Program, Washington, DC, USA. FWS/OBS-81/17.

Chaney, E., W. Elmore, and W. S. Platts. 1990. Livestock grazing on western riparian areas. Northwest Resource Information Center, Eagle, ID, USA.

Fenner, P., W.W. Brady, and D.R. Patton. 1984. Observations on seeds and seedlings of Fremont cottonwood. Journal of Desert Plants 6:55-58.

Friedman, J. M., M. L. Scott, and W. M. Lewis, Jr. 1995. Restoration of riparian forest using irrigation, artificial disturbance, and natural seedfall. Environmental Management 19:547-557.

Friedman, J. M., W. R. Osterkamp, and W. M. Lewis, Jr. 1996. Channel narrowing and vegetation development following a Great-Plains flood. Ecology 77:2167-2181.

Friedman, J. M., M. L. Scott, and G. T. Auble. 1997. Water Management and cottonwood forest dynamics along prairie streams. Ecological Studies 125:49-71.

Green, D. M. and J. B. Kauffman. 1995. Succession and livestock grazing in a

northeastern Oregon riparian ecosystem. Journal of Range Management 48:307-313.

Johnson, R. L. 1965. Regenerating cottonwood from natural seedfall. Journal of Forestry 63:33-36.

Johnson, W.C. 1992. Dams and riparian forests: case study from the upper Missouri River. Rivers 3:229-242.

Johnson, W. C. 1994. Woodland expansion in the Platte River, Nebraska: patterns and causes. Ecological Monographs 64:45-84.

Johnson, W. C., R. L. Burgess, and W. R. Keammerer. 1976. Forest overstory vegetation and environment on the Missouri River floodplain in North Dakota. Ecological Monographs 46:59-84.

Mahoney, J. M. and S. B. Rood. 1991. A device for studying the influence of declining water table on poplar growth and survival. Tree Physiology 8:305-314.

Moss, E. H. 1938. Longevity of seed and establishment of seedlings in species of *Populus*. Botanical Gazette 99:529-542.

Roelle, J. E., and D. N. Gladwin. *In press*. Establishment of woody riparian species from natural seedfall at a former gravel pit.

Scott, M. L., G. T. Auble, and J. M. Friedman. 1997. Flood dependency of cottonwood establishment along the Missouri River, Montana, USA. Ecological Applications 7:677-690.

Scott M. L., J. M. Friedman, and G. T. Auble. 1996. Fluvial process and the establishment of bottomland trees. Geomorphology 14:327-339.

Scott, M. L., M. A. Wondzell, and G. T. Auble. 1993. Hydrograph characteristics relevant to the establishment and growth of western riparian vegetation. 237-246. IN H. J. Morel-Seytoux (ed.) Proceedings of the 13th Annual American Geophysical Union Hydrology Days. Hydrology Days Publication, Atherton, CA, USA

Segelquist, C. A., M. L. Scott, and G. T. Auble. 1993. Establishment of *Populus deltoides* under simulated alluvial groundwater declines. American Midland Naturalist 130:274-285.

Stromberg, J. C., J. Fry, and D. T. Patten. 1997. Marsh development after large floods in an alluvial arid-land river. Wetlands 17:292-300.

Ware, G. H. and W. T. Penfound. 1949. The vegetation of the lower levels of the floodplain of the South Canadian River in central Oklahoma. Ecology 30:478-484.

Cottonwood tree dispersing seeds in spring. Photo: B. Tellman

Watershed Improvement as a Way to Restore Riparian and Aquatic Habitats: a Case Study from the Muleshoe Ranch Cooperative Management Area, Arizona

David Gori, The Arizona Nature Conservancy, Tucson

THE SETTING

The Muleshoe Ranch Cooperative Management Area (CMA) is a 50,000 acre ranch located in the Galiuro Mountains of southeastern Arizona, and is owned and cooperatively managed by The Nature Conservancy, Bureau of Land Management (BLM) and the U.S. Forest Service. There are seven perennial streams on the Muleshoe; four of these are in the Hot Springs Creek watershed and include Bass, Double R, Wildcat and Hot Springs creeks.

These four streams support mixed broadleaf deciduous riparian forest and assemblages of two to five native fish species. Gila chub (*Gila intermedia*), a native fish endemic to the Gila River basin and a candidate for federal listing by the U.S. Fish and Wildlife Service, is present in two of the four streams. All or most of the watersheds of the four streams are contained within the CMA boundary and are vegetated by shrub-invaded (degraded) semi-desert grassland

Despite their high ecological values, these four perennial streams persist in a degraded condition. Frequent, intense floods have:

- Reduced the density of mature riparian trees;
- Stripped away streamside vegetation, leaving stream banks unprotected and subject to erosion; and

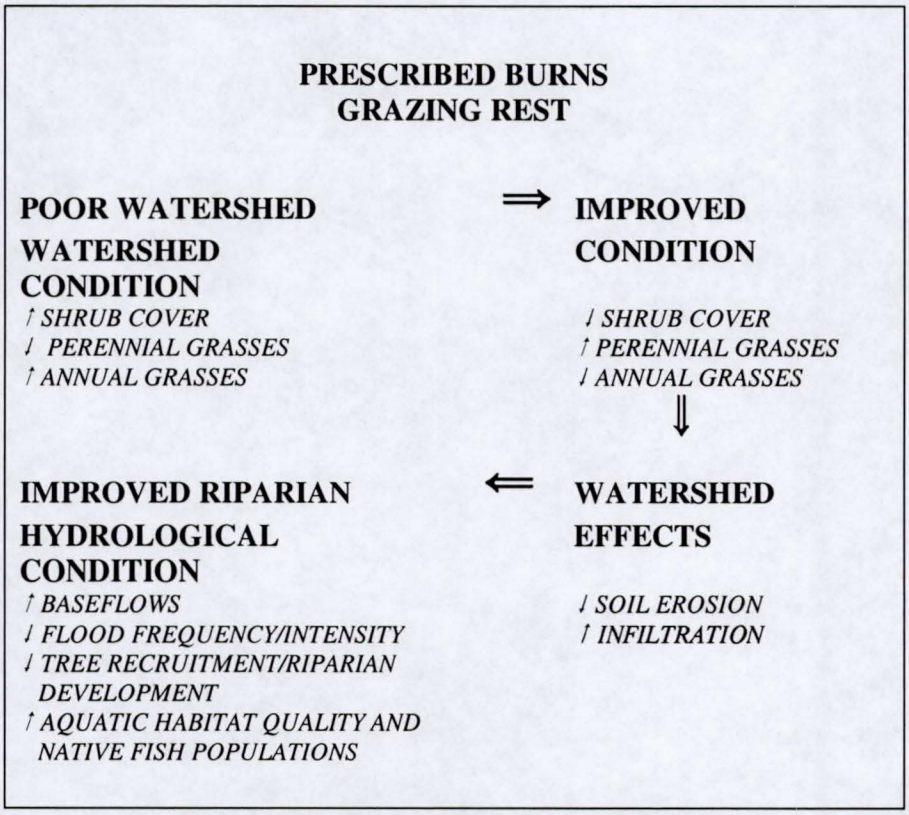


Figure 1. Watershed-Riparian Processes Model

- Limited recruitment of tree seedlings and saplings compared to other riparian reference sites on the Muleshoe in better condition (BLM 1998).

Frequent floods have also eroded mature floodplain terraces (without replacement) resulting in reduced floodplain aquifer storage and reduced baseflows. Finally, frequent floods and reduced baseflows have reduced the extent and quality of aquatic habitat for native fish (Hardy et al. 1990).

To restore and enhance riparian and aquatic habitat in the four perennial streams, The Nature Conservancy and BLM have initiated a long-term project to improve watershed condition—specifically, the goal is to increase the abundance and cover of perennial grasses and reduce cover by shrubs. This vegetation change is being accomplished by restoring fire as a natural process to the Hot Springs water-shed using prescribed burns and continued grazing rest.

Several lines of evidence suggest that wildfires were frequent in semi-desert grasslands in Arizona prior to the 1870's (Humphrey 1958, Bahre 1985, Davis 1994, Kaib et al. 1996). Over the last century, grazing by livestock has reduced the extent and frequency of these wildfires (by reducing the density of fine fuels needed to carry these fires) with the result that semi-desert grassland watersheds, like those at the Muleshoe, have become invaded by shrubs (e.g., Cable 1967, Wright 1974, Wright and Bailey 1982, Archer and Smeins 1991). Livestock grazing has also had direct impacts on the vegetation in semi-desert grasslands, reducing the abundance and cover of perennial grasses, especially tall- and mid-statured bunchgrasses (Humphrey and Mehrhoff 1958, Buffington and Herbel 1964, Blydenstein 1966, Hazel 1967, Bahre and Bradbury 1978, Heitschmidt 1990, Briske 1991, Stuth 1991). These vegetation changes have had profound effects on watershed hydrological processes and stream hydrology.

The relationships between watershed vegetation, watershed hydrological processes, stream hydrology, and riparian condition are summarized in Figure 1; these relationships have been documented in studies conducted in semi-

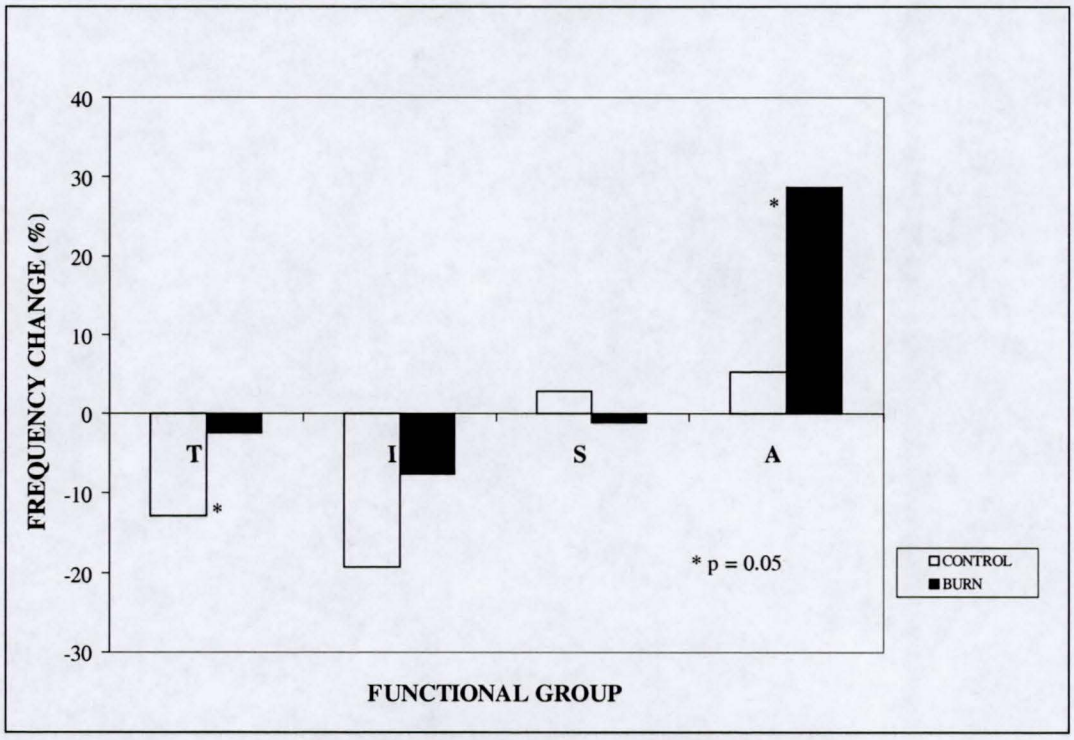


Figure 2. Frequency Change 1991-1996.

desert grassland, chaparral, woodland and forested plant communities. When The Nature Conservancy purchased the Muleshoe Ranch in 1982, the semi-desert grassland watersheds were in poor condition with a great abundance and cover of shrubs and low abundance and cover of perennial grasses. In fact, there was so little perennial grass that the Arizona State Land Department issued a temporary grazing rest in 1982 to allow watershed and range recovery. When the State lease land was transferred to the BLM in a land exchange, grazing rest was continued.

According to the model (Figure 1), prescribed burns and grazing rest combined will result in an increase in the abundance and cover of perennial grasses and a decrease in shrubs; grazing rest alone is not sufficient to reduce shrubs and cause their replacement by perennial grasses (Brown 1950, Glendening 1952, Hennessey et al. 1983). In 1995, The Nature Conservancy and BLM conducted the first watershed-scale burn, burning 2000+ acres (a significant portion) of the Wildcat Creek watershed. In 1998, we were awarded an Arizona Water Protection Fund grant to continue prescribed burning: 4000+ acres in the Double R watershed were burned in June 1998, and 5,000+ acres in the Hot Springs watershed were burned in May 1999.

We are monitoring the long-term effect of these burns on watershed vegetation. The results obtained to date are generally consistent with the model although the direction of the change in perennial grass abundance appears to be mediated by climatic events, especially the amount of summer rainfall received between 1991 and 1996, the period between pre-burn (1991) and post-burn (1996) monitoring. Shrub cover increased significantly by an average of 4.3 percent on control plots between 1991 and 1996 presumably reflecting an increase in the size of existing shrubs and new recruitment; mean shrub cover on control plots in 1996 was 42.0 ± 13.8 (SD) percent. In contrast, shrub cover decreased by 20.8 percent on burn plots to a mean cover of 8.4 ± 3.4 percent following the burn. Thus, prescribed burning dramatically reduced shrub cover two growing seasons after the burn, a result that is consistent with other studies showing reductions in the density and

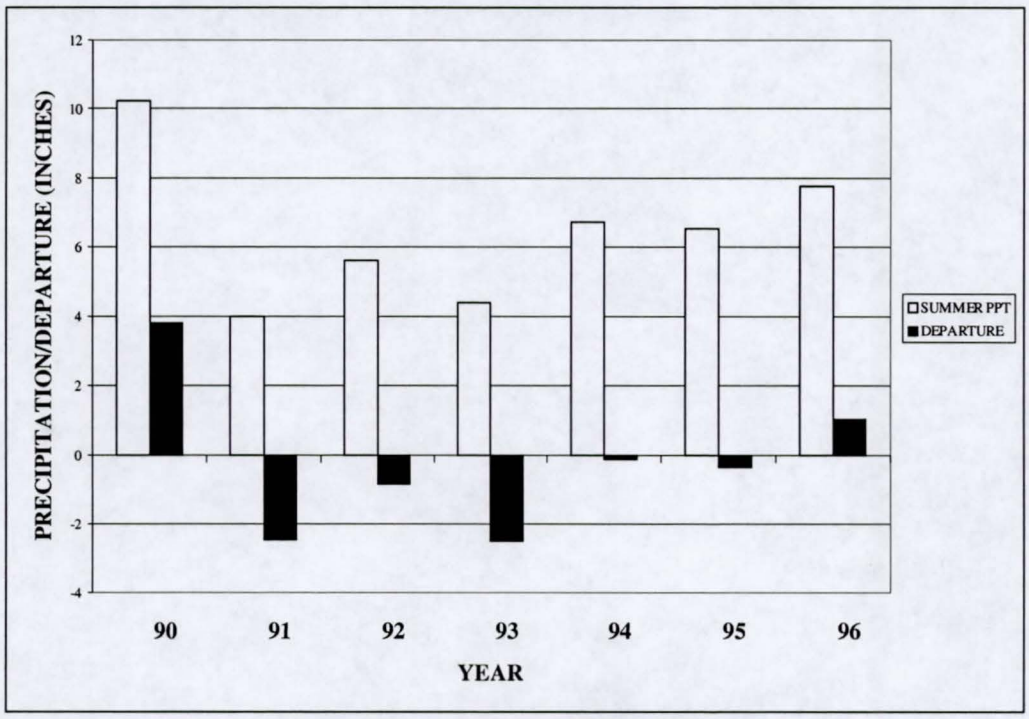


Figure 3. Summer Precipitation, Willcox

cover of shrubs following burns (e.g., Bock et al. 1976, Wagle 1981).

To measure changes in the abundance of grasses, we recorded the presence of grasses by species in nested quadrants (0.01 m^2, 0.16 m^2, 1.0 m^2) that were randomly distributed in monitoring plots (i.e., frequency sampling method). For purposes of analysis, grasses were divided into 4 functional groups: (1) tall- and mid-statured, productive perennial grasses (e.g., side-oats grama, cane beard grass, green sprangle top); (2) intermediate-statured perennials (e.g., blue grama, hairy grama); (3) short-statured, unproductive perennials (e.g., curly mesquite); and (4) annual grasses.

The mean frequency change (in 0.16 m^2 quadrats) between 1991 and 1996 in control plots (shown in blue) and burn plots (in maroon) for the 4 functional groups are shown in Figure 2. Annual grass frequency (abundance) increased on both control and burn plots between 1991 and 1996, but the increase was significantly greater (28.7 $\pm$ 19.8 percent) on burn plots than on control plots (5.3 $\pm$ 3.2 percent). The frequency of tall- and mid-statured perennial grasses, in contrast, declined on both control and burn plots between 1991 and 1996 although not significantly on burn plots, but the frequency decreased significantly more on control plots than on burn plots, i.e., a mean decrease of 12.8 $\pm$ 2.8 percent in control plots compared to a decrease of only 2.5 $\pm$ 3.6 percent for burn plots (t-test, $t = 3.9$, 4 df, $p < 0.02$). There was no significant difference in the frequency change of intermediate and short-statured perennial grasses on control and burn plots between 1991 and 1996 (Figure 2).

Each year from 1991 through 1995, the Muleshoe received below average summer rainfall; the deviations from normal, based on data collected in nearby Willcox, AZ, were extreme in 1991, and 1993. In 1993, the Muleshoe received so little summer rain that grasses produced little new growth and failed to flower that year (Figure 3). The extended drought caused mortality and/or a decrease in the basal diameter of grasses on control and burn plots but the burn had an invigorating effect on tall- and mid-statured perennials, increasing their abundance and basal cover and thereby compensating for the effect of the drought. We have also noticed that individual grasses appear to grow much bigger and more robust after the burn, so now we are measuring basal cover and canopy cover using a point intercept method; this provides a more direct measure of grass cover and better estimates a watershed's ability to absorb precipitation and runoff than does

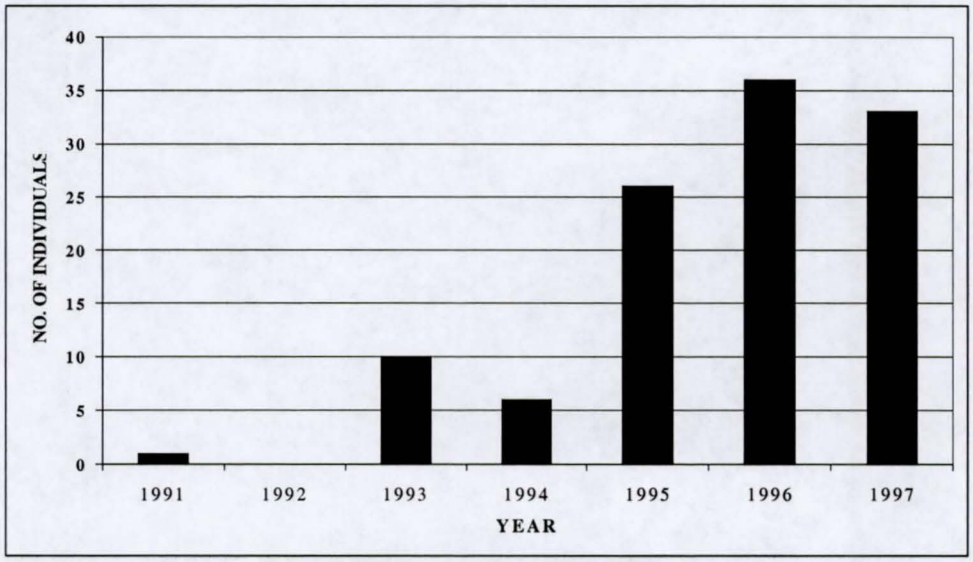


Figure 4. Gila Chub Numbers

frequency sampling (Wilcox et al. 1988).

Numerous studies in semi-desert grassland and forested watersheds have demonstrated decreased soil erosion, decreased runoff and increased infiltration following rainfall events as shrubs are reduced and replaced by perennial grasses (Figure 1; Horton 1937, USDA 1940, Simanton et al. 1977, Wilcox et al. 1988, Woolhiser et al. 1990, Thurow 1991). These changes in watershed hydrology lead to changes in stream hydrology and improvements in aquatic and riparian habitats including a decreased frequency of scouring floods; increased baseflows; increased recruitment and density of riparian trees; increased riparian development; an increase in extent and quality of aquatic habitat; and an increase in native fish populations (e.g., Lewis 1968, Bosch and Hewlett 1982, Johnson and Carothers 1982, Davis 1984, DeBano et al. 1984, Stabler 1985, Stephens and Knowlton 1986, DeBano and Schmidt 1990, Hardy et al. 1990, Heede and Rinne 1990).

Benefits from this project are long-term but will be documented through detailed monitoring of stream flows, watershed vegetation (we now have 38 monitoring plots in 3 burn units), riparian vegetation, aquatic habitat and native fish populations. Increases in native fish populations are already evident. In Hot Springs Creek, the number of Gila chub captured on five permanent monitoring transects has in-creased significantly between 1991 and 1997 (Figure 4). In 1991, chub accounted for only 0.007 percent of all fish captures while in 1996 and 1997, they accounted for 1.2 percent of fish captures, a greater than 100-fold increase over 6-7 years. This increase is not the result of changes in the number of pools and deep glides, the preferred habitat for chub, since the latter fluctuates between years independently of chub numbers. However, the increase may be due to the im-proved *quality* of aquatic habitat; the amount of protective cover, including undercut banks, overhanging riparian vegetation, emergent and floating aquatic vegetation and woody debris, has increased significantly between 1994 and 1998 along a permanent monitoring transect established in Hot Springs to measure changes in aquatic habitat. These improvements are probably not the result of the prescribed burns (since they were initiated only 3 years ago) but rather the result of 16 years of grazing rest and a significant increase in perennial grass cover in the watershed. Future results, we hope, will continue to show improvements in watershed vegetation and restoration of riparian and aquatic habitats as a result of prescribed burning and grazing rest.

LITERATURE CITED

Archer, S., and F.E. Smeins. 1991. Ecosystem-level processes. Pp. 109-139 IN Heitschmidt, R.K., and J.W. Stuth, eds. Grazing management: an ecological perspective. Timber Press, Portland. 259 pp.

Archer, S., C. Scifres, C.R. Bassham and R. Maggio. 1988. Autogenic succession in a subtropical savanna: conversion of grassland to thorn woodland. Ecological Monographs 58:111-127.

Bahre, C.J. 1985. Wildfire in southeastern Arizona between 1859 and 1890. Desert Plants 7:190-194.

Bahre, C.J., and D.E. Bradbury. 1978. Vegetation changes along the Arizona-Sonora boundary. Annals of the Association of American Geographers 68(2):145-165.

BLM 1998. Muleshoe ecosystem management plan and environmental assessment. U.S. Department of Interior, Bureau of Land Management, Tucson, AZ. 206 pp.

Blydenstein, J. 1966. Root systems of four desert grassland species on grazed and protected sites. Journal of Range Management 19:93-95.

Bock, J.H., C.E. Bock and J.R. McKnight. 1976. A study of the effects of grassland fires at the Research Ranch in southeastern Arizona. Journal of the Arizona Academy of Science 11:49-57.

Bosch, J.M. and J.D. Hewlett. 1982. A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. Journal of Hydrology 55:3-23.

Briske, D.D. 1991. Developmental morphology and physiology of grasses. Pp. 85-108 IN Heitschmidt, R.K., and J.W. Stuth, eds.

rzing management: An ecological perspective. Timber Press, Portland. 259p.

Brown, A.L. 1950. Shrub invasion of southern Arizona desert grassland. Journal of Range Management 3:172-177.

Buffington, L.C., and C.H. Herbel. 1964. Vegetational changes on a semidesert grassland range. Ecological Monographs 35(2)139-164.

Cable, D.R. 1967. Fire effects on semidesert grasses and shrubs. Journal of Range Management 20:170-176.

Davis, E.A. 1984. Conversion of Arizona chaparral to grass increases water yield and nitrate loss. Water Resources 20:1643-1649.

Davis, O.K., 1994. Pollen analysis of borderland cienegas. Report to The Nature Conservancy, Arlington, VA.

DeBano, L.F., J.J. Brejda, and J.H. Brock. 1984. Enhancement of riparian vegetation following shrub control in Arizona chaparral. Journal of Soil and Water Conservation 39(5):317-320.

DeBano, L.F., and L.J. Schmidt. 1990. Potential for enhancing riparian habitats in the southwestern United States with watershed practices. Forest Ecology and Management 33/34:385-403.

Glendening, G.E. 1952. Some quantitative data on the increase of mesquite and cactus on a desert grassland range in southern Arizona. Ecology 33:319-328.

Hardy, T. B., B. Bartz, and W. Carter. 1990. Instream flow recommendations for the fishes of Aravaipa Creek, Arizona. Report to The Arizona Nature Conservancy, Tucson.

Hazel, D.B. 1967. Effect of grazing intensity on plant composition, vigor, and production. Journal of Range Management 20(4):249-253.

Heede, B.H., and J.N. Rinne. 1990. Hydrodynamic and fluvial morphologic processes: Implications for fisheries management and research. North American Journal of Fisheries Management 10:249-268.

Heitschmidt, R.K. 1990. The role of livestock and other herbivores in improving rangeland vegetation. Rangelands 12(2):112-115.

Hennessey, J.T., R.P. Gibbens, J.M. Tromble, and M. Cardenas. 1983. Vegetation changes from 1935 to 1980 in mesquite dunelands and former grasslands of southern New Mexico. Journal of Range Management. 36:370-374.

Humphrey, R.R. 1958. The desert grassland: A history of vegetational change and an analysis of causes. Botanical Review 24:193-253.

Humphrey, R.R. and L.A. Mehrhoff. 1958. Vegetation change on a southern Arizona grassland range. Ecology 39:720-726.

Kaib, M., C.H. Baisan, H.D. Grissino-Mayer, and T. Swetnam. 1996. In Ffolliot, P.F., L.F. DeBano, M.B. Baker, G.J. Gottfried, G. Solis-Garza, C.B. Edminster, D.G., Neary, L.S. Allen, and R.H. Hamre, Tech Coords., Effects of fire on Madrean Province ecosystems—A symposium proceedings. March 11-15, 1996; Tucson, AZ. General Technical Report RM-GTR-289. Fort Collins. 277 pp.

Johnson, R.R., and S.W. Carothers. 1982. Riparian habitat and recreation: Interrelationships and impacts in the Southwest and Rocky Mountain region. Eisenhower Consortium Bulletin 12, U.S. Forest Service. 31 pp.

Lewis, D.C. 1968. Annual hydrologic response to watershed conversion from oak woodland to annual grassland. Water Resources Research 4(1):59-72.

Simanton, J.R., Osborn H.B., and Renard, K.G. 1977. Effects of brush to grass conversion on the hydrology and erosion of a semiarid southwestern rangeland watershed. Proceedings Arizona Sec. AWRA-Hydrology Sec., Arizona Academy of Science 7, 249-256.

Stabler, D.F. 1985. Increasing summer flow in small streams through management of riparian areas and adjacent vegetation: A synthesis. p. 206-210 IN R.R. Johnson, C.D. Patton, P.F. Ffolliott, and R.H. Hamre, (technical coordinators). Riparian ecosystems and their management: reconciling conflicting uses. USDA Forest Service General Technical Report RM-120. 523 p.

Stephens, D.B. and R. Knowlton, Jr. 1986. Soil water movement and recharge through sand in a semiarid site in New Mexico. Water Resources Research 22(6):881-889.

Stuth, J.W. 1991. Foraging Behavior. 65-83 IN Heitschmidt, R.K. and J.W. Stuth. eds. Grazing management: An ecological perspective. Timber Press, Portland OR. 259 pp.

Thurow, T.L. 1991. Hydrology and erosion. IN Heitschmidt, R.K., and J.W. Stuth. eds. Grazing management: An ecological perspective. Timber Press, Portland OR. 259 p.

U.S. Department of Agriculture. 1940. Influences of vegetation and watershed treatment on runoff, silting, and stream flow: a progress on research. Miscellaneous Publication No. 397, Washington, DC. 30 pp.

Wagle, R.F. 1981. The University of Arizona, Tucson. 82p.

Wilcox, B.P., M.K. Wood and J.M. Tromble. 1988. Factors influencing infiltrability of semiarid mountain slopes. Journal of Range Management 41(3):197-206.

Woolhiser D.A., D.C. Goodrich, W.E. Emmerich, T.O. Keefer. 1990. Hydrologic effects of brush to grass conversion. 293-302 IN Watershed Planning and Analysis in Action: Symposium Proceedings of IR Conference, Watershed Management/IR Div./ASCI, Durango.

Wright, H.A. 1974. Range burning. Journal of Range Management 27(1):5-11.

Wright, H.A., and A.W. Bailey. 1982. Fire ecology: United States and southern Canada. John Wiley and Sons, New York. 501 pp.

Steps Toward Developing a Realistic Riparian Recovery Objective

Mark Briggs, Sonoran Institute, Tucson

As mentioned in other papers in this volume, developing the objective of the riparian recovery effort is the cornerstone for the entire project. Developing a sound objective, however, is not always easy, nor obvious, and requires some important pieces of information that have been frequently missed by past riparian recovery efforts. Project managers need to take the time at the very onset of the effort to piece together the required information and, based on what is learned, develop an objective that can be realistically achieved as well as self-sustainable in the long-term.

Along the way to developing the objective, there are some important questions that need to be considered: What is the long-term goal of the recovery effort? Can it be described in sufficient detail for purposes of measurement and evaluation? Will site ecologic conditions allow for restoration (i.e., a full return to pre-development conditions) or is it more realistic to aim for something less than full restoration (e.g., rehabilitation or reallocation)? Are there ways to involve residents from nearby communities? Can such post-project considerations as monitoring and evaluation be carried out? What permits will be required to complete the recovery effort?

This paper reviews several practical steps that can assist project managers to organize critical information and focus on the issues that play a key role in developing a sound and realistic objective for the riparian recovery effort (Figure 1).

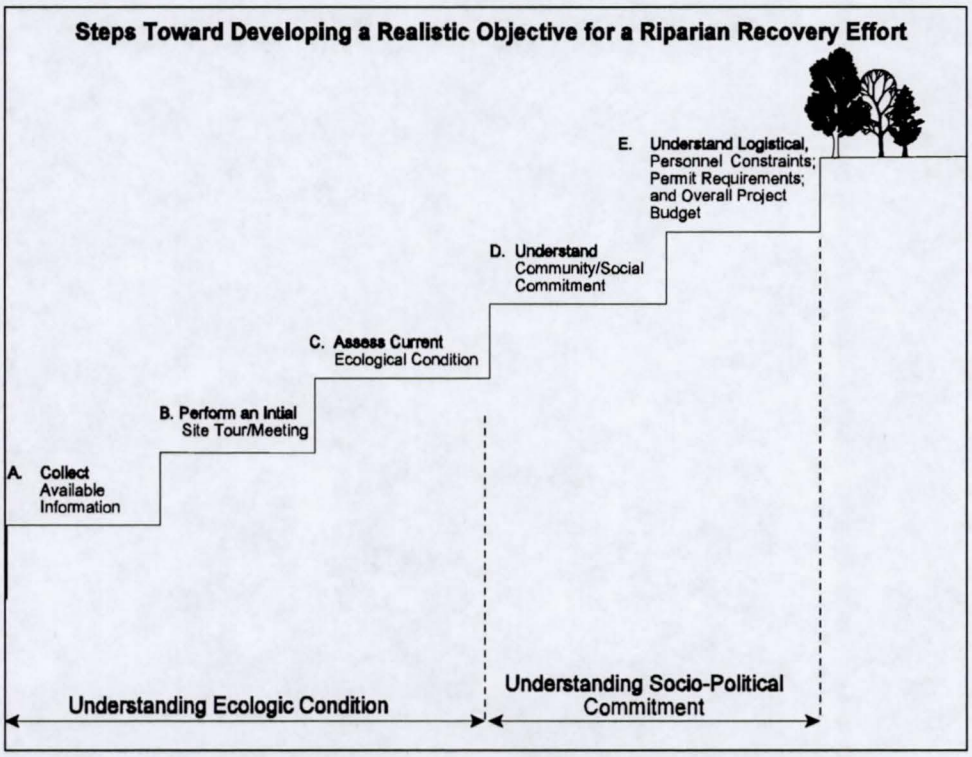


Figure 1. Steps toward developing a realistic riparian recovery objective.

COLLECT AVAILABLE INFORMATION

Understanding a site's current ecologic condition, the extent that the ecological characteristics of the site have changed from pre-development times, and the reasons for the changes are an absolute necessity for designing a riparian recovery effort that will have a realistic chance of meeting its objectives and be viable in the long-term (Briggs 1996). Obtaining information that is already available —both documented and undocumented—can save project managers a lot of time, energy, and money. It is fair to assume that at least some background information is available; it's just a matter of finding out where the information is hidden.

Listed below are some selected sources of ecologic information that will be of benefit to managers planning a riparian recovery effort.

Federal and State Agencies

A variety of federal and state agencies that work in the natural resource field frequently collect a wide range of information that could be helpful in understanding a site's past and current ecologic conditions. Examples of such information include aerial photographs, land photographs, maps, streamflow data, hydrologic reports, permit needs, game and fish records, results of investigations, lists of local flora and fauna species, and well records (e.g., pumping records, well depths, etc.).

University Libraries and Departments

Exploring the availability of natural resource information at nearby universities and libraries is a first-step necessity. Research and teaching institutions often house a variety of natural resource information that could pertain directly to the area being considered by the recovery project. Reports describing investigation results, maps, natural resource reference guides, historical accounts of the area, databases, etc. are often readily available at many university departments and libraries.

Local Conservation Organizations And Consulting Firms

Private natural resource organizations (e.g., non-profit conservation groups, natural resource consulting firms) can provide invaluable information gleaned from their project-related experiences. The types of information commonly found include, results of natural resource inventories, experiences gained from past or on-going conservation efforts, and local community contacts.

Citizens from Nearby Communities

Local citizens can provide a variety of qualitative and quantitative information. Residents that have been in the area for a long period of time can provide valuable information about past ecologic conditions and some of the reasons for the ecologic damage that has occurred. Bird lists, precipitation data, well-depth information, old photographs, hunting and fishing records or accounts are just some of the information that can be obtained from local citizens.

CONDUCT AN INITIAL SITE VISIT

Visiting the riparian site before making any decisions on the recovery strategies that will be employed is critical. This seems obvious, yet all too often the design of past riparian recovery efforts was initiated without first visiting the site and seeing site conditions first hand. Such in-office designs are often doomed to failure because they simply lack the ecologic authenticity on which a realistic recovery effort can be developed. Taking the project team to the area and touring significant parts of the watershed (e.g., reaches upstream and down-stream from the proposed recovery area, tributaries, uplands) will remove assumptions and provide a solid foundation on which the riparian recovery effort can be developed.

The only reason that the site visit is not listed first is that it may be valuable to collect some information before going out to the site for the first time. Maps, aerial photographs, and hydrologic reports can be particularly helpful.

It is important that the initial site visit be conducted in a manner that improves the understanding of the site's current ecologic condition,

how its ecologic condition has changed in recent years, and the reasons for the changes that have occurred. Not only is such information critical for formulizing a recovery plan, but also provides the foundation for determining the extent to which your organization becomes involved. Essentially, should the area be avoided in favor of other areas where funds and personnel can be more effectively used?

Below is a list of selected site and watershed characteristics that should be considered during the first site visit.

Streamflow

Is the stream flowing (an important question in arid climates)? If so, estimate or directly measure the flow. Is the water clear or muddy? Does it possess a color or odor? Are there significant amounts of algae covering channel gravels or rocks? Are significant portions of the water surface covered with algae or other plants?

Groundwater

Are there wells in the area? If so, can the depth to the water table be measured?

Streamside Vegetation

What plant communities are present? Are there multiple age-classes of the dominant plant species? Is there evidence of recent recruitment? Are hydrophytes present? Are significant amounts of non-native species present?

Channel Morphology

Are there signs of channel aggradation or degradation? Do the channel banks show signs of extensive erosion and instability?

Land Uses

What are the prevalent land uses in the watershed? How might they be affecting the ecologic condition of the watershed and its riparian areas? How long have the land uses been in effect?

Upland Conditions

What is the general condition of upland areas? Are there signs of extensive erosion? Are the uplands being heavily developed? Are there signs of overgrazing or extensive timber harvesting?

Downstream and Upstream Conditions

Are there significant differences between the ecologic condition of the site being considered and those upstream or downstream of the site (e.g., water availability, streamflow characteristics)?

Local Community Contacts

Are there citizens in the area that should be contacted (for reasons of access, information gathering, and potential involvement in the recovery project)?

Perform Your Own Natural Resource Investigations

If information describing the current and past ecologic condition of the site is not available or it is insufficient, ecosystem managers will need to collect their own data. There is no substitute for performing your own investigations. Collecting data directly is often more credible than obtaining data from other sources. It also allows ecosystem managers to tailor investigations to answer the questions necessary for designing a riparian recovery plan.

In this proceedings, the paper "Benefitting from the Past: Lessons from Past Riparian Restoration Efforts" goes into greater detail about the need to perform your own investigations and some of the important questions that should be answered as part of understanding the current ecologic condition of a riparian area and the extent to which the area has changed. Other resources along this line are Gordon et al. (1992), Briggs (1996) and Riley (1998).

Understand Community/Social Commitment

Involving teachers, students, academics, ranchers, landowners, local officials, and other community members in the project from the outset can bring numerous benefits. Pride and the sense of inclusion that community involve-

ment fosters can greatly increase the chances for long-term success. Community members can be involved in a wide range of activities, including revegetation, monitoring, irrigation, installing signs and fences, protecting the site from vandalism, and education outreach activities. One of the benefits of riparian revegetation is the potential of involving people of diverse backgrounds directly in the project. Several of the riparian revegetation efforts evaluated in Arizona, for example, united ranchers and environmentalists (Briggs, 1992).

Several organizations across the western United States have been developed specifically to involve communities in identifying and addressing environmental restoration needs. Ecosystem managers are encouraged to contact these and similar organizations to assist in developing community support for their projests. The Adopt-A-Stream Foundation (AASF), based in Everett, Washington, provides funding for community-based habitat restoration and education projects. Using funds from AASF, high school students in Washington have learned how to revegetate streambanks and monitor water quality (Murdoch, 1995). The North Portland Youth Conservation Program, a program of the Wetlands Conservancy, teaches young people to identify environmental needs in their community and develop plans for addressing them (Lev 1995). Along the Santa Cruz River in Sonora, Mexico, the Sonoran Institute is working with several riverside towns to develop community-based strategies for protecting and restoring parts of this valuable river system (Murrieta and Briggs in press).

Understand Permit Requirements, Personnel and Logistical Constraints, and the Overall Project Budget

Before designing the riparian recovery strategy, spend some time investigating the local, state, and federal permit requirements that may pertain to the site. Ignoring this crucial step may stop a project dead in the water after precious time and money have been spent in developing it. Whether or not the work planned for the site requires a permit depends to a large degree on the site's location, the type of work being planned, what is on the site (e.g., designated critical habitat for endangered species), and who is funding the project. For example, a site may be within the jurisdictional boundary of the U.S. Army Corps of Engineers, potentially requiring a 404 permit. If the site contains cultural resources, a permit from a state agency may be required. In Arizona, for example, the State Preservation Act requires consultation with the state historic preservation officer before projects occurring in areas containing historic cultural resources can proceed. If the site contains habitat critical to an endangered species, a Section Seven consultation with the U.S. Fish and Wildlife Service may be required.

As you move from developing a realistic riparian recovery objective to developing the strategies that will be required to realize the objective, it is important to not only develop a realistic budget, but to also make certain that appropriate levels of funding will be available to carry out the recovery plan. Essentially, this issues goes to the heart of understanding the commitment that your organization(s) has for completing the project and following through on such post-project considerations as monitoring and evaluation. Hand-in-hand with funding considerations, it is also important to understand from the onset the personnel and logistical constraints that could slow or even jeopardize the completion of the riparian recovery effort. When the project is ready to begin, what personnel will be available to assist? Will the required transportation and materials be available to fulfill project objectives? Understanding these and other practical considerations are all critical to developing a realistic objective for the recovery effort.

LITERATURE CITED

Briggs, M. 1992. An evaluation of riparian revegetation efforts in Arizona. Master's thesis, School of Renewable Natural Resources, University of Arizona, Tucson.

Briggs, M. 1996. Riparian ecosystem recovery in arid lands: strategies and references. University of Arizona Press, Tucson.

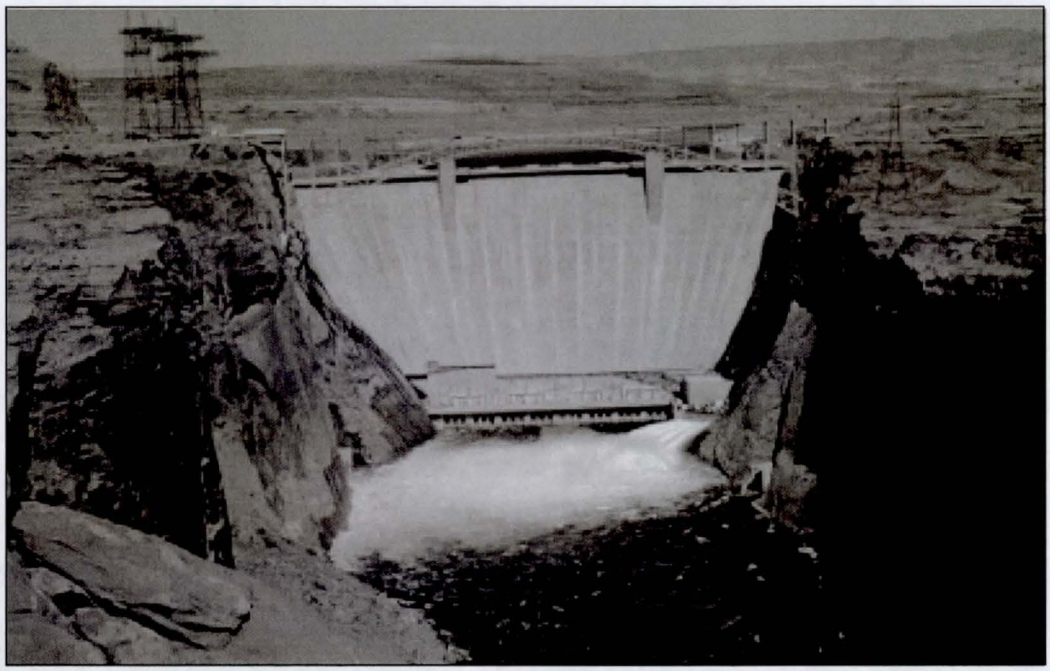
Gordon, N.D., T.A. McMahon, and B.L. Finlayson. 1992. Stream hydrology: An introduction for ecologists. John Wiley & Sons, New York, New York.

Lev, E. 1995. Youth conservation corps carries out streambank project. Restoration and Management Notes 13:20-21.

Murdoch, T. 1995. Stream restoration and environmental education: The Adopt-A-Stream Foundation. Restoration and Management Notes 13:7-11.

Murrieta, J.S. and M.K. Briggs. [in press] Un río fronterizo y sus comunidades: Un perfil de las caracteristicas socioeconomicas y las condiciones ecologicas del Río Santa Cruz en Sonora, Mexico. Sonoran Institute, Tucson, Arizona.

Riley, A. L. 1998. Restoring streams in cities: A guide for planners, policy makers, and citizens. Island Press, Washington D.C.



Glen Canyon Dam in 1993 at the time of the experimental controlled water release to partially mimic historic flows. Photo: Duncan Patten

Case Studies in Riparian Restoration

This section contains descriptions of three case studies of riparian restoration activities in Arizona. The case studies exemplify very different problems, environments, and solutions. One dealt with a mountain meadow, one with a low-elevation perennial wetland area and one with a highly disturbed low elevation urban watercourse.

Participants were divided into three groups, each examining a different case study. The sessions were generally structured so that the speaker presented the setting and the problem(s) to be solved, then asked the participants to help in selecting solutions. Participants were encouraged to ask the kinds of questions that experts working on the project might need to ask before working towards a solution. The problem-solving approach generally followed the procedure described by Mark Briggs above.

Each group's summary was presented to all conference participants. In this publication the presenter's basic information is given along with the chosen plans, where appropriate.

Planting sacaton grass at Bingham Cienega. Photo: Pima County Flood Control District

Bingham Cienega Natural Preserve
The Nature Conservancy Restoration Project

Daniel Baker, Arizona Nature Conservancy

SITE DESCRIPTION AND HISTORIC NATURAL CONDITIONS

Bingham Cienega Natural Preserve occupies 285 acres in the Central San Pedro Valley near the small community of Redington, almost due east of Tucson. In 1978 The Nature Conservancy's Arizona Natural Heritage Program identified Bingham Cienega as one of Arizona's rarest natural features. In a 1988 Arizona Natural Areas Study, the Arizona State Parks Board identified and ranked Bingham Cienega as the 9th most significant site out of over 300 sites proposed for natural area protection in Arizona. In 1989 the Pima County Flood Control District purchased the Cienega and entered into a 25 year management agreement with The Nature Conservancy.

Bingham Cienega is situated along the banks of the San Pedro River, which has received substantial local, national and international attention. The San Pedro and environs was designated as one of The Nature Conservancy's "Last Great Places" because it represents one of the last great relatively intact surviving ecosystems. As one of the longest undammed watersheds remaining in the American Southwest, the San Pedro River stretches 140 miles from northern Sonora, Mexico to its confluence with the Gila River. NAFTA's scientific expert team for the Commission for Environmental Cooperation found that as many as four to five million neo-tropical bird migrants utilize it as their main Western flight corridor between Central and North America. Nearly half of North American birds have been sighted there, and the American Bird Conservancy recognized it as a Globally Important Bird Area. Some of America's rarest forest types line its banks, principally Fremont cottonwood-Goodding willow forest and mesquite bosques. It also supports the highest number of mammal species in North America.

Bingham Cienega is situated in the Central Basin of the San Pedro. The Central Basin presents the rare sight of a nearly unfragmented landscape with no significant development and a very low human population density (a few hundred) between the fifty-five or so miles separating Benson-Pomerene and San Manuel-Mammoth. It also connects the Rincon-Catalina mountain complex with the Winchester and Galiuro mountains. Mountain lion, black bear, bighorn sheep, mule and white-tail deer, gray fox, coatimundi and ringtail cats among others traverse these ranges. Animal corridors such as nearby Buehmann and Redfield Canyons connect these "sky islands" thereby reducing extinction rates from these habitats, increasing recolonization rates after local extinction, and permitting gene flow between habitats. (Gori 1997).

Bingham Cienega is a spring-fed marsh. Rock outcrops from the Catalina Core Complex in the main channel just north of the mouth of Edgar Canyon force underflow to rise up and become streamflow. (Agenbroad 1967).

The shallow water table created by the influence of this same block of consolidated sediments is also thought to be responsible for generating outflow at the spring. (Baird, Ronayne and Maddock, 1997). Bingham Cienega and adjacent agricultural fields occur on the pre-entrenchment flood plain of the San Pedro and are four meters above the active channel. The site was not eroded by flooding in 1983 or 1993.

1879 General Land Office surveys of the Preserve and vicinity indicate that historically moister areas in and near the cienega included dense, shrubby willows, while sacaton grasslands, deciduous riparian forests and mesquite bosques lay outside the cienega. (Fonseca 1994). Pollen analyses show woody riparian vegetation increased during late historic periods, coincident with decreased fire frequency.

(Davis. 1994). Bingham Cienega is now a lotic system supporting extensive stands of cattails, bullrush and other obligate wetland plants. Besides the wetland, mesquite bosque, palustrine wooded swamp and cottonwood- willow riparian forest are on site. Sacaton grass persists along riparian forest edges or in under-story. The adjacent flood-plain is dominated by riparian species, especially mesquite and salt cedar as well as Fremont cottonwood, Goodding willow, Arizona walnut and velvet ash. The sur-rounding upland plant communities are Sonoran desert scrub dominated by mesquite, saguaro and cholla cacti species.

Sites like Bingham with perennial flow and diverse riparian habitats are critically important as stepping stones for migratory birds in the intermittent middle and lower San Pedro. Cottonwood-willow forests support the highest densities of birds in the Southwest, and mesquite bosques the second highest, and both support diverse assemblages of invertebrates, reptiles and mammals. (Stromberg, J. C. 1993). In Arizona 90 percent of streamside wetlands have disappeared. In cienega wetlands the losses are estimated to be closer to 95 percent. (Hendrickson and Minckley 1984). The remaining are threatened by increased water demands on streamflow and groundwater sources. Despite their small area, over 70 percent of all species inhabiting this semi-arid region as well as migratory species depend on these systems. (Carothers, Mills, and Johnson. 1993).

CHANGES TO THE SYSTEM RESULTING IN A NEED FOR RESTORATION

Around the turn of the century approximately 70 acres at Bingham Cienega were modified hydrologically by ditching and ber-

Irrigating sacaton seedlings at Bingham Cienega. Photo: Pima County Flood Control

ming the cienega wetland, and the entire area was cleared for agriculture. These fields are like the thousands of acres of floodplain habitat, especially mesquite bosques and sacaton grass-lands, that were cleared and farmed along the San Pedro. The loss of sacaton grassland is especially notable: over 95 percent of sacaton grassland habitat in Arizona has been lost over the last century. (Humphrey 1960).

Historically, sacaton grasslands formed extensive stands along riparian areas within the semiarid grasslands. It has now been replaced by mesquite due largely to fire suppression and declining water tables. Initial site recovery occurred when farming and livestock grazing were stopped in years following the purchase of the cienega by Pima County in 1989. In addition, the berm was breached and the wet-land was allowed to reestablish over the abandoned fields. Areal extent and hydrology of the cienega has somewhat stabilized at about 22 acres.

Before 1890 the San Pedro flowed slowly in a shallow narrow channel through marshy environments. San Pedro entrenchment occurred around the turn of the century with a series of large floods. This was apparently due to a variety of causes including climactic changes, timber harvesting, fire suppression, overgrazing, draining of swamps, beaver extirpation and earthquake. Today only isolated pieces of the once extensive marshlands persist; commonly attributed to the arroyo cutting episode, and more recently groundwater development in the form of pumping for agricultural, municipal and industrial uses which has lowered water tables and diminished water supply necessary to maintain wetland habitats.

RESTORATION OPPORTUNITIES, CHALLENGES, APPROACHES

Part of the opportunity at Bingham Cienega is the potential for local restoration of the lost character of the San Pedro, which historically included sacaton meadows. Since cienega vegetation often occurs in zones or bands that reflect gradients of water availability. (Hendrickson and Minckley 1984). The Nature Conservancy conducted a "Preliminary Vegetation and Hydrological Analyses for Bingham Cienega." (Baird, Ronayne and Maddock,1997). Its purpose was to relate hydrological gradients across the agricultural fields to spatial distribution of dominant cienega plant species. Three planting areas were identified to support a different historic riparian community type: deciduous riparian woodland, sacaton grassland and mesquite woodland. The entire upland terrace portion of Bingham Cienega was found to be hydrologically suitable for the restoration of sacaton grassland. If successful, such an effort might provide a model for other re-covering areas and abandoned agricultural fields along the length of the San Pedro Valley where sacaton dominated historically.

The conditions that allow this opportunity for riparian deciduous woodland and sacaton grassland restoration are the same ones that make it such a challenge. The lesson of ecology is that all systems and their parts are connected. Bingham is effectively an island in the threatened hydrologic system of the San Pedro. The lack of floods and overbank inundation due to floodplain entrenchment, and which are required to move seeds into sediment, have prevented recruitment and reestablishment of native species. (Haughey, 1997). (Additional inputs of moisture after germination appear to be an important factor in seedling survivorship. (Aldon 1975).

Competition with exotic weeds including Johnson grass and bermuda which dominate the fields are inhibiting factors as well. Sacaton is also adapted to fire of appropriate timing and periodicity. (Bock and Bock 1986). Any controlled burning must match historical timing and intensity of wild fires, as well as be feasible within surrounding environmental and social conditions.

Bingham Cienega Natural Preserve attracts attention for its beautiful, unique and important location and habitat type. It is also interesting for its riparian restoration possibilities. It presents all the opportunities and challenges that constitute the dreams and nightmares of the ecological restoration concept.

LITERATURE CITED

Agenbroad, L. D. 1967. "Cenozoic stratigraphy and paleohydrology of the Redington-San Manuel Area" University of Arizona Ph.D. Dissertation.

Aldon, E. F. 1975. "Establishing Alkali Sacaton on harsh site in the Southwest," Journal of Range Management, 129-132.

Bock, J. H. and Bock, C. E. 1986. "Habitat relationships of some native perennial grasses in Southeastern Arizona," Desert Plants, pp. 3-14.

Baird, Ronayne and Maddock,1997. Preliminary vegetation and hydrologic analyses for Bingham Cienega. University of Arizona Department of Hydrology and Water Resources.

Carothers, Mills, and Johnson. 1993. "The creation and restoration of riparian habitat in Southwestern arid and semi-arid regions, pp. 351-66 IN Kustler, J., and Kentual, M., eds., Wetland Creation and Restoration, Island Press, 1990.

Davis, O. K. 1994 "Pollen analysis of borderland cienegas," Unpublished report to the Arizona Nature Conservancy.

Fonseca, Julia. 1994."Vegetation changes at Bingham Cienega," Pima County Flood Control District.

Gori, D., 1997. Unpublished report to the Arizona Nature Conservancy.

Haughey, 1997. Unpublished report.

Hendrickson, D. A. and Minckley, W. L. 1984. "Cienegas—Vanishing climax communities of the American Southwest," Desert Plants, 131-175.

Humphrey, R.R. 1960. "Forage production on Arizona ranges," University of Arizona, Agricultural Ex. Station Bulletin 302.

Naiman, R. J., Decamps, H., and Pollock, M., "The role of riparian corridors in maintaining regional biodiversity," Ecological Applications, pp. 209-12.

Ohmart, R. D. and Anderson, B. W., "Riparian habitat" in Inventory and monitoring of wildlife habitat, ed. by Cooperrider, A. Y., Boyd, R. J., and Stuart, H. R., Denver: USDI BLM Service Center, 169-199.

Stromberg, J. C. 1993. "Southern Arizona warm-temperate riverine marshes." Arizona Nature Conservancy.

The Santa Cruz River downstream of the Pima County Wastewater Treatment Plant. In occasional situations, the addition of water may be the only thing needed to restore riparian habitat. This section of the river has a constant flow of effluent and here, where there is a wide floodplain, a willow and cottonwood forest is developing without human revegetation efforts, following a souring flood in 1993. Photo: Barbara Tellman.

Strategies and Tactics for Restoring Riparian Meadows: A Case Study from the White Mountain Apache Reservation

Jonathan W. Long and Candy S. Lupe, White Mountain Apache Tribe, Whiteriver

SITE DESCRIPTION AND REFERENCE CONDITIONS

Pacheta Cienega is a large wet meadow at an elevation of 8,900 feet on the eastern edge of the White Mountain Apache Reservation. Pacheta Creek courses through the west side of the meadow. The meadow is surrounded by mixed-conifer forest. The stream harbors a very productive trout fishery. A well-traveled dirt road passes through the north side of the meadow.

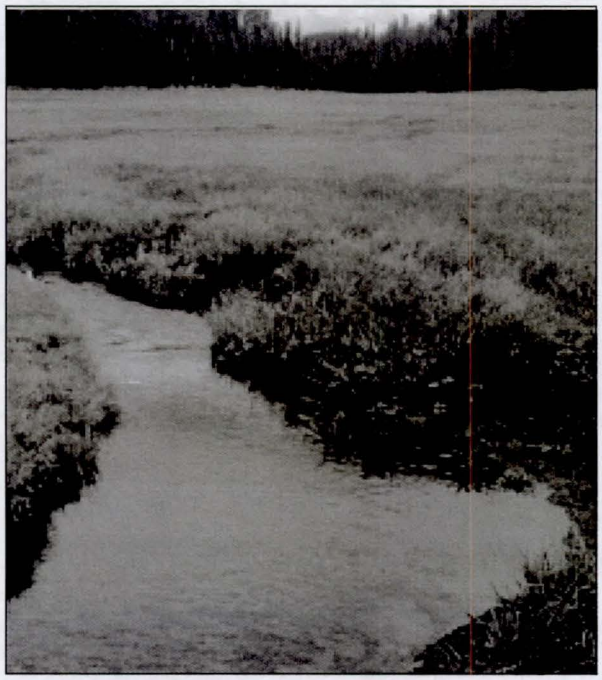
A short reach within the meadow appeared to qualify as a reference condition based on vegetation, morphology, and bank conditions. The channel was a sinuous Rosgen E4-type with stable, undercut banks. Coarse gravels made up the stream bed. Reference vegetation was composed of sedges (*Carex rostrata,* among others) that dominated moist areas and most streambanks.

CHANGES TO SYSTEM RESULTING IN NEED FOR RESTORATION

One reach had downcut to the point where it was entrenched–the bankfull flow did not reach above the stream banks. Many sections of stream bank had begun to crack and collapse into the channel. This reach was relatively straight and fast-flowing. Hardpan clay was visible on the bottom of many of the downcut reaches. However, drier portions of the meadow, and some of the streambanks were dominated by Kentucky bluegrass (*Poa pratensis)*, an undesirable, exotic species that displaces native vegetation. Furthermore, seedlings of alder (*Alnus tenuifolia*) had invaded along some of the desiccated banks.

The primary cause of the degradation was trampling and overgrazing by the combination of livestock and wildlife. Trampling of the streambed gravels was a particular problem at this site, since there were not sufficient materials to replace the loosened rocks that armored the bed. Changes in soil type in the meadow most likely account for the thin layer of gravel at this site. Channel downcutting in turn led to shifts in vegetation toward drier species such as bluegrass that do not provide adequate bank protection. Alders were invading the meadow from the canyon reach above.

Upland watershed conditions and road impacts did not appear to have caused the degradation of this site, although floods could have been the trigger for the changes that have occurred and the road crossing may have been a problem in the past.



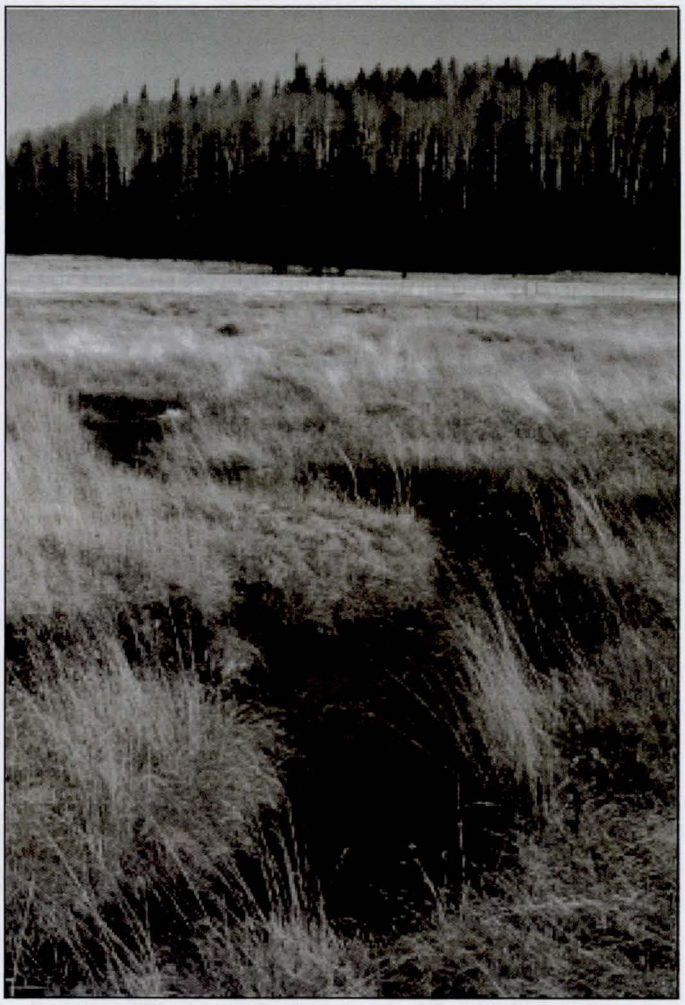
Pacheta Cienega as it appeared in before restoration efforts were undertaken. Photo: White Mountain Apache Tribe.

RESTORATION OPPORTUNITIES, CHALLENGES, APPROACHES

Reducing pressure from livestock and wildlife was paramount, and fencing was the simplest solution. Although a true wildlife fence would have been too costly, a sturdy five-strand fence proved sufficient to deter wildlife use enough for the vegetation to recover. Passive restoration alone was deemed insufficient to restore proper functions to the system. Active treatments to reduce the velocity of the stream through the downcut reach were needed to prevent further erosion. Headward downcutting threatened the healthy reach below the culvert. Riffle features were recreated using imported gravels to stabilize channel geomorphology, to raise the water table, and to replace the gravels that have been washed out. The riffles were stabilized using sedge plugs taken from the wetter parts of the meadow. The native wetland herbaceous vegetation serves as a structural and a biological restoration tool. In addition to transplanting desired wetland species, we removed invading alder seedlings to promote recovery of functions.

CONCLUSION

This case study presented a number of valuable lessons for treating dysfunctional channels. Passive restoration alone is not sufficient when severe channel dysfunctions (i.e. downcutting into an entrenched channel type) have occurred. The Rosgen Channel Classification (Rosgen 1996) system provides a useful tool for identifying when streams have moved past such thresholds. Understanding of vegetation dynamics and roles of different species in restoring riparian functions are both critical. For many meadow systems, native wetland graminoids provide the keys to protect streams. Although this case study is taken from a high-elevation system, these lessons can be extended to low-elevation systems.



Pacheta Cienega in 1997 after one year of restoration efforts. Photo: White Mountain Apache Tribe.

The Santa Cruz River: The Paseo de las Iglesias Project

Nanette Gerstenberger, Collins-Peña, Inc., Tucson

SITE DESCRIPTION AND HISTORICAL NATURAL CONDITIONS

The Santa Cruz floodplain experienced a complex alluvial history culminating in a major cut and fill cycle between 500 and 300 years ago, with resumed downcutting 100 years ago. Dis-continuous arroyos existed 6 to 12 miles upstream of Tucson as early as 1849, but elsewhere the stream flowed across the valley surface with perennial reaches 25 miles south of Tucson, near San Xavier and at Tucson.

Early accounts of the vegetation in these areas show dense mesquite (*Prosopis velutina*) growth in the dry reaches above and below the perennial stretch through Tucson. Near Tucson, cottonwoods and willows marked the course of various irrigation ditches. A grassy marsh co-veered 1.5 square miles on each side of the Spring Branch above San Xavier. An impressive mesquite forest, interspersed with small meadows, was located mostly on the western flood-plain of the Santa Cruz River near the San Xavier Mission. Several historical accounts of the mesquite forest describe specimens with trunks over four feet in diameter and reaching a height of over sixty feet. The density of the forests was de-scribed as so thick as to prevent passage.

Prior to 1890, the Tucson Basin reach was characterized by lengthy segments of unincised alluvium interrupted by short and discontinuous gullies downstream from marshes. Historic development of headcuts was staggered temporally along the Santa Cruz River occurring first in the San Xavier area. In 1871, early surveyors recorded two headcuts, one below the Punta de Agua spring (south of Martinez Hill on the San Xavier Indian reservation) along the main stem, and the other below the extensive marshlands watered by the Spring Branch. Between 1871 and 1882, the latter headcut deepened to intercept the near-surface underflow, providing the source for Tucson's first municipal water supply.

CHANGES TO SYSTEM RESULTING IN NEED FOR RESTORATION

Water development and channel works have largely contributed to the need for restora-tion along the Santa Cruz River. For example, in 1935, the Works Projects Administration straightened the channel from San Xavier downstream to Congress Street. The current was deflected into the channel by revetments made of discarded automobile frames. The remaining riparian vegetation was destroyed during this process of placing the revetments. In the 1950s and 1960s, nearly a million tons of garbage were dumped in the channel or on the adjacent floodplain, resulting in an artificial

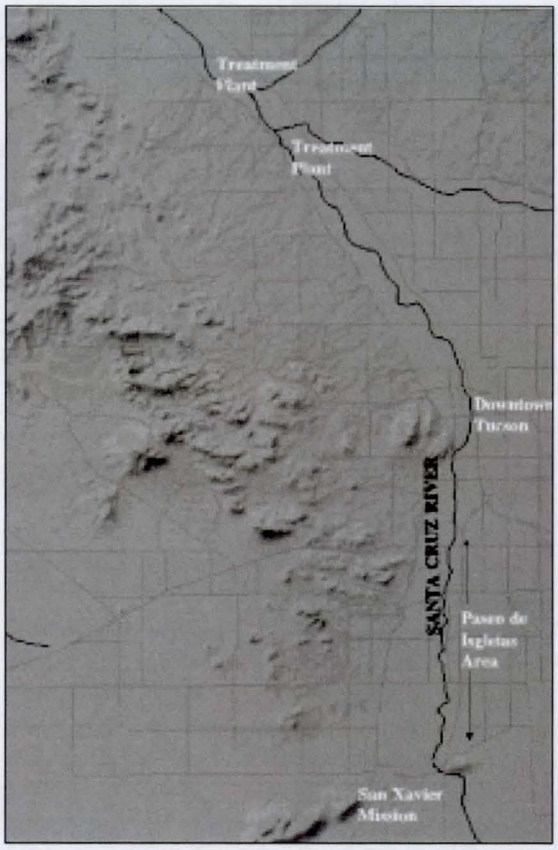


Figure 1. The Santa Cruz River through Tucson. The river flows north.

narrowing of the channel. Overburden from highway construction was also deposited on the east bank of the river allowing construction inside the meander. Significant riparian and uplands (typical Sonoran species) vegetation, mesquite bosques and stands of cottonwood and willow, were lost during the construction on Interstate 10 and Interstate 19. Certain areas of the Santa Cruz River have been channelized and embanked with soil cement to combat the destruction resulting from flooding. A narrow 100-year floodplain is characteristic of the Santa Cruz River from Los Reales Road to Silverlake Road. Soil cement revetment has been constructed up and downstream of the Valencia Road Bridge, Irvington Road to Ajo Way and Silverlake Road up to Grant Road. The Santa Cruz channel conveys the design 100-year flood-waters in these areas. However, the 100-year design flows will inundate areas upstream of St. Mary's Road where the Santa Cruz River has not been bank protected. Within the Paseo study area, stretches of the Santa Cruz River that lack channel stabilization are located from Los Reales Road (the boundary with the San Xavier District) to Irvington Road, and Ajo Way to Silverlake Road.

Due to excessive groundwater withdrawals, the Santa Cruz River ordinarily flows only from stormwater runoff. More than half of the groundwater pumped in the Tucson area comes from wells near the Santa Cruz River. Groundwater levels continue to drop every year as more water is withdrawn than recharged. However, north of Paseo de las Iglesias, segments of the Santa Cruz River have continuous flows from discharges at the Roger Road Wastewater Treatment Facility and the Ina Road Water Pollution Control Facility. Some of the treated effluent produced from these plants is reclaimed for irrigation and recharge. The remaining effluent, about 65 MGD is released into the Santa Cruz River. According to the USGS Infiltration Study, most of the effluent discharged into the Santa Cruz River infiltrates into the aquifer below. The secondary treated effluent contains total dissolved solids (TDS), nitrate, sulfate, metals, and bacteria at concentrations suitable for habitat development.

Today, the natural environment in the study area includes riparian and upland vegetation. The river contains sparse vegetation consisting mostly of tamarisk (*Tamarix* spp.), African sumac (*Rhus lancia*), and non-native grasses. Tamarisk is found in the channel bottom throughout the study area and provides relatively poor habitat compared to native riparian vegetation. The tops of the banks have both native and restored Sonoran upland vegetation which is characterized by native mesquite (*Prosopis velutina*), palo verde (*Cercidium* spp.), and creosote (*Larrea tridentata*). The restored vegetation is along a constructed bike path that runs parallel to the river through approximately half of the project area. These vegetated areas provide a biological corridor and habitat linkage to and from the Tucson Mountains to the west. The area includes both native and introduced species.

RESTORATION OPPORTUNITIES, CHALLENGES, APPROACHES

Planting

Native plant communities could be established in the habitat areas by a variety of methods, including container stock planting, cutting planting, seeding, pole planting, and wattle planting. Plant materials would be ac-quired through nurseries, contract growers, site salvage operations, and harvesting from exis-ting riparian areas in the vicinity. A com-bination of the above planting methods should be selected to provide for a natural succession in the habitat areas. For example, the majority of plant species may be placed with a seed mixture, with large container stock and cuttings planted in critical areas to provide immediate habitat benefits. The plant communities should be irrigated until the plants become established. After establishment, the need for irrigation would depend on how much water was available in the river and the location of the plantings in relation to the water. The created habitats will provide shelter and foraging for migratory waterfowl. Use of the area by reptiles, amphibians, and small mammals is expected to increase and add to the overall biological diversity. As a result, the area will be

useful for educational groups to study the created systems and the animals that make use of them.

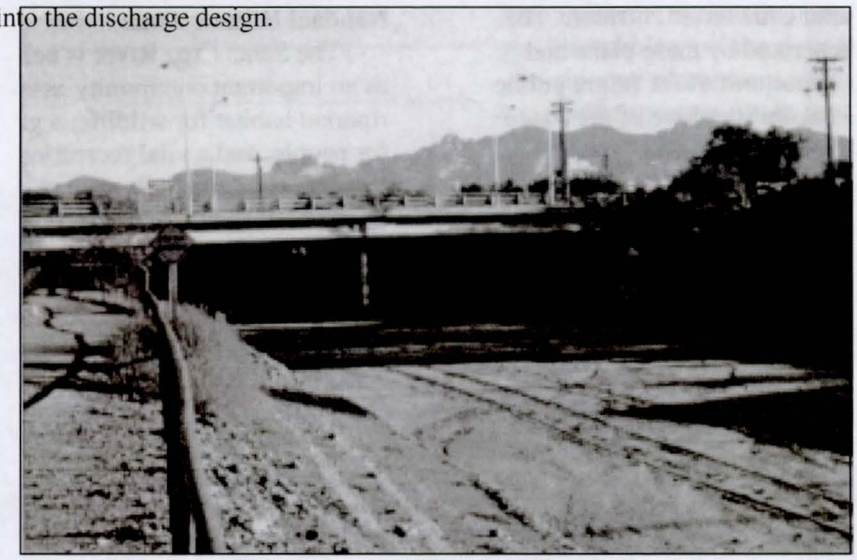
Managed Flow Releases

Multiple opportunities are available for the discharge of water into Paseo de las Iglesias for habitat restoration. The discharge of 15,000-acre feet per year into the Santa Cruz River has been proposed. Reclaimed treated effluent from a municipal treatment facility could be an addi-tional source of water to the reach. The water could be discharged seasonally or continuously, depending upon the rates and volumes available. The objective of any discharge schedule would be to recreate portions of the riparian habitat along the Santa Cruz River to its historical level. A thorough water budget analysis of the stretch would have to be completed as part of the feasibility study to analyze the effects of the discharge. The analysis would have to take into consideration the existing clay lenses, the re-gional groundwater table and its existing inter-action with the Santa Cruz River, the volumes of the discharged water, the increase in the rate of evapotranspiration due to increased vegetation, and any potential subsurface interflow between the river and the aquifer. In addition, management of water flows for vector control would be incorporated into the discharge design.

The periodic or continuous addition of water to the normally dry riverbed would also require sediment transport/scour analysis. The discharged water could create low-flow channel meandering, undercutting, reduced soil cohesion and slumping. Controls to prevent erosion could include the stabilization of soils close to the discharge points, a designed low flow channel for the discharge, and the establishment of clay layers lining the channel stretches intended to carry the water.

Any Central Arizona Project or reclaimed water discharged to the Santa Cruz River would have to be analyzed for its effect on sediment deposition/scour within the channel and water quality. The discharge could have dramatically different concentration of sediments and dissolved solids than storm water, altering the existing equilibrium of the channel bed. In addition, the water quality would have to be analyzed to demonstrate that the quality of any discharged water would not conflict with the ecosystem restoration design.

Finally, if ecosystem restoration and water release are attempted within the Santa Cruz, flood control analysis and comprehensive floodplain modeling of the entire study stretch would have to be incorporated into any pro-



The Santa Cruz River near downtown Tucson. Notice the vehicle tracks down the center of the river. Photo: B. Tellman

posed profile or cross section alterations. This would ensure that any changes would not jeopardize the carrying capacity of the river.

Land Use

Several of the problems identified earlier in this report, such as the degradation of environmental and visual resources from landfills and wildcat dumping, are the consequences of inappropriate land uses in the river corridor. Many of these activities took place prior to federal, state, or local environmental legislation. Since the passage of the National Environmental Protection Act (NEPA) and local environmental ordinances, the adverse impacts of development have been mitigated to some extent. Local jurisdictions and agencies, particularly the Pima County Flood Control District and the City of Tucson Department of Transportation, have initiated more comprehensive watershed management programs. Pima County and the City of Tucson now actively promote protection and restoration of river and wash corridors and floodplains.

Key techniques to accomplish this include acquisition of flood prone land to prevent future development, and land use regulation to prevent or mitigate floodplain encroachment. Neighborhood groups and the general public have supported special projects that address riparian habitat, cultural resource protection, and recreation within the Santa Cruz River corridor. The local momentum generated by these plans and activities suggests opportunities for future public support during the feasibility phase of the Paseo de las Iglesias study.

Other Considerations

Restoration efforts also need to consider possible effects on the numerous prehistoric, historic, and cultural sites along the banks of the Santa Cruz River. The latter includes Hohokam canals, Sobaipuri and Papago ditches and Spanish acequias.

Another major archaeological site which is largely undisturbed and undeveloped is located east of the river north of San Xavier. The most significant set of archaeological ruins is the San Agustín Mission,Convento, Mission Gardens, and associated canal system, near the downtown area.

This site, listed on the National Register of Historic Places, represents some 500 years of Hohokam occupation and includes a central plaza and ball court ringed by several hundred houses. The site is one of the last remaining large prehistoric village sites along the Santa Cruz River in the greater Tucson area. Several other historic resources dating from the late 19th century are located along the west bank of the Santa Cruz River within the study area, including Warner's Mill and Silverlake Resort.

Finally, both Pima County and the City of Tucson have developed river parks along the Santa Cruz River. These linear parks are part of a regional system that connects City and County parks and trails to large public reserves, such as Saguaro National Park. In addition, the west bank of the Santa Cruz River includes the trail alignment of the Juan Bautista de Anza National Historic Trail.

The Santa Cruz River is being recognized as an important community asset—as critical riparian habitat for wildlife, a gathering place for people, and a vital recreation link in the regional bike and trails system. Landfill clean up, protection of cultural resources, and recreational linkages and improvements will be important secondary benefits of ecosystem restoration within the study area.

Gila Basin Riparian Restoration Workshop: Summary

Duncan T. Patten, Department of Plant Biology, Arizona State University, Tempe

This paper summarizes the many ideas generated by the presentations and discussions at the Gila Basin Riparian Restoration Workshop. There are many details that will not be presented, but the general scheme of this paper includes comments on the following questions:

- What knowledge base is needed before attempting a restoration project?
- What approaches might be taken during implementation? and
- How might outcome and success be determined?

WATERSHED/ECOSYSTEM APPROACH SCALE CONSIDERATION

Riparian ecosystems and their associated streams often are a product of activities that take place at some distance in the stream's watershed Activities such as timber harvest, grazing and home building all alter hydrology of the watershed and thus have the potential to impact downstream ecosystems in some way. The cumulative effects of watershed modifications have a greater influence on stream reaches that are farther down the watershed and of higher stream order. Consequently, in restoration planning, scale of the restoration site, as well as scale or size of the upstream watershed, need to be taken into account. The bigger the watershed, the greater the potential for increasing numbers of interacting modifications of hydrology and water quality. Therefore, success of restoration is partially dependent on the size of the upstream watershed because correction of watershed modifications that influence downstream riparian integrity may nearly be impossible to achieve in large watersheds (Figure 1). When planning restoration activities, both the size of the watershed and the size of the reach to be restored must be part of the restoration planning and design model.

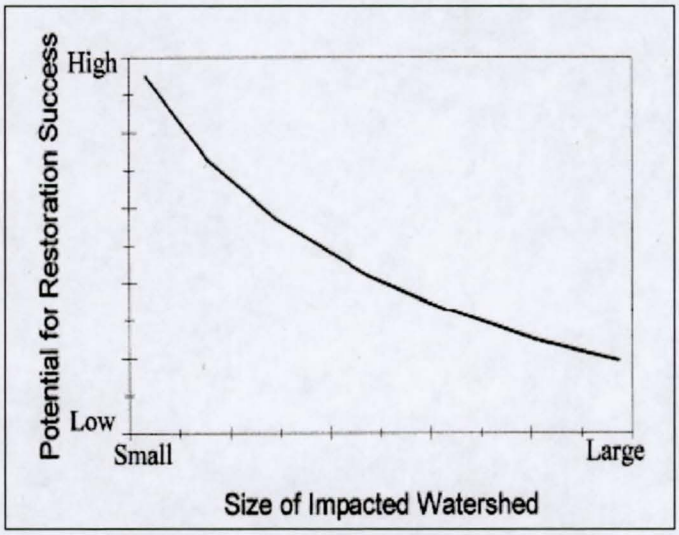


Figure 1.

UNDERSTANDING ECOSYSTEM STRUCTURE, FUNCTIONS, AND PROCESSES

Riparian ecosystems are complex because their structure, functions and processes are the result of responses of ecosystem components to many internal and external driving variables. External hydrology drives fluvial processes which create and alter the hydrogeomorphology of the river reach and thus the riparian recruitment sites and riparian biotic community. In turn, the existence and structure of the riparian community has a feed-back loop that influences the role of hydrological events on channel morphology (Figure 2). Riparian restoration planning needs to recognize the role of the many driving variables as well as the response mechanisms of the riparian ecosystem. This is fundamental information, without which riparian restoration efforts will likely fail.

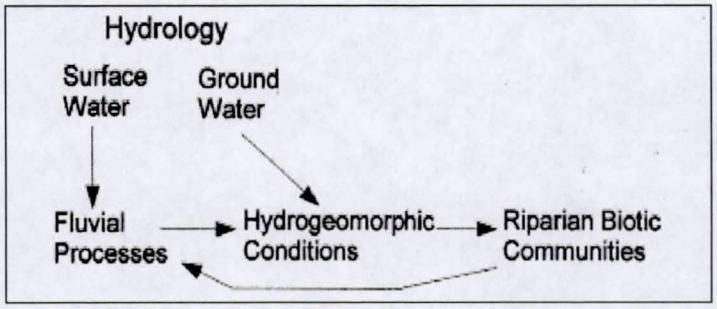


Figure 2.

Changes and Trends

Driving variables and the resultant riparian system are dynamic and change over time. It is important in planning a restoration program to understand what changes have taken place to the external variables in response to anthropogenic activities, as well as changes to the components of the altered riparian ecosystem. The trends of these changes are important background information to restoration planning. For example, how have hydrological patterns changed over the past fifty years relative to amount of summer and winter precipitation? How has the relative presence or abundance of exotic vs. native understory plant species changed?

Endpoints

Information on past and present conditions, provided by monitoring and other research programs, will show spatial and temporal trends of physical and biological attributes. Restoration planning must then consider the direction of future changes based on selection of endpoints of the restoration program. Realistic endpoints must be selected based on knowledge of the ability of future driving variables, including those altered by human activities, to produce an acceptable, restored ecosystem. It is unlikely in most riparian restoration efforts that all of the attributes and integrity of the past unaltered state can be restored. Endpoint goals thus must be carefully and realistically selected or the restoration effort will fail.

Response to Manipulation

Most riparian areas considered for restoration have been altered because of human manipulation of driving variables, including hydrology, channel morphology and species availability. In studies designed to understand how the system has changed over time, it is important to determine how the system might respond to future manipulation of external drivers. Understanding of system response to manipulation will come from a thorough database of ecosystem processes for that particular riparian system or through ecological modeling.

Reference Sites

If the riparian area to be restored is so altered that information obtained on riparian function and processes is inadequate for planning restoration goals and activities, studies should be undertaken in comparable ecosystems, reference sites, that are less altered, or better yet, not altered. Reference sites need to be carefully selected to ensure that features like valley morphology and basic hydrology are similar to the restoration location. Information on appropriate reference locations may already be available in the literature which should be searched prior to starting expensive studies at new reference sites.

Sustainability

Once reference site structure, function and processes are understood, and the relationship to the restoration site is determined, it should be possible to identify those attributes of the restoration site that, once restored, will be most resistant to future perturbations. The restoration effort should emphasize these attributes with the goal of creating a long-lasting, durable and sustainable riparian ecosystem. It is obvious, however, that by restoring only some of the system's attributes (recognizing that it will be impossible to restore all attributes), the resultant riparian ecosystem will not be equivalent to the one originally altered by human activity, but rather a sustainable, functional facsimile of the original.

UNDERSTANDING SYMPTOMS AND CAUSES OF DEGRADATION

One of the early steps in developing a restoration plan is understanding the causes of degradation and how the riparian ecosystem has changed (i.e., symptoms). An altered riparian system tends to remain altered if the causes of degradation, or stressors, remain in place. Their effects on the riparian system may change over time as other external variables change. Consequently, it is important to understand trends in the changes of the riparian attributes, as discussed above, as well as trends in changes of the stressors. For example, changes in natural stressors may include climatic changes, while anthropogenic stressors that could change because of management philosophy may include dam operations and downstream flow patterns.

IMPLEMENTATION OF RESTORATION: GOALS AND APPROACHES

Removing Stressors

Design of restoration programs should encourage recovery of as many natural processes as possible. This includes fostering processes that enhance the potential for natural regeneration or recruitment of riparian species. The simplest approach to achieving this goal is to remove as many stressors as possible. There may be one apparent stressor, such as an upstream dam, but secondary stressors develop as a result of the primary one, in this case including reduced nutrients, or invasion of exotic species in the moderated, reduced-flood environment. The greater the number of stressors that can be removed, or even partially corrected, the greater the potential for successful restoration of the riparian ecosystem (Figure 3).

If it is impossible to totally remove a stressor, or recreate a predisturbance condition, the next best approach is to mimic the "natural" process that has been altered by human intervention. Attempts to recreate "natural" floods downstream of dams is one example of mimicking nature, as is mechanically altering the channel margin to enhance seedling recruitment. The latter example is an active approach to restoration discussed below.

Passive Restoration

Restoration planning should consider both passive and active approaches. More than likely, a combination of these two approaches will be the best design. Passive restoration involves removing or changing some action, often a management action, to allow natural riparian dynamics to proceed. For example, changes in dam operations can return many natural hydrological processes. Altering grazing management, or removal of cattle from the riparian zone, may be all that is needed to restart the recruitment processes that result in a healthy riparian ecosystem. In both cases no active or mechanical activity was used to restore the system. Altering dam operations may not fully restore the downstream riverine ecosystem, but with proper planning, it may achieve most restoration goals.

Active Restoration

Active restoration includes invasive approaches to changing or removing stressors. For example, if an exotic species has invaded a riparian area and its presence inhibits recovery of native vegetation, fire, mechanical, or herbicide removal, or a combination, may be the best active approach. If following this mechanical approach grazing is removed from the river

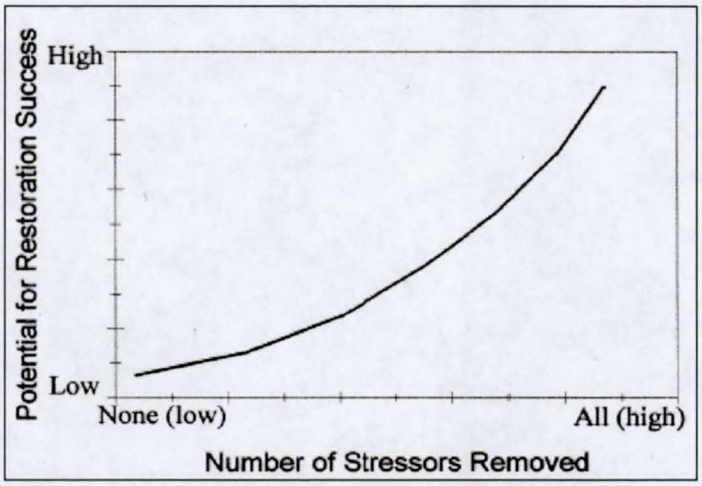


Figure 3.

system, the combination of active and passive restoration management actions may result in a successful restoration project. Other forms of active restoration may be applied to enhancing recruitment or reestablishment of native plant species. Mechanical shaping of the channel margin to form better recruitment sites, stabilizing erosive banks with soft vegetative materials, planting riparian trees or poles, or artificially flooding an area during seed dispersal are all examples of active restoration. It is obvious how these approaches, combined with simple changes in management of riverine resources might result in high levels of restoration success.

MONITORING

Long-term Monitoring

Every restoration project should include a comprehensive post-project monitoring program. This monitoring program should be as comprehensive as the programs established during the design phase of restoration which included site assessment and pre-restoration research. The monitoring program should also be sufficiently long-term to determine whether the restoration program is meeting the endpoint goals. There is not just one level of restoration success. Restoration planners and resource managers should agree at the onset on the level of success expected and also accepted. Monitoring will demonstrate not only how well the riparian ecosystem is recovering following use of the various approaches discussed above, but also how well the restoration program has removed or corrected the symptoms of degradation. One can anticipate that the more symptoms of degradation corrected, the greater the potential for restoration success (Figure 4). Not all symptoms can be corrected in a short-time frame. Consequently, the monitoring program must be sufficiently long, at least a decade and probably more, to track changes in those riparian ecosystem attributes that are slow to recover, but that will recover over time if the appropriate ecosystem processes are restored.

Secure Funding

Funding for monitoring may be part of the original restoration plan, but it usually is insufficient in amount, and budgeted short-term. When funds get tight during the actual restoration project period, future monitoring funds are often transferred into present restoration activities. This may result in an adequate restoration project, one that fulfills the original endpoint goals; however, without an adequate long-term monitoring program to follow active restoration, one will never know whether endpoint goals were met.

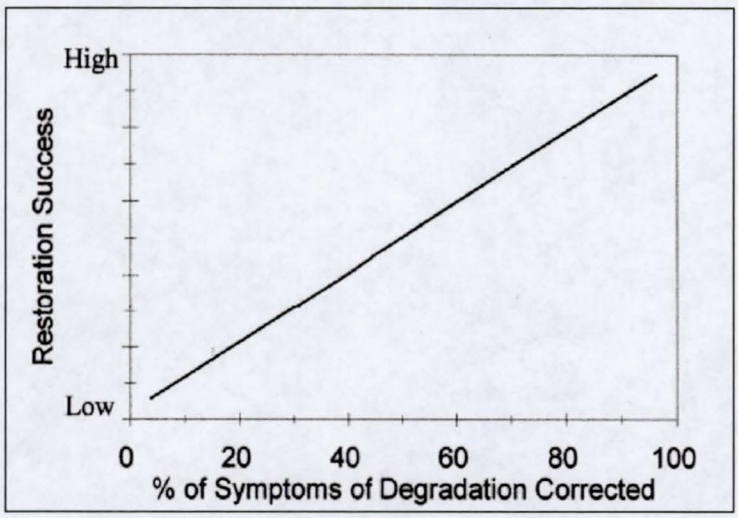


Figure 4.

Sources of Additional Information

INTRODUCTION

The reference list that follows was compiled from references provided by the authors of the sections above and by the editors. It is not intended to be a complete listing of all relevant sources, but a list of useful and easily available materials that may be of assistance in restoration work.

EXOTIC SPECIES

American Cynamid Company. 1994. Arsenal herbicide technical manual. 319 pp.

Anderson, B. 1998. The case for salt cedar. Restoration and Management Notes 16: 130-134.

Barrows, C. 1998. The case for wholesale removal. Restoration and Management Notes 16: 135-139.

Brock, J. H. 1994. *Tamarix* spp. (Saltcedar) an invasive exotic woody plant in arid and semi-arid riparian habitats of western USA. pp. 27-44. IN C. De Waal (ed.). Ecology and management of invasive riverside plants. J. Wiley & Sons. New York, N.Y.

Brotherson, J.D. and D. Field. 1987. Tamarix: Impacts of a successful weed. Rangelands 9:110-112.

Brotherson, J.D. and V. Winkel. 1986. Habitat relationships of saltcedar. (*Tamarix ramosissima*) in central Utah. Great Basin Naturalist 46:535-541.

Carman, J.G. and J.D. Brotherson. 1982. Comparison of sites infested and not infested with saltcedar (*Tamarix pentandra*) and Russian olive (*Eleagnus angustifolia*). Weed Science 30: 360-364.

Crawford, C.S. et al. 1993. Middle Rio Grande ecosystem: Bosque biological management Plan. Final report to the U.S. Fish and Wildlife Service. Albuquerque NM. 219 pp.

DeLoach, J.C. 1989. Saltcedar, a week of Western North American riparian areas: A review of its taxonomy, biology, harmful and beneficial values, and its potential for biological control. Final report for the Bureau of Reclamation, Lower Colorado Region. Boulder City. 296 pp.

DiTomaso, J.M. 1998. Impact, biology, and ecology of saltcedar (*Tamarix* spp.) In the southwestern United States. Weed Technology. 12:337-344.

Frasier, G.W. and T.N. Johnsen, Jr. 1991. Saltcedar (tamarisk): classification, distribution, ecology and control. 377-386. IN L.F. James et al. (Eds). Noxious range weeds. Westview Press. Boulder.

Horton, J.S. 1977. The development and perpetuation of the permanent tamarisk type in the phreatophyte zone of the Southwest. U.S.D.A. Forest Service Technical Report RM 43: 124-127.

Horton, J.S., F.C. Mounts and J.M. Kraft. 1960. Seed germination and seedling establishment of phyreatophyte species. Rocky Mountain Forest and Range Experiment Station. Ft. Collins. Paper #48.

Kerpez, T.A. and N.S. Smith. 1987. Saltcedar control for wildlife habitat improvement in the southwestern United States. USDA Fish and Wildlife Service Resource Publication 169. 16 pp.

Knopf, F.L. and T.E. Olson. 1984 Naturalization of Russian olive: Implications to Rocky Mountain wildlife. Wildlife Society Bulletin. 12(3): 289-298.

Olson, T.E., and F.L. Knopf. 1986 Naturalization of Russian olive in the western United States. West. Journal Applied Forestry 1 (3): 65-69.

Robinson, T. W. 1965. Introduction, spread, and area extent of saltcedar (*Tamarix*) in the western states. U.S. Geological Survey Professional Paper 491-A.

Shafroth, P. B., Auble, G. T., & Scott, M. L. 1995. Germination and establishment of the native plains cottonwood (*Populus deltoides* Marshall subsp. *monilifera*) and the exotic Russian olive (*Elaeagnus angustifolia* L.). Cons. Bio. 9(5):1169- 1175.

FLUVIAL PROCESSES AND GEOMORPHOLOGY

Collier, M.C., R.H. Webb and J.C. Schmidt. 1996. Dams and rivers. Primer on the downstream effects of dams. U.S. Geological Survey. Circular 1126. Tucson.

Gordon, N.D., T.A. McMahon, and B.L. Finlayson. 1992. Stream hydrology: an introduction for ecologists. John Wiley & Sons, New York, New York.

Graf, W. L. 1988. Fluvial processes in dryland rivers. Springer- Verlag, Berlin Heidelberg.

Harrelson, C.C., C.L. Rawlins, and J.P. Potyondy. 1994. Stream channel reference sites: An illustrated guide to field technique. U.S. Department of Agriculture, Rocky Mountain Forest and Range Experiment Station, General Technical Report RM-245, 61 pp.

Hedman, E.R. and W.R. Osterkamp. 1982. Streamflow characteristics related to channel geometry of streams in western United States. U.S. Geological Survey Water Supply Paper 2193. 17pp.

Heede, B.H., and J.N. Rinne. 1990. Hydrodynamic and fluvial morphologic processes: Implications for fisheries management and research. North American Journal Fisheries Management 10:249-268.

Hupp, C.R. 1985. The headward extent of fluvial landforms and associated vegetation on Massonutten Mountain, Virginia. Earth Surface Processes and Landforms. 11:545-555.

Leopold, L. B. 1994. A view of the river. Harvard University Press, Cambridge, MA.

Lewin, J. 1978. Floodplain geomorphology. Progress in Physical Geography 2:408-437.

Moody, Thomas O. and Wilbert Odem. 1999. Regional relationships for bankfull stage in natural channels of Central and Southern Arizona. Northern Arizona University, Flagstaff, Arizona. 37 pp.

Osterkamp, W.R. 1978. Gradient, discharge, and particle-size relations of alluvial channels in Kansas, with observations on braiding. American Journal of Science. 278:1253-1268.

Osterkamp, W.R. and C.R. Hupp. 1984. Geomorphic and vegetative characteristics along three northern Virginia streams. Geological Society of America Bulletin 5:1093-1101.

Rosgen, David L. 1996 Applied river morphology. Printed Media Companies, Minneapolis.

Scott M. L., J. M. Friedman, and G. T. Auble. 1996. Fluvial process and the establishment of bottomland trees. Geomorphology 14:327-339.

Wahl, K.L. 1977. Accuracy of channel measurements and the implications in estimating streamflow characteristics. Journal of Research U.S. Geological Survey 5:811-814.

Wallace, D.E. and L.J. Lane. 1976. Geomorphic thresholds and their influence on surface runoff from small semi-arid watersheds. Hydrology and Water Resources in Arizona and the Southwest. Office of Arid Land Studies. University of Arizona. Tucson. 6:169-176.

Wolman, M.G., and L.B. Leopold. 1957. River flood plains: some observations on their formation, p.87-107. Geological Survey Professional Paper 282-C, United States Printing Office, Washington.

JOURNALS—ENTIRE ISSUES DEDICATED TO RELEVANT TOPICS

Restoration Ecology, December 1997. Volume 5, number 4S.

Wetlands, December 1998. Volume 18, number 4.

OTHER

American Public Health Association. 1980. Standard methods for the examination of water and wastewater.

Belsky, A. J., A. Matzke, and S. Uselman. 1999. Survey of livestock influences on stream and riparian ecosystems in the western United States. Journal of Soil and Water Conservation 54: 419-431.

Green, D. M. and J. B. Kauffman. 1995. Succession and livestock grazing in a northeastern Oregon riparian ecosystem. Journal of Range Management 48:307-313.84.

Horner, R. and K. Raedeke.1989 Guide for Wetland mitigation project monitoring, Washington State Transportation Center (TRAC). University of Washington. JE-10. Seattle.

Knopf, F.L. and R.W. Cannon. 1982 Structural resilience of a willow riparian community to changes in grazing practices. J. M. Peek and P.D. Dalke, (ed.) 198-209. IN Wildlife-Livestock Relationships Symposium. University of Idaho Forest, Wildlife and Range Experiment Station Moscow.

Kulakowski, L. and B. Tellman. 1994 (2nd ed). Instream flow rights: A strategy for protecting Arizona's streams. Water Resources Research Center. The University of Arizona. Tucson.

Shaw, D. W. and D. M. Finch (eds.). Desired future conditions for southwestern riparian ecosystems: Bringing interests and concerns together. USDA Forest Service General Technical Report RM-GTR-272. Fort Collins.

Swetnam, T. W. and J. L. Betancourt. 1998. Mesoscale disturbance and ecological response to decadal climatic variability in the American Southwest. Journal of Climate 11: 3128-3147.

Tellman, Barbara, Yarde, Richard, and Wallace, M.G. 1997. Arizona's changing rivers: how people have affected the rivers. Water Resources Research Center. The University of Arizona. Tucson. 200 pp.

Tellman, Barbara, Yarde, Richard, and Wallace, M.G. 1996. Where to find information about the history of Arizona's's rivers. Water Resources Research Center. The University of Arizona. Tucson. Computer disk bibliography.

World Wildlife Fund. 1992. Statewide wetlands strategies. A guide to protecting and managing the resource. Island Press. Washington. 268 pp.

PROCEEDINGS

Abell, D. L. (technical coordinator) Proceedings of the California Riparian Systems Conference: Protection, management, and restoration for the 1990s; September 22-24, Davis, California. General Technical Report PSW-110. U.S. Department of Agriculture, Pacific Southwest Forest and Range Experiment Station, Berkeley.

Johnson, R.R. and D.A. Jones, (eds.) Importance, preservation, and management of riparian habitat: A symposium, U.S. Department of Agriculture Forest Service General Technical Report RM-43. Rocky Mountain Forest and Range Experimental Station, Fort Collins.

Johnson, R.R., et al. 1985. Riparian ecosystems and their management: Reconciling conflicting uses. USDA Forest Service Technical Report RM-120.

Kunzman, Michael, R.R. Johnson, and P.S. Bennett. 1987. Tamarisk control in southwestern United States. Proceedings of tamarisk conference. University of Arizona and National Park Service. 144 pp.

Olsen, D. S. and J. P. Potyondy (editors). 1999. Proceedings Specialty Conference Wildland Hydrology, June 30-July 2, 1999, Bozeman, Montana. Wildland Hydrology, American Water Resources Association, Herndon, Virginia, TPS-99-3, 536 pp.

Patton, P.F. Ffolliott, and R.H. Hamre, (technical coordinators). Riparian ecosystems and their management: Reconciling conflicting uses. USDA Forest Service General Technical Report RM-120. 523 pp.

Tellman, Barbara, Cortner, H. J., Wallace, M. G., and DeBano, L. F. (Technical Coordinators). 1993, Riparian management: common threads and shared interests. USDA Forest Service General Technical Report RM 226 U.S. Department of Agriculture. 419 pp.

RESTORATION

Anderson, B.W. 1989. Research as an integral part of revegetation projects, p.413-419. IN D.L. Abell (technical coordinator). Proceedings of the California Riparian Systems Conference: Protection, management, and restoration for the 1990s. September 22-24, Davis, California. General Technical Report PSW-110. U.S. Department of Agriculture, Pacific Southwest Forest and Range Experiment Station, Berkeley.

Anderson, B.W. and R.D. Ohmart. 1982. Revegetation and wildlife enhancement along the Lower Colorado River. U.S. Department of the Interior, Bureau of Reclamation. Contract No. 7-07-30-V0009. 215 pp.

Aronson , J., C. Floret, E. Le Floc'h, C. Ovalle, and R. Pontanier. 1993. Restoration and rehabilitation of degraded ecosystems in arid and semi-arid lands. I. A view from the south. Restoration Ecology 1(1): 8-17.

Bonham, C.D. 1989 Measurements for terrestrial vegetation. John Wiley & Sons, New York. 338pp.

Born, S. M., K. D. Genskow, T. L. Filbert, N. Hernandez-Mora, M. L. Keefer, and K. A. White. 1998. Socioeconomic and institutional dimensions of dam removals: The Wisconsin experience. Environmental Management 22: 359-370.

Briggs, M. 1996. Riparian ecosystem recovery in arid lands: Strategies and references. University of Arizona Press, Tucson, Arizona.

Briggs, M. and S. Cornelius. 1998. Opportunities for ecological improvement along the lower Colorado River and delta. Wetlands 18:513-529.

Briggs, M. K., B. A. Roundy, and W. W. Shaw. 1994. Assessing the effectiveness of riparian revegetation in Arizona. Restoration and Management Notes 12:160-167.

Brown, S.C. and B. L. Bedford. 1997. Restoration of wetland vegetation with transplanted wetland soil: An experimental study. Wetlands 17: 424-43

Cairns, J. ed. 1980. The recovery process in damaged ecosystems. Ann Arbor Science Publishers, Inc. Ann Arbor.

Coutant. 1996. A general protocol for restoration of regulated rivers. Regulated Rivers: Research and Management 12: 391-413.

DeBano, L.F., and L.J. Schmidt. 1990. Potential for enhancing riparian habitats in the southwestern United States with watershed practices. Forest Ecology and Management 33/34:385-403.

Falk, Donald A., M.K. Briggs, and W.K. Halvorson. 1998. R3 the riparian restoration ranking (R3) system users' manual. Society for Ecological Restoration. 45 pp + appendices. Available from the U.S. Forest Service. Albuquerque.

Federal Interagency Stream Restoration Working Group. 1998. Stream corridor restoration: Principles, processes, and practices. U.S. Department of Commerce, National Technical Information Service, Springfield, VA.

Friedman, J. M., M. L. Scott, and W. M. Lewis, Jr. 1995. Restoration of riparian forest using irrigation, artificial disturbance, and natural seedfall. Environmental Management 9:547-557.

Glass, Steve 1989 The role of soil seed banks in restoration and management. Restoration and Management Notes 7(1):24-29. Society for Ecological Restoration, Madison, Wisconsin.

Hill, M. T. and W. S. Platts. 1998. Ecosystem restoration: A case study in the Owens River Gorge, California. Fisheries 23: 18-27.

Jordon, W.R. and ME. Gilpin, and J.D. Aber, eds. (pp.53-74) Restoration ecology: A synthetic approach to ecological research. Cambridge University Press, Cambridge, England.

Middleton, B. 1999. Wetland restoration: Flood pulsing and disturbance dynamics. New York: John Wiley and Sons.

Molles, M.C., C. S. Crawford, L. M. Ellis, H. M. Valett, and C. N. Dahm 1998. Managed flooding for riparian ecosystem restoration —Managed flooding reorganizes riparian forest ecosystems along the middle Rio Grande in New Mexico. BioScience 48: 749-756.

Ohmart, R.D. and B.W. Anderson. 1986. Riparian habitat. 169-199. IN Inventory and monitoring of wildlife habitat. U.S. Dept. Inter., Bureau of Land Management Service Center. Denver, Co. xviii, 858 pp.

Pastorok, R. A., A. MacDonald, J. R. Sampson, P. Wilber, D. J. Yozzo, and J. P. Titre. 1997. An ecological decision frame-work for environmental restoration projects. Environmental Engineering 9:89- 107.

Pinkney, F.C. 1992. Revegetation and enhancement of riparian communities along the Lower Colorado River. Bureau of Reclamation, Denver, CO. 187 pp.

Poff, N. L., J. D. Allan, M. B. Bain, J. R. Karr, K. L. Prestegaard, B. D. Richter, and J. C. Stromberg. 1997. The natural flow regime: A paradigm for river conservation and restoration. BioScience 47: 769-784.

Riley, A. L. 1998. Restoring streams in cities: A guide for planners, policy makers, and citizens. Island Press, Washington D.C.

Roelle, J. E., and D. N. Gladwin. In press. Establishment of woody riparian species from natural seedfall at a former gravel pit. Shuman, J. R. 1995. Environmental considerations for assessing dam removal alternatives for river restoration. Regulated Rivers - Research and Management 11: 249-261.

Stanford, J. A., J. V. Ward, W. J. Liss, C. A. Frissell, R. N. Williams, J. A. Lichatowich, and C. C. Taylor, J.P. and K.C. McDaniel. 1998. Restoration of saltcedar (Tamarix sp.)-infested floodplains on the Bosque del Apache National Wildlife Refuge. Weed Technology. 12:345-352.

Swenson, E.A. and C.L. Mullins. 1985. Revegetating riparian trees in southwestern floodplains. IN Riparian Ecosystems and Their Management: Reconciling conflicting uses (First North American Riparian Conference, April 16-18, 1985, Tucson, Arizona), coordinated by R.R. Johnson, C.D. Siebell, D.R. Patton, P.F. Ffolliot, and R.H. Hamre, 135-139. USDA Forest Service General Technical Report RM-120. Rocky Mountain Forest and Range Experiment Station. Fort Collins.

Taylor, J.P., Wester, D.B., and L.M. Smith. 1999. Soil disturbance, flood management, and riparian woody plant establishment in the Rio Grande floodplain. Wetlands 19:372-382.

Thompson, William H., Robert C. Ehrhart, Paul L. Hanson, Thomas G. Parker, and William C. Haglan. 1998. Assessing health of a riparian site. IN Proceedings AWRA Speciality conference on rangeland management and water resources May 27-29, Reno, Nevada. American Water Resources Association. 3-12.

Wolden, L. G. and J. C. Stromberg. 1997. Restoration of an arid- region, riparian herbaceous understory. Restoration and Management Notes 15:161- 167.

RIPARIAN ECOLOGY

Auble, G. T., M. L. Scott, J. M. Friedman, J. Back, and V. J. Lee. 1997. Constraints on establishment of plains cottonwood in an urban riparian preserve. Wetlands 17:138-148.

Bradley, C. E., and D. G. Smith. 1986. Plains cottonwood recruitment and survival on a prairie meandering river floodplain, Milk River, southern Alberta and northern Montana. Canadian Journal of Botany 64:1433-1442.

Busch, D.E. 1995. Effects of fire on southwestern riparian plant community structure. Southwestern Naturalist 40(3): 259-267.

Fenner, P., W.W. Brady, and D.R. Patton. 1984. Observations on seeds and seedlings of Fremont cottonwood. Journal of Desert Plants 6:55-58.

Friedman, J. M., M. L. Scott, and G. T. Auble. 1997. Water management and cottonwood forest dynamics along prairie streams. Ecological Studies 125:49-71.

Friedman, J. M., W. R. Osterkamp, and W. M. Lewis, Jr. 1996. Channel narrowing and vegetation development following a Great Plains flood. Ecology 77:2167-2181.

Gladwin, D. N. and J. E. Roelle. 1998. Survival of plains cottonwood (*Populus deltoides* subsp. *monilifera*) and saltcedar (*Tamarix ramosissima*) seedlings in response to flooding. Wetlands 18: 669- 674.

Gregory, S.V., F.J. Swanson, W.A. McKee, and K.W. Cummins. 1991. An ecosystem perspective of riparian zones. BioScience 41:540-551.

Hupp, C. R. 1992. Riparian vegetation recovery patterns following stream channelization: A geomorphic perspective. Ecology 73:1209-1226.

Johnson, W. C. 1994. Woodland expansion in the Platte River, Nebraska: Patterns and causes. Ecological Monographs 64:45-84.

Johnson, W.C. 1992. Dams and riparian forests: Case study from the upper Missouri River. Rivers 3:229-242.

Johnson, W. C., R. L. Burgess, and W. R. Keammerer. 1976. Forest overstory vegetation and environment on the Missouri River floodplain in North Dakota. Ecological Monographs 46:59

Mahoney, J. M. and S. B. Rood. 1998. Streamflow requirements for cottonwood seedling recruitment—an integrative model. Wetlands 18: 634-645.

McBride, J.R., and J. Strahan. 1984. Establishment and survival of woody riparian species on gravel bars of an intermittent stream. The American Midland Naturalist 112:235-245.

Naiman, R. J. and H. Decamps. 1997. The ecology of interfaces: Riparian zones. Annual Review of Ecology and Systematics 28:621- 658. Rood, S. B., J. M. Mahoney, D. E. Reid, and L. Zilm. 1995. Instream flows and the decline of riparian cottonwoods along the St. Mary River, Alberta.. Canadian Journal of Botany 73: 1250-1260.

Rood S. B, A. R. Kalischuk, and J. M. Mahoney. 1998. Initial cottonwood seedling recruitment following the flood of the century of the Oldman River, Alberta, Canada. Wetlands 18: 557-570.

Segelquist, C. A., M. L. Scott, and G. T. Auble. 1993. Establishment of *Populus deltoides* under simulated alluvial groundwater declines. American Midland Naturalist 130:274-285.

Shafroth, P. B., G. T. Auble, J. C. Stromberg, and D. T. Patten. 1998. Establishment of woody riparian vegetation in relation to annual patterns of streamflow, Bill Williams River, Arizona. Wetlands: 18: 577-590.

Scott, M. L., G. T. Auble, and J. M. Friedman. 1997. Flood dependency of cottonwood establishment along the Missouri River, Montana, USA. Ecological Applications 7:677-690.

Stromberg, J.C., B.D. Richter, D.T. Patten and L.G. Wolden. 1993 Response of a Sonoran riparian forest to a 10-year return flood. Great Basin Naturalist 53(2): 118-130.

Stromberg, J. 1998. Dynamics of Fremont cottonwood (*Populus fremontii*) and saltcedar *(Tamarix chinensis*) populations along the San Pedro River, Arizona. Journal of Arid Environments 40: 133-155.

Ohmart, R.D., B.W. Anderson, and W.C. Hunter. 1988. The ecology of the Lower Colorado River from Davis Dam to the Mexico-United States International Boundary: A community profile. U.S. Fish and Wildlife Service Biological Report Number 85(7.19). 296 pp.

Szaro, R.C. 1989. Riparian forest and scrubland community types of Arizona and New Mexico. Desert Plants 9:69-138.

Szaro, R.C. 1990 Southwestern riparian plant communities: Site characteristics, tree species distributions, and size-class structures. Forest Ecology and Management 33-34:315-334.

Zimmerman, R.C. 1969. Plant ecology of an arid basin, Tres Alamos-Redington area, southeastern Arizona. U.S. Geological Survey Professional Paper 485-D, 51pp.

WILDLIFE

Dawson, D. G. 1981 Experimental design when counting birds. 392-398 IN C. J. Ralph and J.M. Scott (eds.). Estimating the numbers of terrestrial birds. Studies in Avian Biology 6.

Ellis, L.M. C.S. Crawford and M.C. Molles, Jr. 1997 Rodent communities in native and exotic riparian vegetation in the middle Rio Grande Valley of central New Mexico. Southwestern Naturalist 42(1): 13-19.

Jakle, M.D. and T.A. Gatz. 1985 Herpetofaunal use of four habitats of the middle Gila River drainage, Arizona. 355-358 IN Johnson, R.R., et al. 1985. Riparian Ecosystems and their management: Reconciling conflicting uses. USDA Forest Service Technical Report RM-120.

Lambeck, R. J. 1997. Focal species: A multi-species umbrella for nature conservation. Conservation Biology 11: 849-856.

Nelson, S.M. and D.C. Andersen. 1994 An assessment of riparian environmental quality by using butterflies and disturbance susceptibility scores. Southwestern Naturalist. 39(2): 137-142.

Ohmart, Robert D. and Bertin W. Anderson. 1986. Riparian habitat in monitoring wildlife habitat, Bureau of Land Management. Phoenix

U.S. Bureau of Reclamation. 1998. Long term restoration program for the historical southwestern willow flycatcher (*Empidonax traillii extimus*) habitat along the Lower Colorado River. Bureau of Reclamation, Boulder City, NV. 70 pp.

Wiens, J.A. and J.T. Rotenberry. 1981. Censussing and the evaluation of avian habitat occupancy. 522-532. IN Ralph, C.J and J.M. Scott (eds.). Estimating the numbers of terrestrial birds. Studies in Avian Biology 6.

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