Defining Reference Conditions for Restoration of Riparian Plant Communities: Examples from California, USA

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ABSTRACT / Currently, there is an emphasis on restoration of riparian vegetation in the western United States. Deciding on what and where to restore requires an understanding of relationships between riparian plant communities and their environments along with establishment of targets, or reference conditions, for restoration. Several methods, including off-site data and historical analysis have been used for establishing restoration reference conditions. In this paper, criteria are proposed for interpreting reference community composition and structure from the results of multivariate cluster analysis. The approach is illustrated with data from streams in the California Sierra Nevada, Central Valley, and southern coastal region to derive descriptions of reference communities for stream reaches and floodplain landforms. Cluster analysis results can be used to quantify the areas of both degraded and reference communities within a floodplain, thereby facilitating restoration cost estimation.

Restored riparian plant communities on public and private lands in the western United States provide improvements to terrestrial and aquatic wildlife habitat and water quality. Most riparian restoration continues to be site-specific (e.g., riparian plantings for bank stabilization, etc.), but there has been increasing interest in restoration of entire stream corridors. This amounts to a shift from single-community or single-species restoration to restoration of several communities within variable floodplain environments.

Restoration of riparian corridors or landscapes with multiple communities is a new area of research and practice; methods are currently being developed and tested (see *Restoration Ecology,* Volume 5, Number 4S, December 1997). Planning for restoration of riparian corridors requires several important pieces of information: (1) the composition and structure of riparian communities existing within the corridor must be quantitatively described; (2) environmental conditions (e.g., in the western United States, exposure to flood disturbance) affecting community composition and structure must be described as must any departure from natural conditions such as streamflow diversions; (3) the spatial associations between environmental conditions and communities must be identified; and (4) reference states (i.e., restoration targets) for community composition and structure for each environmental condition and each community to be restored must be chosen. The definition of reference community composition and structure are particularly difficult problems. Even for single communities, there is typically a lack of quantitative information on ''natural'' structure and composition. Techniques available for defining reference conditions include historical analysis (Kondolf and Larson 1995), modeling (Camp and others 1997; Harris and others 1997), ecological analysis (Sagers and Lyon 1997), and the federal interagency ''process for assessing proper functioning condition'' (USDI Bureau of Land Management 1995). In this paper, the use of multivariate cluster analysis for estimating reference conditions for riparian communities is illustrated. There is nothing particularly novel about using cluster analysis for classifying plant communities, but its application to restoration has rarely been exploited (but see Allen and Wilson 1994). Restoration scientists and managers seeking approaches to complement or replace historical or off-site reference community descriptions may find the technique useful.

KEY WORDS: Riparian vegetation; Watershed planning; Riparian restoration; Cluster analysis

Geomorphic and Ecological Basis for Restoration of Riparian Corridors

In California and other semiarid regions of the United States identifying the flood disturbance gradient, as represented by stream reaches and floodplain landforms subject to different frequencies and intensities of flooding, is a critical step in the riparian restoration planning process. From a stream's headwaters to its mouth, flood disturbance is directly proportional to basin area, channel slope, and floodplain width and can be expressed as stream power (Hack 1973). Across a floodplain, severity of flood disturbance is generally correlated with distance from, and elevation above, the main channel. It may be quantified in terms of definable topographic features on the floodplain; sometimes referred to as "bedforms" (e.g., Allen 1965, 1970; Harms and Fahnestock 1965), substrate (i.e., surface soil texture) and flood frequency (Harris 1987; Stromberg and Patten 1990, 1991; Carlson and others 1992), or landform type and position may be used as a surrogate for levels of disturbance (Auble and others 1994). Floodplain landforms can be classified into disturbance categories with multivariate cluster analysis or modeling techniques using both categorical and continuous data (Harris 1987; Auble and others 1994). Generally, there are three major types of landform that must be distinguished: frequently flooded, mobile sedimentary deposits (sand bars, gravel bars, mid-channel bars, secondary channels) within or adjacent to the bankfull limits of the stream; infrequently flooded (>2 year recurrence interval), relatively stable, vertically accreting floodplains and abandoned channels; and unflooded or rarely flooded higher floodplains and terraces. The presence and relative proportions of these landforms varies with the stream and reach geomorphology.

On streams in California and elsewhere in the United States, there are close associations between flood disturbance and occurrence patterns of obligate riparian species and communities at both the stream reach and floodplain landform scales (e.g., Hupp and Osterkamp 1985; Harris 1987, 1988; Szaro 1990; Auble and others 1994). In the semiarid western United States, reaches and landforms subject to frequent flooding naturally tend to support communities simple in structure and composition, often dominated by sprouting shrubs and annual herbs experiencing "perpetual succession" (Campbell and Green 1968). On less-frequently disturbed landforms, interactions between fluvial forces, especially sedimentation, and vegetation permit establishment and growth of more complex communities (Hickin 1984). On landforms least disturbed by floods, such as higher floodplains, factors such as plant interactions, herbivory, autecology of species, soil development, groundwater, and land use exert increasing control over community structure and composition. It is the landforms least disturbed by floods where the most complex and diverse riparian communities tend to occur.

The ecological functions of riparian communities are determined by their composition (species, species richness, presence of exotics), vertical structure (canopy cover and architecture), horizontal pattern (patch size, shape, area and their relative locations), and total area or continuity (Forman 1983; Gutzwiller and Anderson 1987a,b; Risser and Harris 1990). These functions are not static; they change over time in response to succession and disturbance (Sprugel 1991). Pioneer plant communities on recent fluvial deposits may provide wildlife habitat, stabilize substrate, and moderate flooding effects. They may be periodically removed (and rejuvenated) by floods, or they may change to other communities. More complex communities on higher floodplains can provide habitat for wildlife that range between uplands and valley bottoms, moderate extreme flood events, and buffer streams from upland land-use impacts (Forman 1983; Delong and Brusven 1991).

Restoration of natural ecological functions throughout a riparian corridor requires information on associations between flood disturbance and other fluvial processes and vegetation and quantitative descriptions of communities as they presently exist and as they would exist under natural conditions, i.e., in reference states. Restoration of riparian corridors should entail the recreation of natural patterns of association between fluvial landforms and riparian communities. Often, these natural patterns have been disrupted by vegetation clearing (Kondolf and Larson 1995), invasion of exotic species, or changes in stream hydrology (Williams and Wolman 1984; Kondolf 1990). For each community, restoration involves moving vegetation from its present condition to the reference condition. This may require reestablishment of natural hydrologic and geomorphic processes (Kondolf 1990).

Criteria for Defining Reference Communities

In restoration ecology, the need for and use of quantitative descriptions of reference sites for project design have captured much attention (Cairns 1989; Sprugel 1991; Aronson et al. 1993a,b, 1995; Pickett and Parker 1994). In a recent paper, White and Walker (1997) categorize four sources of reference data: (1) contemporary information from the site to be restored; (2) historical data from the site to be restored; (3) contemporary information from reference sites; and (4) historical data from reference sites. White and Walker (1997) suggest that each of these sources has its benefits and drawbacks. Underlying the use of reference data from source 1 is the assumption that even in a quite altered setting some remnants of reference plant communities should exist, and a thorough inventory should capture at least some samples representing their composition and structure (Aronson and others 1995). This assumption must be evaluated for specific areas to be restored, but if it is violated (i.e., if an area is so altered that no residual reference conditions exist), perhaps the feasibility of restoration should be questioned. If source 1 is to be used in the context of restoring a stream corridor, the implication is that there will be a relatively intensive survey of existing communities and that some form of statistical analysis will be performed. Guidelines for interpreting statistical results are required.

There may be several different communities present in a specified floodplain environment. Abundance of one community relative to others is the first criterion for establishing the reference community. This will not suffice for many floodplains, however, where the reference community may be rare. The following additional criteria are proposed here, depending on the specific objectives for an area: (1) community complexity, e.g., species richness and structure; (2) presence / absence of exotics; and, if information is available, (3) floristic and structural similarity to reference communities elsewhere in the region. Applying these criteria will lead to defining a reference community as the most complex one found in a specified environment, which is free of exotic species and comparable to other known reference communities. Unless special objectives are driving the effort (i.e., there is a desire to maintain or enhance certain communities to achieve some specific function, such as the recovery of an endangered wildlife species), restoration might focus on maximizing the amount of reference community present for each flood disturbance class. Because chronic disturbance limits the sustainability of active restoration in steep stream reaches or within the bankfull limits of a stream, most efforts should concentrate on infrequently flooded landforms in alluvial reaches.

Cluster Analysis

Large field data sets have not commonly been produced by restoration ecologists in the United States. This is primarily due to the site specificity of restoration efforts to date. If study objectives are to determine the environmental conditions within a stream corridor, determine relationships between environmental conditions and vegetation, and define riparian community reference states, there are several ordination and classification methods available. The reader interested in the advantages or disadvantages of the various methods or the technical details of their use is urged to consult the many texts and papers on the subject (Gauch 1982; James and McCulloch 1990; van Tongeren 1995). One of these methods, multivariate cluster analysis, is rarely used in restoration ecology but is widely used for classifying plant communities. It has been applied to establishing reference forest communities for specified environments (Allen and Wilson 1994) and reference aquatic macroinvertebrate communities (Wright 1995). It has been specifically applied to classification of riparian communities at several scales including regions (Harris 1989), individual streams (Harris 1987; Sagers and Lyon 1997), and stream reaches (Auble and others 1994). Cluster analysis accepts many types of vegetation data including species presence and abundance by sample; canopy cover by height class (by species if desired); or presence / absence of key indicator species. It is also receptive to environmental data, which, for example, can be classified into flood disturbance classes (Harris 1987; Olson and Harris 1997). Clustering algorithms need to be carefully chosen, depending on the application (van Tongeren 1995). The user must not only be familiar with the technique but must possess the scientific background to properly design the analysis and interpret the results.

Cluster analysis groups samples by maximizing either their within-group similarities or their between-group differences (James and McCulloch 1990). Samples falling within a specified range of values are grouped together; samples falling outside that range are placed in other groups. In cluster analysis routines developed primarily for vegetation data, such as TWINSPAN (Hill 1979), communities are commonly defined by presence and abundance of plant species (i.e., floristics and dominance). Other algorithms, such as the minimum variance cluster routine (Orloci 1967), allow vegetation and environmental data to be classified separately or together (Harris 1987). In application to restoration, it is useful to identify and group samples on the basis of canopy structure as well as composition or dominance (Sagers and Lyon 1997). A typical input data set might include total canopy cover and canopy cover by canopy position for each species in each sample. The output will be clusters of samples that have similar total canopy cover, similar dominant species, similar canopy architecture, and similar associated species. Cluster interpretation, including the naming of plant communities, proceeds from review of the sample data (averages and variability) for each cluster.

A properly conducted field study and cluster analysis should yield descriptions of communities and associated environmental conditions and an estimate of the area of each community. Community descriptions can include dominants, codominants, and associated species with full species lists that can be used to interpret intracommunity dynamics. Average values for communities (e.g., cover, species richness, etc.) can be used as points of departure for evaluating reference conditions. In some cases, a reference condition may be represented by samples within a cluster that are far from the average. This point is illustrated in examples presented below in which the outputs of cluster analysis are interpreted for the following applications: (1) defining reference communities (dominance types) for stream reaches with specified geomorphology; (2) defining reference communities for specified landforms/flood disturbance classes on two alluvial floodplains; and (3) defining reference composition and structure for a single community. Only one of these studies was specifically oriented towards restoration (Olson and Harris 1997), but various implications for restoration can be drawn from all. In all cases, the guidelines previously presented are used for interpretations. For brevity, limited data are presented here. The reader should consult the cited publications for further information.

Reference Communities for Stream Reaches

As part of a study in the eastern Sierra Nevada, California, to determine the effects of streamflow diversions on riparian vegetation, TWINSPAN was used to classify >100 sample transects into riparian dominance types that are associated with specific stream-reach-scale (1 to 10-km-long) geomorphic settings (Table 1) (Harris 1988). Transects were purposely placed in relatively homogeneous geomorphic settings. The objective was to determine reference riparian communities at the stream-reach scale that would capture the range of variability in the region. As an illustration of the application to restoration, results indicate two communities occupying alluvial fans, one dominated by *Populus fremontii* (cottonwood) and one dominated by *Chrysothamnus nauseosus–Artemesia tridentata* (rabbitbrush–sagebrush). If the criteria previously presented are applied to distinguishing the reference community between these two (abundance, complexity, presence of exotics, similarity to reference communities elsewhere), the cottonwood community would be the reference community for alluvial fans. Historically, it was abundant on alluvial fans in the region (Taylor 1982). It consists of tree, shrub, and herb layers and is more complex in both structure and composition than the rabbitbrush–sagebrush shrub community. Neither community has a high proportion of exotic species. Finally, the cottonwood community has been considered the reference community by others (Stromberg and Patten 1991). The rabbitbrush–sagebrush community is actually characteristic of upland rather than riparian environments in this region. Restoration of alluvial fans to cottonwood from the rabbitbrush–sagebrush community would be a logical step towards recreating former ecological functions. This would have to be accompanied by restoration of streamflows (Stromberg and Patten 1991) and, perhaps, restoration of floodplain landforms conducive to maintenance of the restored community.

Table 1. Associations between stream geomorphic settings and riparian communities, eastern Sierra Nevada, California (adapted from Harris 1988)

Geomorphic setting	Riparian community	Description
U-shaped bedrock valley	*Pinus contorta*/meadow	High elevation meadows; incised streams; sand or cobble substrate
U-shaped bedrock valley	*Salix* spp./*Glyceria striata*	High elevation; braided channels; gravel substrate
U-shaped till valley	*Salix* spp./*Cornus stolinifera*	Midelevation; incised or one-sided floodplains; cobble substrate
U-shaped till valley	*Populus fremontii*/*Salix* spp.	Midelevation; one- or two-sided floodplains; any substrate
V-shaped till valley	*Betula occidentalis*/*Salix* spp.	Mid-low elevation; any cross-section; any substrate
Depositional flat	*Salix* spp./*Glyceria striata*	Mid-low elevation; braided, broad floodplains; sand substrate
Alluvial fan	*Chrysothamnus nauseosa*/*Artemesia tridentata*	Low elevation; braided channels; gravel substrate
Alluvial fan	*Populus fremontii*/*Rosa californica*	Low elevation; braided channels; gravel substrate

Reference Communities for Specified Floodplain Landforms

The results of a study on the San Luis Rey River in San Diego County, California, illustrate the application of cluster analysis to determining reference communities for landforms within a stream corridor (Olson and Harris 1997). In the first phase of this work, eight reaches comprising 28 km of stream and 1100 ha of floodplain were selected for field studies from a total study area of 70 km and 4900 ha based on their need for restoration. Reach boundaries (longitudinally and horizontally across the floodplain) were defined on the basis of stream gradient, soil characteristics, and floodplain width. The field sampling program for each selected

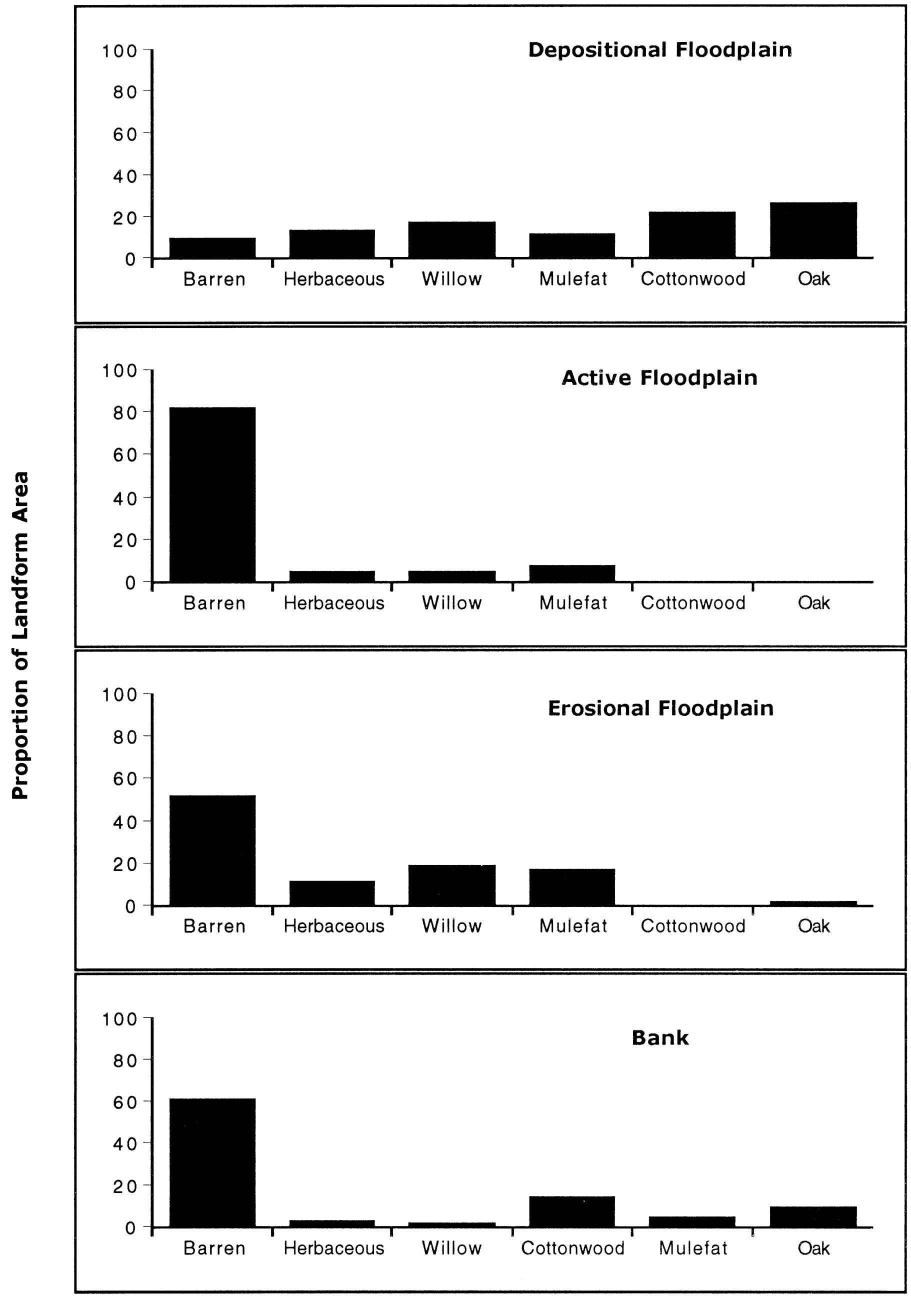

Figure 1. Proportional distribution of major riparian community types [*Baccharis viminalis* (mulefat), *Salix* spp. (willow), *Populus fremontii* (cottonwood), exotic graminoids and herbs (herbaceous) and *Quercus agrifolia* (oak)] across four landform classes, San Luis Rey River, California.

reach was a series of transects placed systematically perpendicular to the stream at a fixed interval, 150 m. Circular plots were located systematically at a 30-m interval along each transect. This sampling intensity was adequate to collect 30 samples for any community occupying 1% of the total field study area. In each 3.5-m-radius plot (0.004 ha), landform class (following Harms and Fahnestock 1965) and surficial substrate (indices of flood disturbance), vegetation cover by canopy layer for the two dominant tree and/or shrub species, and species composition were recorded.

Each of the 3000 field samples was placed into one of four general landform classes representing the flood disturbance gradient: active floodplain; depositional, infrequently flooded floodplain; erosional, infrequently flooded floodplain; and channel banks, which experience varying degrees of disturbance depending on their location and elevation. Minimum variance cluster analysis (SAS Institute 1987) was used to separately classify vegetation sample data for each landform class (Figure 1) (Olson and Harris 1997). In addition to a barren class, five distinct riparian communities [dominated by

Baccharis viminalis (mulefat), *Salix* spp. (willow), *Populus fremontii* (cottonwood), exotic graminoids and herbs (herbaceous) and *Quercus agrifolia* (oak)] were distinguished, some of which are most abundant on one landform (i.e., willow on erosional floodplain, oak on depositional floodplain) and some of which are found in all disturbance classes (mulefat, herbaceous, and willow). Depositional floodplain, where flood disturbance is least severe, has the widest range of communities. Active floodplain, conversely, is over 80% barren. This analysis provides a first approximation of the associations between communities and flood disturbance.

Several implications for restoration were drawn from the analysis, including a recommendation that limited restoration should occur within active floodplain (Olson and Harris 1997). One illustration concerns communities dominated by riparian trees (cottonwood and oak). These are relatively rare and, where they occur, they appear to be reduced in tree cover relative to historical conditions (Kondolf and Larson 1995). These communities are most common on infrequently flooded depositional floodplain, are the most complex communities found there, and are comparable to reference communities found on floodplains elsewhere in the region. Over 15% of the area of depositional floodplain is dominated by an exotic herbaceous community (Figure 1). If the ecological functions associated with tree communities (e.g., wildlife habitat) are to be enhanced, replacement of herbaceous vegetation by planting riparian cottonwood and oak and management to attain the composition and structure indicated by the sample data for reference communities would be a high priority.

In a second example, using a slightly different approach on a tributary to California's Sacramento River, Harris (1987) collected detailed field data on microtopography, substrate, floodplain position, and flood frequency and then used cluster analysis to classify 38 kinds of floodplain landform representing the flood disturbance gradient in a 12-km-long study area. Vegetation data for each of the 38 landform types were then classified into six riparian communities whose composition and structure vary along the flood disturbance gradient (Table 2). Environments most frequently and severely disturbed have a high probability of annual flooding, have coarse substrate, and are either barren or dominated by willows or exotic annual grasses. Total canopy cover is low (<25%) and canopy structure is simple on these landforms (relative cover of dominants is commonly >50%; Table 2). At lesser levels of disturbance other species, including *Juglans hindsii* (walnut), *Populus fremontii* (cottonwood), and *Quercus lobata* (oak) in mixed stands dominate the landforms.

Table 2. Riparian communities and their relationships to flood disturbance, Cottonwood Creek, California (adapted from Harris 1987)

Community type	Relative cover of dominant (%)[a]	Flood disturbance level
Salix hindsiana	49–100	Moderate–severe
Populus fremontii	58–100	Moderate–severe
Exotic annual grasses	43–61	Low–moderate–severe
Juglans hindsii	36–68	Moderate–severe
Quercus lobata	35–65	Low
Mixed riparian (walnut–oak–cottonwood)	Cover shared by two or more species	Low

[a]Relative cover is defined as the following proportion: average cover of species / total average canopy cover of community.

Applying criteria for defining a reference community, on a level floodplain distant from the stream with silt substrate there is an array of communities dominated by exotic annual grasses and herbs, willows, and mixed riparian forest. The latter are the most complex in that environment, are relatively abundant there, and are similar to the oak–walnut–cottonwood climax riparian forest community described for higher floodplains in the Sacramento Valley (Conard and others 1977). The reference community for this environment is multistoried riparian forest dominated by oak, walnut, and some cottonwood with an understory of associated native lianas and shrubs. In the reference community, the total canopy cover of 60%–100% is equally distributed among the tree, shrub, and herb layers (Harris 1987).

Reference Composition and Structure for Single Communities

At the scale of a single community, variability of within-community measures such as composition, cover, density, species richness, etc., relative to cluster averages can be used to guide the choice of reference conditions. These may be identified by reviewing samples encompassing the range of variability within a given cluster representing a community and picking the samples meeting the guidelines presented above. At San Luis Rey River, there are five groups of samples on the depositional floodplain that are classified as willow-dominated (Figure 2). This is an early successional stage relative to the oak or cottonwood reference communities in that environment. Review of data for individual

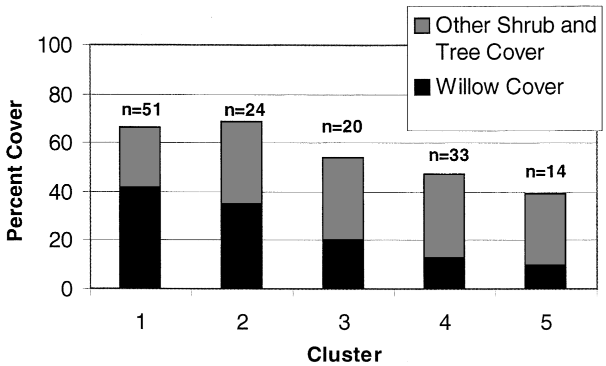

Figure 2. Sample clusters representing the willow community at San Luis Rey River, California, indicating the range in variability of willow versus other tree and shrub cover including cottonwood and giant reed. n = number of sample plots within a cluster.

samples within clusters indicates that some patches are in transition from a willow community to a community dominated by cottonwood. This is indicated by the presence of subdominant cottonwoods in the shrub layer that will eventually overtop the willow. If the objective of restoration is to achieve communities dominated by cottonwood, succession could be accelerated by selective removal of the willow overstory. Although this might be a goal if the aim is to achieve greater cover of the tree community, it might not be the best if other objectives are to be met. For example, if willow communities are to be maintained in environments where they are naturally succeeding to cottonwood communities, restoration practice would be to remove cottonwood and, perhaps, rejuvenate the willow artificially through coppicing. Willow communities are important at San Luis Rey because they provide habitat for the endangered least Bell's vireo (*Vireo bellii* AOU) (Hendricks and Rieger 1989). A willow community is found on all landforms; total tree and shrub cover ranges from 39% to 94%, and the proportion of tree and shrub cover in willow ranges from 25% to 83%. Many samples from this community from all landforms indicate the presence of the aggressive exotic giant reed (*Arundo donax*) in one or more canopy layers. Since the vireo requires dense, relatively pure willow stands (similar to cluster 1 in Figure 2), invasion by exotic plants would be considered a serious problem. Reviewing the range of variability in willow versus giant reed cover within community clusters helped to identify which samples are being overtaken by the exotic and consequently have the greatest restoration need. Samples where exotics are abundant were mapped in a geographical information system. The area of degraded willow habitat was quantified at the reach and whole-stream levels by plot expansion from samples to estimate approximately 70 ha overall (Olson and Harris 1997), thereby providing an estimate of the magnitude of the restoration effort needed.

This example illustrates that when some community types are to be preserved for specific reasons (or to promote greater between-community level diversity), communities different from the reference might be intentionally created and maintained.

Summary and Conclusions

Planning riparian restoration for a stream corridor should culminate in the definition of restoration need for each plant community found on the floodplain. A comprehensive field sample coupled with cluster analysis / classification is an effective way to prioritize community restoration. This paper illustrates four uses for cluster analysis that are relatively uncommon in restoration ecology. First, cluster analysis is a valuable tool for classifying floodplain environmental attributes and explicitly defining the disturbance gradient (demonstrated at Cottonwood Creek). Second, data from clusters of vegetation samples can be used to identify reference communities for a specified stream reach or landform environment (demonstrated at Cottonwood Creek, San Luis Rey River, and the Sierra Nevada). Third, samples for a specified community can be interpreted relative to reference conditions for that community to determine restoration needs (demonstrated at San Luis Rey River). Finally, with proper georeferencing of samples, the area of communities requiring restoration can be quantified (demonstrated for San Luis Rey River). As pointed out previously, caution is needed in applying cluster analysis (James and McCulloch 1990). The utility of the approach depends on expertise in riparian ecology, geomorphology, and hydrologic processes.

The biology of the species to be restored will have a bearing on the success of their establishment and survival. Information on physical and environmental factors responsible for sustaining communities must also be used. Stratification of reference communities by environment avoids the uncertainty associated with using references from other locations with unknown or confounding environmental conditions (Wright 1995). Subjective decision making in the absence of data on what constitutes a reference community, based on assumptions in the field, as in the "proper functioning condition" approach (USDI Bureau of Land Management 1995), may also be avoided. Placement of the wrong community on a floodplain landform where it cannot be sustained is less likely.

There are numerous other multivariate approaches that may be used for classifying communities and evaluating environmental relationships (Gauch 1982; James and McCulloch 1990). The advantages of the approach described are that it is quick, relatively inexpensive, does not depend on subjective selection of reference sites, and does not presuppose access to sophisticated analysis tools or computer systems. For an agency or land management entity, it will generally be within the experience and technical capacity of staff.

The approach identifies candidate communities and sites for restoration. Subsequent site-specific planning at candidate locations is critical and may require engineering design and hydrologic modeling (Kondolf 1990; Carlson and others 1992).

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