Guidelines for Establishing Monitoring Programs to Assess the Success of Riparian Restoration Efforts in Arid and Semi-arid Landscapes

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PURPOSE

This technical note is a product of the Ecosystem Management and Restoration Research Program (EMRRP) work unit titled "Techniques for Reestablishing Riparian Hardwoods in Arid and Semi-arid Regions." The objectives of this work are to provide technology to improve capabilities of restoring riparian areas in arid and semi-arid regions. The work unit focuses on site evaluation and selection, hardwood species selection, planting techniques, and long-term monitoring protocols. This technical note supports the Corps' mission of ecosystem restoration as well as established environmental operating principles by promoting ecosystem sustainability and recognizing the interdependence of life and the physical environment. This publication addresses the establishment of a monitoring program to gauge progress toward meeting restoration project objectives.

Figure 1. Healthy riparian areas in the Southwest support diverse plant and wildlife communities and perform numerous important ecological functions

INTRODUCTION

The rehabilitation and restoration[2] of riparian ecosystems is a focal issue for many organizations and agencies, including the U.S. Army Corps of Engineers (National Research Council 1992, Fischer 2002). Most riparian ecosystems in the arid and semi-arid western United States

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[2] *Rehabilitation* is returning an ecosystem to a similar, but not identical, pre-disturbance condition (e.g., return a portion of the functions, but not all). *Restoration* is defined as the process of returning an ecosystem to a natural pre-disturbance structure and function (Briggs 1996).

have been significantly degraded, with losses approaching 99 percent in some areas (Briggs 1996). The tools and techniques available to assist with rehabilitating and managing these ecosystems have increased dramatically (National Research Council 2002, Perrow and Davy 2002), improving our ability to restore or enhance numerous physical, chemical, and ecological functions (Figure 1). Monitoring programs provide critical information that allows managers to assess restoration success and to modify future efforts to more effectively return pre-disturbance structure and function to these systems (Davis and Muhlberg 2002). One way to assess success is to investigate changes in various structural characteristics and functional processes over time, preferably in conjunction with a comparison of a nearby undisturbed (or high-quality) riparian reference site (Smith et al. 1995, Davis and Muhlberg 2002). Appropriate metrics to measure progress toward these objectives should then be developed and monitored between restored and reference sites. In the absence of a reasonable reference site, managers may have to monitor and determine restoration success using before/after comparisons, or devise specific measurement goals of plant and animal community metrics (perhaps based on historical records for the area) (Kondolf and Micheli 1995). Metrics often include parameters associated with floral and/or faunal communities, but may also include a variety of physical characteristics (e.g., channel width to depth ratio) or chemical processes (e.g., carbon input to stream).

Reasons for Riparian Rehabilitation and Restoration

Impacts of human activities have had drastic, and largely damaging, effects on the structure, functions, and integrity of arid and semi-arid riparian ecosystems throughout the southwestern United States (Figure 2). Channel diversions and construction of dams and dikes have reduced or eliminated natural stream meandering, created deeply incised channels, reduced groundwater levels and severely altered natural stream and river hydrologic processes (Briggs 1995, 1996). Water storage in reservoirs for water supply and flood reduction, for example, have decreased flood frequency in many western rivers and streams, which has reduced or eliminated the formation of sandbars that constitute prime seedling habitat for regenerating stands of native cottonwood (*Populus* spp.) and willow (*Salix* spp.). In this degraded state, conditions become optimal for the invasion of saltcedar (*Tamarix* spp.) and other non-native plant species that can out-compete native vegetation. In highly degraded systems, overall diversity of native plants and animals is greatly reduced, and many southwestern wildlife species dependent on riparian habitats are threatened or endangered, or are experiencing long-term population declines.

Figure 2. Human activities such as off-road vehicle travel have significantly degraded many southwestern riparian habitats

Types of Restoration and Rehabilitation Efforts

Numerous techniques, including bioengineered bank stabilization, placement of in-stream structures, and various planting regimes, have been developed to rehabilitate riparian systems. Current rehabilitation strategies fall into three basic categories (Stromberg 2000a): (1) *Passive* – refers to efforts that restore a more natural hydrologic regime by either removing existing dam and dike structures, controlling water releases to mimic the rate and temporal patterns of the natural hydrologic regime, or removing significant sources of degradation such as overgrazing by livestock. Rehabilitation and revegetation of riparian areas is then left to occur naturally through succession. (2) *Active* – refers to efforts that use mechanical means to prepare the site, followed by planting or seeding. Often such efforts require structures that stabilize streambanks and protect the planted vegetation from erosion and herbivores. Active methods of rehabilitation are typically necessary for adequate plant growth when the natural hydrology cannot be restored, when propagules are absent, or where invasive plants may outcompete native plants. Other active methods include reintroducing mycorrhizal inoculum in areas where long-term dewatering of the system has occurred. Similarly, rather than using intensive hand-planting, seed banks obtained from high-quality reference sites may be useful to restore plant diversity to degraded sites; however, soil seed banks often lack seeds of woody plants; therefore some manual planting may still be necessary. (3) *Combination of Passive and Active* - refers to rehabilitation efforts that use both techniques. It is often not possible to "restore" a riparian system to an original "undisturbed" state; however, a functional and sustainable riparian system can still be attained through rehabilitation. Such efforts might include timing of water release from dams that create some suitable substrate for revegetation, yet manual seedbed creation and planting may still be required to achieve desired results.

Getting Started

Before developing a monitoring protocol for any riparian rehabilitation effort, potential sites must first be selected and evaluated for rehabilitation potential. First and foremost, causes of water quality and streamside habitat degradation must be identified, understood, controlled, or possibly eliminated (Briggs 1995, Holl and Cairns 2002). In some cases, sources of degradation such as non-point source pollution can be reduced through buffer strips (Fischer and Fischenich 2000) or other means. Briggs (1996) noted that the ability of some riparian sites to recover in Arizona was more related to the removal of the critical cause for site degradation than it was to the actual revegetation effort. Rehabilitation of riparian areas where damaging activities (e.g., development or agricultural expansion) have not been adequately addressed may not succeed since the primary cause of the degradation will compromise any potential success (Fischenich 2000). Also, land-use activities far from rehabilitation sites (i.e., upstream or in upland areas of the watershed) may still compromise restoration efforts; therefore, the assessment of any site for rehabilitation should take potential landscape level impacts of the entire watershed into consideration. Potential project sites should also be investigated for their relative condition, conduciveness to meet project goals, ability to withstand high flow events, and past/present/future land uses at and adjacent to the site (Briggs 1996, Perrow and Davy 2002).

Depth to groundwater is another important factor in determining whether a project will be successful. Most plants in arid riparian areas cannot be successfully established without irrigation if groundwater is >3 m from the surface (Stromberg 2000a).

The general process for implementing riparian restoration and monitoring is outlined below in five basic steps. These include: (1) setting goals and objectives, (2) developing a monitoring protocol, (3) designing and implementing data collection, (4) analyzing and interpreting monitoring data, and (5) assessing restoration efforts. Specific details of these steps are discussed below, and the essential ideas are outlined in Table 1.

Step 1. Setting Goals and Objectives

Once a site has been selected, setting clearly defined goals and objectives can lead to development of a concise suite of evaluation criteria (Kondolf and Micheli 1995, Perrow and Davy 2002). Identifying the key goals and objectives of a project is paramount to assessing success. In general, most goals of restoration efforts are to return a degraded riparian ecosystem to its pre-disturbed state. Specific ecological features of a pre-disturbed state may be characterized quantatively using a nearby or regionally acceptable reference site (Davis and Muhlberg 2002, Davis et al. 2001). These quantified characteristics can then act as guideline measurement targets for the restoration effort. In the absence of a reasonable reference site, quantifiable measurable targets of the restoration success may need to be formulated through estimates based on historical records for the region. After passive/active restoration efforts have been completed, a well-designed and implemented monitoring program is needed to document that functional ecological processes are progressing on the restored site according to restoration objectives.

To meet project goals, objectives should include a realistic list of desired or enhanced functions (e.g., improve water quality or wildlife habitat) or structural characteristics. Specific goals or

Table 1. Basic Steps in Restoring and Monitoring Functions of Riparian Areas

Basic steps	Process	Example
1) Establish goals and objectives	State reasons for restoration effort	Return of habitat for breeding birds
2) Develop a monitoring protocol	Identify habitat (flora and fauna) variables of interest	Plant and bird community data
3) Design and implement data collection effort	Establish sampling design, number of plots, and frequency of effort	Stratified random bird and habitat survey plots throughout the riparian area
4) Analyze and interpret data conduct	Use statistical comparisons or other methods	Analysis of variance between restored area and reference site
5) Final assessment	Interpret results; compare with reference sites	Successful increase in vegetation structure and bird community richness indicates a successful effort

measurement targets will vary from site to site, and should account for potential impediments such as altered hydrology, unfavorable soil type, current land-use pressures, and economic considerations that may limit success. For example, it may be virtually impossible to remove all non-native plant species on a degraded site. Therefore, one goal may involve improving conditions for native species so that persistence of exotic species is reduced. Similarly, complete restoration of hydrologic functions of a river system to pre-disturbance water flows may be an unattainable goal due to current demands on the water resource. However, improved hydrologic function may still be accomplished through watershed-level efforts (e.g., upland reforestation), which in turn may improve riparian habitat for more diverse and sustainable plant and wildlife communities.

Restoration and monitoring goals should be achieved in phases. The first goal should be to restore to the fullest extent possible a more natural hydrologic flow regime. A proper hydrologic regime is likely the most important factor influencing the ability to meet specific objectives associated with stream/riparian structure and function, and is necessary to maintain a functional riparian area following a rehabilitation project (Stromberg 2000b, 2000c, 2000d; Briggs 1996). Better conditions should then exist for the regrowth of a native plant community, either through natural regeneration or manual planting. The second goal should be the reestablishment of plant communities of the proper species composition, width, vertical complexity, and age categories throughout the area to be restored. For example, newly restored plant communities should assist in capturing nutrients and forming organic soil layers, stabilizing streambanks, and creating early-successional wildlife habitat (Stromberg 2000b). Finally, rehabilitation of the native plant community should form the structural foundations for supporting viable native wildlife populations. The reestablishment of diverse and viable plant and animal communities is an important feature determining a successful restoration effort (Davis et al. 2001, Kondolf and Micheli 1995).

Step 2. Developing a Monitoring Protocol

Monitoring plant communities and a variety of mammalian, avian, reptilian, amphibian and fish populations may be cost-prohibitive or too labor-intensive. Therefore, focusing on vegetation and one vertebrate group, or selecting one or more focal species of local interest, is often a more reasonable and cost-effective way to determine degree of success (Davis et al. 2001, Da Silva and Vickery 2002, Holl and Cairns 2002). Focal species should serve as indicators of habitat quality, therefore an increase in the presence and/or abundance of these organisms should reflect an improvement during the restoration process. In some cases, focal species may be regional or local species listed as endangered, threatened, or of special concern.

- Developing a list of characteristics to monitor.

  Ideally, a monitoring protocol should be developed and baseline data collected before the project begins. These baseline data may help planners in determining reasonable goals and measurement targets to achieve during the restoration process, and achievement of these goals then can be verified through post-project monitoring. Any riparian rehabilitation project should include vegetation monitoring. To monitor faunal community response to vegetation changes, avian communities may be the easiest taxonomic group to monitor because birds are conspicuous and relatively easy to identify. However, mammal, fish or herpetofaunal communities may also be important, and various protocols exist for their sampling (e.g., Heyer et al. 1994, Wilson et al. 1996, Morrison 2002). Species or species groups selected for monitoring will likely depend on stated objectives for specific sites.

  When developing a list of metrics to characterize floral or faunal communities, several factors should be considered:

  - What is the appropriate method to use?
  - What metrics are appropriate for assessing goals?

- Where and how are sampling plots to be located?
- How many plots are to be sampled?
- How many persons will be required to collect, enter, analyze, and interpret monitoring data?
- How often will the plots need to be sampled (once a year or seasonally; every other year)?

- Data to collect

Stream morphology/water quality. Numerous methodologies have been developed to assess stream morphology and water quality (Davis et al. 2001). A rapid assessment procedure that focuses on the hydrogeomorphic structure of riparian systems (Smith et al. 1995) may provide managers and planners with useful places to start. Specific aspects of stream morphology can be useful to compare between impacted areas and non-impacted reference sites, and may provide important aspects of stream structure and function that need to be restored. Morphological aspects of riparian ecosystems that may be considered include:

- Channel slope.
- Stream depth and velocity.
- Substratum material.
- Stream discharge.
- Temperature and solar radiation.
- Local and/or regional topography and geology.

Numerous aquatic and terrestrial organisms require a source of un-contaminated fresh water. Therefore, restoration of riparian ecosystems must often assess aspects of water quality. Numerous standardized methods of determining water chemistry are available and summarized in Davis et al. (2001). Important aspects of water quality generally include:

- Alkalinity.
- Hardness.
- pH.
- Specific conductance.
- Turbidity.
- Concentration of potential pollutants (nitrates, phosphorus, etc.).

Plant communities: During the first year after revegetation efforts have begun, newly forming plant communities should be monitored to assess initial survival of plants. This should be done after the first year or at the end of the first growing season. Herbaceous species may need to be sampled at least twice a year (Stromberg 2000b, 2000c, 2000d). As plants become established, monitoring efforts may be conducted on a biannual or longer time frame. Time interval between sampling efforts may differ regionally, and will likely depend on the plant species present and factors such as annual rainfall and climate. Monitoring efforts may also seek to identify and remove any invasive species (e.g., saltcedar) that threatens establishment of a native plant community. Specific variables that will need to be collected to provide an index of the type and structure of the plant community include (from Anderson and Ohmart (1986), Causton (1988)):

- Number[1] and species diversity of overstory trees ($\geq$20 cm dbh).
- Number and species diversity of mid-story trees (>5-19 cm dbh).
- Number and species diversity of understory trees and saplings ($\leq$5 cm dbh).

[1] Frequency of occurrence may be substituted for raw numbers; also, raw numbers may be converted to density or basal area estimates.

- Number and species diversity of shrubs.
- Species richness and percent cover of herbaceous species.
- Overall plant density as measured by a density board (approx. 3 m in height) or pole.
- Canopy height.
- Canopy cover.

Vertebrate Communities: Most vertebrate communities can show considerable annual variation, especially in a newly restored area that is changing due to successional processes. Therefore, most vertebrate surveys will need to be conducted at least annually, and perhaps seasonally, depending on the restoration goals. When investigating bird communities, most species of interest (e.g., of conservation concern) in the arid Southwest are those dependent on riparian areas either for migratory stopover habitat or for breeding (Powell and Steidl 2000). Therefore, surveys only need to be conducted during summer, and perhaps spring and fall migration. There is, however, growing interest from the scientific community in monitoring winter bird communities, which suggests that this time period may also be critical for population health and sustainability (Askins et al. 1990, Gutzwiller 1991). The specific season(s) selected for monitoring efforts will depend upon site-specific objectives of the restoration effort. Specific variables that should be collected include relative abundance of all bird species, and species richness and/or diversity of the bird community.

In some cases, more detailed information (particularly concerning species of conservation concern) may be needed to gauge progress toward meeting restoration goals. For example, simply monitoring the return of a focal species to a restored site does not indicate that the individual is part of a sustainable viable population (e.g., the species is breeding successfully to offset annual mortality) (Krebs 1989). In some situations, detection of a focal species may represent an unmated individual. Even if a breeding attempt by the focal species on the restored site is confirmed, reproductive success is not ensured.

If riparian restoration goals include return of a viable population of an endangered or sensitive species, for example the federally endangered Southwestern Willow Flycatcher (*Empidonax traillii extimus*), then a more intensive and costly monitoring protocol will be needed. In this case, determining population viability will include the collection of a different suite of ecological and life-history variables, such as:

- Number of breeding pairs.
- Number of territories per habitat patch.
- Mean number of eggs per nest.
- Mean number of successful young hatched and fledged per nest; a nest is generally considered successful when at least one young is successfully fledged (Mayfield 1975).
- Estimate of rate of return by breeding individuals (birds will have to be captured and color-banded for identification).
- Estimate of mortality (mortality of adults can be indexed by the number of adults that fail to return or that cannot be relocated in subsequent years).

Efforts to monitor populations of the Southwestern Willow Flycatcher provide an excellent example (Finch and Stoleson 2000).

Step 3. Implementing a Monitoring Design and Protocol

Establishing sampling plots is an essential component of ecological monitoring and research. Within these plots, count data of specific ecological metrics are collected to estimate the physical and biotic components of the restoration and reference sites. Monitoring efforts involve regularly collecting quantitative and/or qualitative data from established sampling plots. Since it is generally impossible to quantify all aspects of an ecosystem, or even a single study area, data collected from these sampling plots represent 'samples' of the area from which the ecological features can be determined and compared to other areas. In order to achieve an accurate representation of the ecological characteristics of an area, one will need to determine the best size, shape, number, and distribution of sampling plots. Also, basic time and frequency protocols of the sampling effort must be determined.

- Plot characteristics

The size and shape of sampling plots often vary depending upon the ecological community being monitored. Plant communities are most often sampled using square to rectangular quadrats (Krebs 1989). Determining the best size and shape of sampling quadrats for monitoring may be accomplished by reviewing the literature for prior studies conducted within the same or similar habitat types. One may also conduct a pilot study that uses plots of varying shapes and sizes, and then determine the quadrat size that yields data with the best balance of low variability and cost of the sampling effort. Statistical procedures that can help identify optimal quadrat size and shape from pilot study data are summarized by Causton (1988), Ludwig and Reynolds (1988) and Krebs (1989).

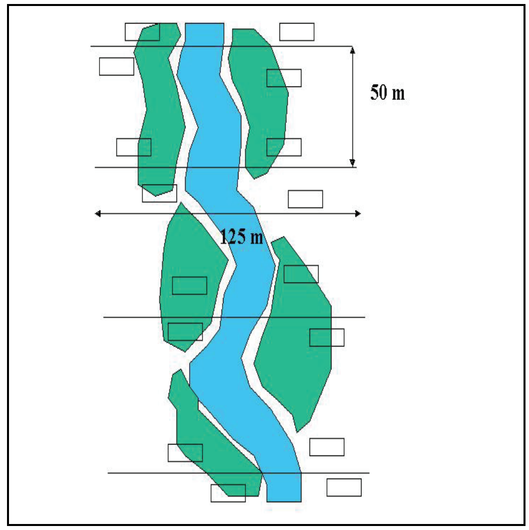

Figure 3. An example of a randomized sampling approach, where sampling quadrats are located randomly along transects. Transects should be spaced approximately 50 m apart and should be long enough to cover the width of the riparian zone (Stromberg 2000a)

Monitoring vertebrate populations may include the establishment of a grid system, where population sampling occurs at the center of a grid cell. Such sampling often entails the use of live or snap traps, or perhaps pitfall traps for small mammals or herptofaunal species (Cooperrider et al. 1986, Heyer et al. 1994, Wilson et al. 1996). Avian populations are frequently sampled using standardized protocols that incorporate the use of point-count stations, which may use a fixed-radius or unlimited radius circular plots to sample birds from a fixed position (Hamel et al. 1996).

- Placement of plots

An essential objective of sampling during the monitoring effort is to gather data that are representative of conditions on the restored and reference sites. Inferences about the overall population from samples are generally valid only when the data represent random samples. Possible samples are defined as random when each sample has an equal chance of being chosen (Krebs 1989). However, randomizing the sampling protocol is often easier said than done. Often, researchers may be limited by accessibility issues, private landowner concerns, and perhaps by specific attributes of selected focal species.

Because restoration efforts will likely consist of a large target area, establishing a grid system may be preferred rather than simple random placement of quadrats. A simple alternative to achieve adequate randomization in a grid system is to use a systematic sampling approach (Krebs 1989), where quadrats are established along line transects at randomly selected distances (Figure 3). Quadrats can be placed directly on the transect, or multiple plots can be placed on either side of the transect. The distance of any plot from the transect can be constant among all plots, or randomly selected for each plot.

A stratified random approach may also be used where quadrats are placed only in patches of various plant communities present on the site (Causton 1988, Stromberg 2000d) (i.e., it may not be necessary to collect data at a randomly selected location where no vegetation exists). Transects should be adequate in length to sample the entire width of the riparian vegetation (Kondolf and Micheli 1995). If the stream channel is too wide and/or deep to cross, then independent transects may need to be established on both sides of the stream.

Permanent sampling plots may be established and resampled during the course of the monitoring period to assess plant growth/ population trends during the restoration effort. However, a better assessment of site-wide progress of restoration may be obtained by randomly selecting quadrat locations during each sampling effort. Note that methods of statistical analysis of data from permanently established quadrats may require a repeated measures analysis (Green 1979, Sokal and Rohlf 1981, Zar 1984). Consult a statistician during development of the monitoring design, and discuss thoroughly the data needed to meet assessment objectives before actual data collection begins.

- Plotless versus plot techniques for vegetation monitoring

Establishing quadrats can be time-consuming and expensive when sampling a large area. If large samples are needed, but logistically difficult to collect, then utilizing a plotless sampling technique such as the Point-centered Quarter (PCQ) method (Cottom and Curtis 1949) may be an option. Generally, this method is used for trees, but can also be applied to shrubs. To use this technique, a point along a transect is randomly located and the species and distance of the nearest shrub and/or tree to the center point in each of the four quadrants is measured. This technique can be modified to monitor restored sites by adding measurements of canopy cover, canopy height, vegetation structure, or other similar variables at each point. A primary advantage to using a plotless technique is that many more samples can be collected in a relatively short amount of time.

- Sample size and frequency of data collection

Plant communities: After determining the type, size, and distribution of quadrats to be used, decisions will need to be made on the actual number of quadrats to be sampled, and the frequency of data collections (e.g., annually, biannually, every 2 years, etc.). During the course of the monitoring period, suitable numbers of samples will need to be collected to: (1) determine changes in vegetation structure during the monitoring period, and (2) evaluate habitat characteristics and compare with measurement targets from reference sites or other sources. The number of samples needed should be determined statistically based on size of area and variation determined from pilot studies; however, funding, personnel, and other logistic constraints may also play a role in determining how many plots can be monitored. An initial estimate of sample size may be obtained by first determining the smallest difference you wish to detect (i.e., differences of variables measured among years and differences between variables on the restored and reference sites), the level of confidence desired (generally, $\alpha = 0.05$), and then by conducting a pilot study, where the standard deviation for a selected variable is calculated. Numerous examples of sample size determination procedures for plant communities are provided in Green (1979), Ludwig and Reynolds (1988) and Krebs (1989).

Vertebrate communities: Sample sizes will also need to be determined for sampling any vertebrate populations during the monitoring process. Numerous methods exist for monitoring vertebrate populations (Cooperrider et al. 1986, Heyer et al. 1994, Wilson et al. 1996). Many animal communities, particularly small mammals and herpetofaunal communities, require intensive sampling during many times of the year and may require a system of traps (live traps or pit-fall traps) that demand considerable time and effort to establish and maintain. Summaries of sampling and monitoring techniques can be found in Cooperrider et al. (1986), Heyer et al. (1994) and Wilson et al. (1996).

Birds are conspicuous and are often the easiest vertebrate communities to monitor because community composition and relative abundance can be obtained by quickly counting all birds detected at a series of survey stations. Furthermore, birds are often excellent indicators of ecological changes (O'Connell et al. 2000, Bryce et al. 2002, Da Silva and Vickery 2002). Surveyors generally use 50-m-radius circular plots to denote bird locations within the area; however, an index of species occurrence is often obtained with unlimited distance counts (Hamel et al. 1996). When using unlimited distance counts, survey stations must be placed far enough apart to prevent double counting of individual birds at different survey stations (at least 250 m apart). In open habitats, distance between survey stations may need to be increased. Surveys usually last at least 5 to 10 min per survey station, so in one morning, a single surveyor can usually collect data on approximately 10 – 15 survey stations. General methodology for conducting point-count bird surveys can be found in Ralph et al. (1995) and Hamel et al. (1996). Moreover, Sauer and Droege (1990), Hamel et al. (1996) and Eagle et al. (1999) provide instructions for estimating the number of survey stations needed to assess annual changes in avian populations.

Assessing vertebrate population viability: In addition to sampling vertebrate populations to assess changes in species richness and relative abundance, one may wish to monitor reproductive success of specific focal species as a metric of restoration success. As mentioned earlier, presence of a target species as detected by monitoring is no guarantee that the habitat is suitable to provide a sustained population of that species. To determine population viability, individual animals will need to be monitored and their reproductive success evaluated. Ideally, a sample size of 20 to 40 individuals is reasonable to estimate reproductive success for a population at a particular location (Chasko and Gates 1982, Holmes et al. 1986, Martin 1993). However, for extremely rare species, like the Southwestern Willow Flycatcher, attaining reasonable sample sizes may not be possible. For example, approximately 39 percent of all Willow Flycatcher breeding locations in New Mexico consist of only one defended territory (Marshall 2000). Therefore, for restoration purposes, simply the presence of this and other rare species (e.g., Western Yellow-billed Cuckoo (*Coccyzus americanus occidentalis*) and Least Bell's Vireo (*Vireo bellii pusillus*) on a restored site may be a good indication that restoration efforts are headed in the right direction.

If assessing reproductive success remains a restoration objective, then monitoring reproductive success of multiple common species may be a reasonable means to evaluate the value of the location and quality of the habitat (Martin 1993). In some cases, selecting several species and assessing reproductive success by observations of breeding pairs and presence of fledged, yet dependent young, may provide an index of reproductive success (Vickery et al. 1992). Only using observations may be a cost-effective, less-invasive method to assess reproductive success without the need for large crews to conduct nest searches, band adults, and monitor nests.

Table 2. Common Analytical and Statistical Methods Applicable for Assessing Characteristics Between Restored and Reference Sites

Statistical test	Application
Linear Regression	Comparison of means; trend analysis
Logistic Regression	Presence absence; trend analysis
T-Test; One-way Analysis of Variance	Comparison of means
Chi-square Test (χ^2)	Comparison of frequencies
Analysis of Variance and Multiple Range Tests	Comparison of means among multiple sites
Multiple Regression / Multiple Analysis of Variance	Comparison of means among multiple sites and variables
Mann-Whitney Test (*U*); Kruskal-Wallis Test (*H*)	Comparison of ordinal data sets among sites
Ordination procedures (e.g., Principal Components Analysis (PCA), Canonical Correspondence Analysis (CCA)	Multivariate ordination of habitat characteristics and/or population metrics of study sites
Time Series Analysis	Trend analysis
Rapid Assessment Models (e.g., Habitat Evaluation Procedure (HEP), Index of Biological Integrity (IBI), Hydrogeomorphic Method (HGM)	Comparison of index values among sites; qualitative comparisons

Step 4. Analysis and Interpretation of Monitoring Efforts

The basic concept of restoration is the reestablishment of 'natural conditions' in an area, typically following periods of extensive disturbance. The monitoring data are then analyzed to determine if the objectives of the restoration effort have been met. The quantitative and statistical methods used to analyze the data should be carefully chosen in consultation with a statistician before data collection begins. Once the data have been collected, results of the analysis should be presented in an accessible, easy-to-understand form for land managers and researchers.

Restoration ecology is growing rapidly, and the scientific literature on restoration techniques and analytical tools is growing with the developing science. Numerous statistical and analytical tools are available to the restoration ecologist, from rapid assessment procedures, univariate tests, parametric and non-parametric comparisons, to complex ordination and multivariate techniques.

It is beyond the scope of this technical note to describe in detail all the statistical and analytical tools available for assessment of a restoration program. Table 2 provides a brief introduction to several common statistical tools applicable to most restoration efforts. The reader is also encouraged to refer to numerous texts on restoration ecology (e.g., Elzinga et al. 2001, Hill and Platt 1998, Morrison 2002, Perrow and Davy 2002), review of rapid assessment techniques (Smith at al. 1995, Treweek 1999), and statistical techniques used in ecological research (e.g., Green 1979, Sokal and Rohlf 1981, Zar 1984, Ludwig and Reynolds 1988, Krebs 1989, Nur et al. 1999, National Institute for Science and Technology (NIST) 2003).

Step 5. Assessing Success

Once a monitoring effort has been implemented and data have been collected and analyzed, the results need to be evaluated according to the initial objectives and measurement targets as established in Step 1. Four primary achievement levels can be used to determine the overall success of the restoration effort:

- **Return of hydrologic functions.** Does the post-project hydrology reflect pre-disturbance or reference site conditions better than pre-project conditions? Do flood events create and maintain depositional areas that provide suitable recruitment for native trees species (e.g., willow and cottonwood)?
- **Improved water quality.** Are desired pH, temperature, dissolved oxygen concentrations achieved? Have there been significant reductions in non-point source pollution (e.g., nitrogen or phosphorus, herbicides, pesticides, suspended sediment)?
- **Rehabilitation of plant communities.** Are measures of the plant community, such as stem density, size and age class distribution, and species diversity reasonably close to pre-disturbance levels or reference sites? Is plant survival acceptable? Do current conditions minimize propagation of non-native species?
- **Recovery of vertebrate communities.** Are relative abundance and diversity measures of vertebrate species close to pre-disturbance levels or reference sites? Have rare, focal, or otherwise sensitive species returned to use the site(s)? Is the population of the focal species viable (reproductive success greater than mortality)?

Most restoration and rehabilitation activities will probably never accomplish total success, and hopefully will rarely or never result in complete failure. Assessing success is complicated by the lack of standards that managers can measure at a regional level (Carothers et al. 1990, Davis and Muhlberg 2002). In evaluating the overall success of restoration efforts using the above factors, managers may choose to develop assessment criteria categories, such as Poor, Moderate, Good, and Excellent, to judge the relative success of their efforts. These criteria should reflect the degree of success that has been achieved on the restored site compared to measurement targets established during the formulation of restoration and monitoring objectives. These measurement targets may have been developed in comparison with a reference site, before/after comparisons on the restored site, or comparison of measurement goals identified through historical records of past ecological conditions. Depending on the final comparison of the restored site data, the assessment criteria could be applied as follows:

- **Poor:** Little or no success in restoring hydrologic functions to the stream system; few suitable banks or bars exist for plant recruitment; manual planting efforts have limited or no success (e.g., 0-20 percent survival); plant communities remain sparse and distinct from reference sites; little or no change in the vertebrate communities; no recruitment or establishment of viable populations of targeted focal species.
- **Moderate:** Some success in restoring hydrologic functions; manual planting efforts have limited success (e.g., 30-60 percent survival); patchy changes in plant communities, yet still remain distinctly different from reference sites; limited changes in the vertebrate communities, yet different from reference sites; limited or no success in recruitment of targeted focal species.
- **Good:** Observe some return of natural hydrology, including spring/summer floods; higher success of manual planting efforts (e.g., 60-80 percent survival); significant progress in establishment of plant communities and vertebrate population metrics, though differences with reference sites still exist; limited success in recruitment of focal species, yet no success in establishing viable populations.
- **Excellent:** Observe return of more natural hydrologic functions; good success of manual planting efforts (e.g., >80 percent); significant changes in plant community structure with much closer agreement to reference site data; significant changes in vertebrate abundance and species diversity with results much closer to reference site data; successful recruitment and/or establishment of viable populations of targeted focal species.

The assessment process will be unique to each restoration effort, and will depend largely upon the initial goals and measurement targets established before the monitoring process begins. For example, restoration of mature cottonwood stands may take more than 30 years, which is more time than is dedicated to most monitoring efforts. Therefore, a "Good" or "Excellent" rating may depend upon suitable recruitment of cottonwood saplings, indicating that the restoration effort is 'going in the right direction.' Also, during short-term monitoring efforts (e.g., $\leq$3 years), restored sites will probably show limited success in developing plant and vertebrate communities comparable to older, mature reference sites. These sites, however, may provide high-quality early-successional habitats in addition to other functions such as streambank stabilization. Managers will have to accommodate these limitations and "developing" functions into their final assessment of restoration efforts. Finally, even those efforts assessed as "Fair" or "Poor" need to be described so that causes of failure can be identified and remedied in future efforts. It is clear that the longer a monitoring effort is conducted, the better chance managers will have in gauging progress toward meeting the stated objectives of the restoration effort.

SUMMARY

Riparian ecosystems in the arid and semi-arid western United States perform vital ecological functions that are essential for long-term maintenance of our natural resources, including groundwater quality and availability, and persistence and conservation of native plant and animal diversity. Dramatic losses and degradations of riparian ecosystems pose a serious threat to sustaining the ever-increasing human populations. Because riparian areas in the Southwest are often limited by a regular source of water, returning the timing, quantity and duration of water flows is often the best approach to successfully establishing a diverse, and locally appropriate, assemblage of plant communities.

Riparian rehabilitation and restoration are effective when done correctly (Briggs 1995, 1996) and numerous examples exist (e.g., National Research Council 1992, Hill and Platts 1998, Stromberg 2000d). To increase success and minimize the cost of mistakes, continued testing and evaluation of available techniques are necessary to develop Southwestern regional guidelines and to formulate standards to assess restoration success. A well-planned monitoring effort is often the best way to test the effectiveness of currently available techniques (Stromberg 2000b, 2000c, 2000d). Monitoring goals will largely depend upon the degree of degradation of the project site and availability of funds to establish a monitoring program. Therefore, monitoring goals will vary from site to site. Once goals have been established, a monitoring protocol with clearly stated objectives should be developed to obtain the necessary data that will determine whether the goals have been achieved.

This technical note provides an outline of actions necessary to develop a plan for assessing restoration and rehabilitation efforts in arid and semi-arid environments. There are five steps in this process: (1) establishing monitoring goals and objectives, (2) developing a monitoring protocol, (3) implementation of the monitoring design, (4) analysis and interpretation of monitoring data, and (5) final assessment of restoration efforts.

The science of ecosystem restoration and rehabilitation is young and techniques need continuing refinement and testing. Implementing a monitoring protocol involves the collection of data in a manner that ensures randomization of plot locations and adequate sample sizes that permit an accurate and unbiased analysis of the data. Data analysis generally involves comparisons of quantified ecological conditions between the restored site and measurement targets established from a reference site, before/after comparisons on the restored site, or measurements derived from historical records. Numerous statistical procedures are available to assess changes during the monitoring period and to compare monitoring data sets with data from appropriate data sets. Results of data analyses must be interpreted in the context of the uniqueness of each restoration effort to assess whether the restoration has been successful. Regardless of whether the restoration effort is considered successful or not, results of monitoring efforts should be presented in a professional context to increase the overall knowledge of the science of riparian ecosystem restoration.

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