Geographic Information System Based Riparian Restoration Site Selection Model: Application to the Cosumnes River Watershed

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ABSTRACT:

The selection and prioritization of riparian restoration sites is an important component of restoration planning. Site selection models developed in Geographic Information Systems (GIS) can assist resource managers in prioritizing restoration sites using a combination of environmental variables and user-defined selection criteria. The two-step selection model described in this paper was applied to the lower Cosumnes River watershed. The first step of the model was the development of a potential riparian vegetation dataset using logistic regression with presence and absence of riparian vegetation and physical characteristics of the watershed. The second step of the model was the prioritization of the potential riparian vegetation with user-defined selection criteria. Over 85% of the existing riparian vegetation in the study area was identified within the potential riparian vegetation dataset. The equations developed for the model may be specific to environments similar to the lower Cosumnes River watershed, but the method can be applied in any watershed.

INTRODUCTION:

It was estimated that, in the late 1980's, 0.45% of the Central Valley was covered by riparian forest even though the floodplain covered 13.4% (Hunter et al., 1999). Riparian communities are not only reported to contain many threatened and endangered species but are also considered an endangered ecosystem in many areas of western North America (Richardson, 2000). Because of the continued loss of riparian habitat, restoration of degraded riparian systems has become an important tool for many land managers. An important goal of the Ecosystem Restoration Program (ERP) of CALFED is to improve ecosystems in the Bay-Delta and its tributaries using adaptive management. As of June 2001 ERP had distributed $335 million on 323 projects (CALFED, 2001). During 2002 they were planning to spend another $150 million on projects ranging from fish ladders to habitat restoration and research (CALFED, 2000). The sites where the riparian restoration projects are implemented can be determined with a riparian restoration site selection model. A tested restoration site selection model that addresses the physical setting as well as the conservation needs of a habitat can provide land managers with the necessary science-based tools to develop more effective restoration plans.

Often restoration sites are selected because a landowner is willing to sell, or decides to restore, the riparian area (Kentula, 1997). While this can result in successful restoration projects, it does not always achieve watershed scale or regional conservation goals. In addition, the restoration project may be implemented because the land is available, but it may not be a successful project because the hydrologic regime, groundwater and other physical factors required to support the riparian habitat is no longer intact. Using watershed scale restoration site selection models will assist managers in restoration planning, site prioritization and potentially lead to more coordinated restoration projects (Kentula, 1997). Planning restoration efforts at a regional scale can help address larger conservation issues, such as patch size, connectivity between habitats, and habitat fragmentation (Meffe and Carrol, 1997). Site selection in the planning process is key to successful restoration projects (Kentula et al. 1993) and should take into account that riparian communities are shaped by many different physical factors. Malanson (1993) identifies flood regimes, stream channel dynamics, soil moisture, groundwater as key physical factors that influence riparian communities.

The model described in this paper incorporates some of these key physical factors in the identification of potential restoration sites. Existing site selection models have relied on additive modeling techniques along with limited hydrologic indicators; this model uses a logistic regression technique with presence and absence of riparian vegetation, along with physical parameters in order to better identify potential riparian habitat. The model is able to identify more than 85% of existing riparian vegetation in the study area. Once the potential riparian habitat is identified, different site prioritization scenarios based on user defined selection criteria can be applied. After the sites are identified, the restoration managers can determine the best method for acquiring the land and implementing the restoration project. This riparian restoration site selection and prioritization model can help CALFED and other watershed groups identify sites in which to invest their restoration efforts. Identification of potential restoration sites at a watershed scale will provide a method for land managers to incorporate restoration into watershed management plans.

The lower Cosumnes River watershed in the Central Valley of California was used to demonstrate the two-step process of the riparian restoration site selection model. The first was the identification of potential restoration sites based on the logistic regression; the second was the ranking of potential restoration sites using the user defined selection criteria.

BACKGROUND

Riparian Processes:

The success of the restoration of an ecosystem is dependent on the conditions of the physical setting. The distribution of riparian vegetation is often related to flood regime, channel dynamics, soil moisture and depth to groundwater (Malanson, 1993).

In the riparian zone, there are many different sources of disturbance, such as flooding, fluvial processes, mass wasting and debris-flows (Fetherston et al. 1995, Malanson, 1993, Tabacchi et al., 1998). Flood frequency, duration and timing are often associated with the patterns of riparian vegetation (Fetherston et al., 1995, Malanson, 1993 Van Splunder et al. 1995, Trowbridge, 2002, Auble et al., 1998, Pettit et al., 2001, Hupp et al. 1996). Flooding acts as a mechanical force, clearing surfaces and creating both new habitats and anoxic environments in which only flood tolerant plants can survive (Mitsch, 1993, Auble et al., 1998, Bendix et al., 2000). The establishment of riparian species is often linked to the frequency and timing of flood flows (Auble et al. 1998, Burns, 1990, Bradely et al. 1986, Baker, 1990, Kalischuk et al., 2001, Stromberg, 2001). Changes in the flood regime can result in lower establishment rates, establishment of upland species in the riparian zone, and reduction of riparian habitat (Stromberg, 2001).

Another key disturbance factor in riparian habitat consists of changes to the channel (Scott et al., 1996, Tabacchi et al., 1998). A meandering river channel deposits new sediment on point bars, while the outside of the meander bend is cut away (Dunne and Leopold, 1978, Nanson and Beach, 1977). This pattern of erosion and deposition creates new areas for species to colonize (deposition zones), while removing vegetation from the cut bank (erosion zones) (Hupp, 1992, Hupp et.al., 1996, Bendix et al., 2000). The changing topography adjacent to the river channel and the floodplain result in a mosaic of vegetation communities associated with the different rates of disturbance and physical characteristics (Scott et al. 1996, Malanson, 1993, Huggenberger et al., 1998). Historically the Cosumnes River was an anastomosing river (Florshiem et al., 2002). As the river creates new channels or reoccupies abandoned channels, abandoned channels are colonized by riparian vegetation. The changes to the channel and floodplain provide the bare, moist substrate required for the establishment of many riparian pioneer species (Bendix et al., 2000, Scott, 1996, Malanson, 1993).

Two physical requirements for many riparian species are sufficient soil moisture and access to groundwater. Researchers have found that riparian communities vary along moisture gradients away from the river (Malanson, 1993, Adams et al., 1980, Wheeler et al., 1978). To become established and survive many riparian species depend on a certain level of soil moisture. It has been demonstrated that as the soil dries, cottonwood roots follow the soil moisture to the groundwater (Mahoney et al., 1998). There is a strong link between riparian vegetation and depth to groundwater (Stromberg et al., 1996a, Stromberg et al., 1996b, Malanson, 1993, Scott et al, 1998, Mahoney et al., 1998, Amilin, et al., 2002, Stromberg, 2001). In a vegetation – depth to groundwater study on the San Pedro River in Arizona, riparian vegetation such as *Populus fremontii*, *Salix gooddingii*, and *Fraxinus velutina* dominated the wettest areas (Stromberg et al., 1996b). The Establishment of pioneer riparian species often occurs in areas with depth to groundwater of less than 1 meter. In several studies of cottonwood and willow species' response to groundwater decline, researchers found that rapid decline of groundwater (~>1-2cm/day) resulted in a decline in establishment and growth and an increase in mortality (Scott et al, 1998, Mahoney et al., 1998, Amilin, et al., 2002, Stromberg et al. 1996b). More gradual declines did not significantly impact tree survivorship (Scott et al., 1998, Amilin et al., 2002).

Existing Site Selection Models:

As digital datasets become more common and available, researchers and managers are able to develop models to assist in identifying potential restoration sites. We reviewed riparian restoration site selection models that have been developed using GIS data (Table 2.1). There have been two general categories of models that have been used for restoration site selection. The first is a watershed scale model and the second is a reach scale model. Watershed scale models are more general and provide information on potential sites but are not specific enough to indicate what riparian vegetation communities may be appropriate at the site scale. The reach scale models include data collection in the field about the geomorphic features associated with a variety of riparian communities. Two of the models reviewed relied on a modified version of the wetness index from TOPOMODEL that Philips (1990) used to identify wetlands (Russel et al. 1997, O'Neil et al., 1997). The relative wetness index used in these models is calculated from the log of the upslope drainage area multiplied by the surface slope (see Methods section for full description). Russel et al. limited their model to the wetness index and land uses. The O'Neil et al. GIS based model was similar to the Russel et al. model except that they included a calculation of stream power as an indicator of disturbance. The specific stream power indicated the ability of a stream to erode and create new landforms. Harris and Olsen (1997) developed a multiple scale selection model. Geomorphic features and land use data were used to identify similar reaches within a watershed. Field surveys of associations between geomorphic features and riparian vegetation were used to prioritize restoration sites.

Limitations of Existing Models:

The models used by Russel et al. Olsen and Harris, and O'Neil et al. to identify potential restoration sites provide a starting point for identifying the locations of restoration sites, but the models were limited by the lack of data available at the time. While the wetness index may have worked in the San Luis Rey watershed in Southern California and the Arkansas River watershed, it may have limited use in areas such as the lower Cosumnes River watershed where there is little topographic relief. Higher resolution Digital

Elevation Models (DEMs) and LIDAR data are becoming more common, providing better representations of topography in low relief areas. As the underlying topographic data improves, the wetness index may become more significant in lower relief areas.

The method proposed by Harris and Olsen (1997) is important for restoration site design, but it is often too time and money intensive to be feasible at the watershed scale. In addition, the geomorphic features required in the analysis are rarely mapped in detail and in GIS format.

Data Limitations:

Not all of the physical environment requirements that are associated with riparian vegetation are found in GIS data sets. Site-specific information such as channel shape, erosion and deposition zones, duration and timing of flooding is often unavailable at a watershed scale. If a data set such as groundwater is not available, surrogate measures, which are available, can be substituted until the data becomes available. In cases where groundwater often fluctuates with surface water (Stromberg, 1996a, Primack, 2000), surrogate values such as change in elevation from the nearest body of water and distance to nearest body of water can be used. A riparian restoration site selection model must be sufficiently flexible that, as additional data or better resolution data becomes available, the model can be easily updated and modified.

Cosumnes River Riparian Restoration Site Selection Model:

The model we developed to be used in the Cosumnes River watershed builds on features in earlier models, but expands the parameters to reflect more detail in the physical conditions that affect riparian community growth and establishment. It also introduces the use of logistic regression to guide the identification of potential riparian habitat, in place of using an additive model based on categories selected by the user. Logistic regression allows for the use of continuous variables, such as distance from the nearest body of water, in addition to categorical variables such as flood frequency. Additive models require the user to define the break points for the continuous variables to become categories, whereas the data used in the logistic regression allows the variation of the continuous variables to be retained in the analysis.

The physical parameters used in the model are flood frequency, distance from the nearest body of water, change in elevation from the nearest body of water, maximum soil permeability, and a calculated wetness index. The physical parameters used in the site selection model were significant factors in Valley Oak tree growth at the Cosumnes River Preserve Restoration sites (Keller and Quinn, submitted 2002). The results from this study were used to guide the selection of physical factors used in the riparian restoration site selection model

METHODS:

This two-step model identifies potential riparian communities using physical factors and then potential riparian restoration sites are prioritized with user defined selection criteria

(Figure 2.1). The first step is the development of the potential riparian community data set. This data set was developed using logistic regression in S-PLUS and ARC/INFO's Grid module. The second step is the application of site selection criteria and the production of a final map of potential restoration sites.

Riparian Community Datasets (Step 1)

The data used in step one consists of flood frequency, change in elevation from the nearest body of water, distance from the nearest body of water, maximum soil permeability, a wetness index and presence and absence of riparian vegetation. The flood frequency and the soil permeability data were derived from the Natural Resource Conservation Service SURRGO data set for Sacramento County. The nearest body of water was calculated from a 1:24,000 scale streams layer generated from scanned USGS quadrangles. The change in elevation from the nearest body of water was calculated from the streams layer and a USGS 10 meter Digital Elevation Model (DEM). The wetness index was a modified form of the wetness index calculated from TOPMODEL (Russel et al. 1997)

$$Wi = \ln(\alpha/T * \tan\beta)$$

Where

Wi = relative wetness at point I

α = upslope drainage area

T = soil transmissivity

β = surface slope in degrees

Russel et al.(1997) modified the TOPMODEL wetness index by dropping T, soil transmissivity, because the soils data were either incomplete or too general. T was also dropped from this model because the data were unavailable. The variables were calculated from the USGS 10 meter DEM.

The riparian vegetation presence and absence data were digitized as points from the USGS Digitial Ortho Photo Quarter Quads (DOQQ). Approximately one point per vegetation patch was digitized. Some of the larger patches had a larger number of samples to represent a range of values within the patch. The absence points were generated randomly using Excel to create the x-y coordinates. The points were then displayed on a DOQQ, and points falling in riparian vegetation were removed. The riparian vegetation validation data set was digitized as polygons on the DOQQ's.

A logistic regression was run in S-PLUS, with the presence/absence data and the corresponding data from the five physical characteristics. The resulting equation was used to produce a layer of probability from the five variables in ARC/INFO's Grid module. The riparian vegetation polygons digitized from the DOQQ's were used to determine the percentage of the existing riparian vegetation that could be identified using the probability layer.

The model was repeated after the addition of 4 presence points representing areas that have been successfully restored at the Preserve. These areas were not used in the initial analysis because the DOQQ's did not show them as having riparian vegetation.

Model Validation:

The validation of the model is limited by the lack of true absence points. At the time of the model construction, it was not possible to identify points that represented areas where riparian vegetation has always been absent. Some areas can be identified as historically upland, but areas along the boundary between upland and riparian have not been mapped. The study area has been farmed for over 100 years, and the historic extent of riparian vegetation was not mapped. We were able to validate the identification of areas with existing riparian without this information, but were unable to test for areas identified as potential riparian that cannot support riparian vegetation (i.e., we could test for errors of omission, but not errors of commission). The points that were used to create the model were used to calculate sensitivity, specificity and map accuracy (Pearce and Ferrier, 2000). The points used were not an independent test, but they do help provide an indication of model fit.

Site Prioritization (Step 2)

Step two of the model consisted of setting up the site selection criteria (Figure 2.2). Three different site selection criteria were used to select the largest areas of highest restoration potential. The Corridor Criteria was based on the goal of a continuous riparian corridor along the main stem of the Cosumnes River. The Corridor Criteria used a corridor of potential riparian habitat and existing land uses. The goal of the Public Land Criteria was to identify potential restoration areas on public land using the potential riparian dataset, existing land use and ownership. The Private Land Criteria was the same as the Public Land Criteria except it was targeting potential restoration sites on private lands.

Corridor Criteria Data:

The least cost path analysis technique in ARC/INFO's GRID module was used to identify the potential riparian corridor. Least cost path analysis determines the path that has the least cost for movement from one location to another. The path must travel through a raster data set composed of cells with different "costs" associated with them. The final path is a path that had the least accumulated cost in the movement from cell to cell. In this example, the start and end locations were the upstream and downstream ends of the Cosumnes River in the study area. The "cost" grid was set up such that existing riparian areas had the least cost, potential riparian areas were a middle cost, and areas that were outside of the potential riparian areas and that did not have existing riparian vegetation were the highest cost. The resulting data set indicated the areas that would create a corridor between existing riparian areas and that had the highest probability of riparian restoration success.

Public and Private Land Use Criteria Data

The final data set used, in the Public Land Use Criteria and the Private Land Use Criteria analysis, was an ownership layer developed from the statewide ownership dataset and the boundaries of the Cosumnes River Preserve. Areas managed for conservation activities (public land and private land managed for conservation) and private land (not managed for conservation) were assigned values of 1 or 0 depending on the selection criteria. The

Public Land Use Criteria set conservation areas to a value of 1 and other private land to a value of 0. The reserve was used in the Private Land Criteria.

The potential riparian data layer, the potential corridor data layer, and the generalized land-use layer were then ranked between 0 and 1 and added together. The top scoring sites can then be investigated further to determine site specific suitability for riparian restoration.

Data for all criteria:

The data set used for all of the site selection criteria was a land use layer from Ducks Unlimited and the California Department of Fish and Game. This dataset was generalized into categories of land-use that would be easy to convert to riparian (natural vegetation), more difficult to convert (flooded agriculture, row crops), and very difficult to convert or unrestorable areas (urban, orchards and vineyards, barren) (Table 2.2).

RESULTS:

Logistic Regression:

The logistic regression produced the following equations, which were used to generate the probability map:

Run 1	$Y = 1.465 + (0.112 * X_1) + (-0.018 * X_2) + (0.179* X_3) + (3.030 * X_4) + (3.403 * X_5) + (-3.401 * X_6) + (-0.060 * X_7)$
Run 2	$Y = 5.102 + (-0.003* X_1) + (-0.010* X_2) + (0.0.62* X_3) + (2.669 * X_4) + (3.258 * X_5) + (1.163* X_6) + (-0.031 * X_7)$

Variables:

X_1 = Change in elevation from the nearest body of water

X_2 = Distance to the nearest body of water

X_3 = Maximum Soil Permeability

X_4 = Flood category 1

X_5 = Flood category 2

X_6 = Flood category 3

X_7 = Wetness Index

Model Validation:

Of the 5 variables used in the analysis, flood frequency and distance to the nearest body of water were the most significant factors. The analysis was repeated using only the two most significant variables, and very little changed in the resulting probability map. A probability map of potential riparian habitat was produced in the first step of the analysis (Figure 2.3, 2.4). The test of Model Run 1, identifying existing riparian patches, shows an 85% probability that existing riparian falls in an area that is mapped at >75% (Table

2.3). When compared to a 100 meter buffer of the river, this is an increase of 13%. The second probability map (Model Run 2) using 4 additional points, produced a probability map with 99 % of existing riparian in the > 90% probability range (Figure 2.4).

Sensitivity, specificity and a measure of accuracy were calculated for both Model Run 1 and Model Run 2. Model Run 1 scored higher in all three categories than Model Run 2 (Table 2.4).

Selection Criteria:

The second step in the analysis was to apply user defined selection criteria to the potential riparian vegetation data sets. The site selection analysis produced maps prioritizing the areas that should be visited to determine the best methods to restore the sites. The two potential riparian vegetation model runs identified very similar amounts of area for potential restoration under the Corridor Criteria analysis (Table 2.5). The Public Lands Criteria and the Private Lands Criteria were applied to the potential riparian vegetation data set from Model Run 1. The five largest patches of land for riparian restoration identified under the three sets of user defined selection criteria ranged in size and location (Figure 2.5, 2.6, 2.7, Table 2.6).

DISCUSSION:

Prioritization of restoration sites at the watershed scale will assist managers in the identification of restoration sites that address multiple conservation goals. A model based on an evaluation of the physical system will increase the probability of restoration success and maximize the ecological benefits (Kentula, 1997). Additional components of restoration site selection models include “both the role of the site in the functioning of the landscape and the effects of the surrounding landscape on the structure and function of the site in the design of projects” (Kentula, 1997). The model applied to the lower Cosumnes River watershed uses the landscape scale physical characteristics to address the suitability of a site for riparian restoration. Restoration sites are prioritized at the landscape scale using patch size, connectivity of existing habitat, existing land uses and ownership.

The application of the site selection model to the lower Cosumnes River watershed demonstrated the two-step riparian site selection model based on physical characteristics of existing riparian. Eighty-five to ninety-nine percent of existing riparian vegetation was identified using the logistic regression equation developed from presence and absence of riparian vegetation, flood frequency, distance from the nearest body of water, elevation change from the nearest body of water and maximum soil permeability. Site visits will still be required to ensure that the site is suitable, but the model can assist land managers in determining the areas with the most potential for restoration.

The accuracy assessment was limited by the lack of verifiable absence values for historical riparian vegetation. Even though we could not determine the number of areas that we incorrectly identified as potentially restorable to riparian forest, we could identify areas that had similar physical characteristics to those of existing riparian areas. Model Run 2, which used additional points, was able to identify more of the existing riparian but did not rate as well as Model Run 1 in sensitivity, specificity and overall accuracy. Some of the variation can be attributed to a larger area of potential riparian identified in Model Run 2, which would result in more of the existing riparian polygons being within the potential areas and also increase the potential of “absence” points falling within that area. A conservative use of the model would be working on restoring areas identified in both models and using the success and failure data from these restoration activities to refine the model further in an adaptive management framework.

The benefit of this technique is that, as better data is collected, additional layers can be added and surrogate data can be replaced. For example, when the Cosumnes River Research group completes the groundwater data set for the area, groundwater data can be added to the analysis. With groundwater data added to the model, it may be possible to remove the surrogate groundwater variable of distance to the nearest body of water and change in elevation to the nearest body of water. As shown with the points added for the restoration sites, additional sites can be added to the presence (successful restoration) and absence (unsuccessful restoration) datasets as additional information is developed. The potential restoration map will change as the variables change, which will result in a model that continues to be refined. The restoration managers will also be able to examine the sites that were predicted to be successful but failed. Examining these sites for differences will help refine the model and increase our understanding of the ways riparian communities interact with the physical environment.

In addition to refining the underlying potential riparian data set, the model is also flexible in the site selection criteria. As the conservation goals change or different restoration groups become active in the watershed, the model can be customized to select sites that fit their goals. The underlying potential riparian dataset is the same, but the areas which are ranked higher will depend on the user-defined selection criteria. The results from the three sets of selection criteria illustrate the ways that the user-defined selection criteria can change the location and size of the priority restoration sites. In the Corridor Criteria example, the largest areas meeting the criteria of connection between existing riparian vegetation patches and easily converted land uses are identified and prioritized (Table 2.6, Figure 2.5). The Public Land Criteria were used to identify and prioritize the largest patches of potential riparian habitat located on the Cosumnes River Preserve (Table 2.6, Figure 2.6). The final example identified areas on private land that could be targeted for future restoration efforts by the owners or purchase by a restoration group (Table 2.6, Figure 2.7).

We assume that the equation developed for this model is specific to the Lower Cosumnes River watershed. As datasets improve, so will the equation. Even though the model's parameters will change, the method can easily be applied to other watersheds. All of the data used in this example are available throughout California or will be available in the next few years. In addition, many of these datasets are from Federal data sources, and should also be available for most of the United States. Because of the variation in the ways riparian communities interact with the physical environment, we do not believe that this method should be applied uncritically to multiple watersheds. With local validation, the current model is probably applicable to low elevation Central Valley settings with similar histories as wooded floodplains with seasonal or freshwater tidal marshes. It may also be appropriate to split watersheds into different areas when the model is developed. For example, in the Cosumnes watershed, the lower watershed has a different hydrologic regime than does the upper watershed. Both the topography and the influence of groundwater are very different. Treating both the upper and lower watersheds as the same environment could result in a poor potential riparian vegetation data set.

Modeling potential riparian vegetation at the watershed scale allows resource managers to prioritize restoration at the watershed scale and potentially address larger scale resource issues such as habitat connectivity. The identification of potential riparian habitat based on physical characteristics and selection based on user-defined criteria will assist managers as they invest restoration money in sites that meet multiple conservation goals.

FIGURES

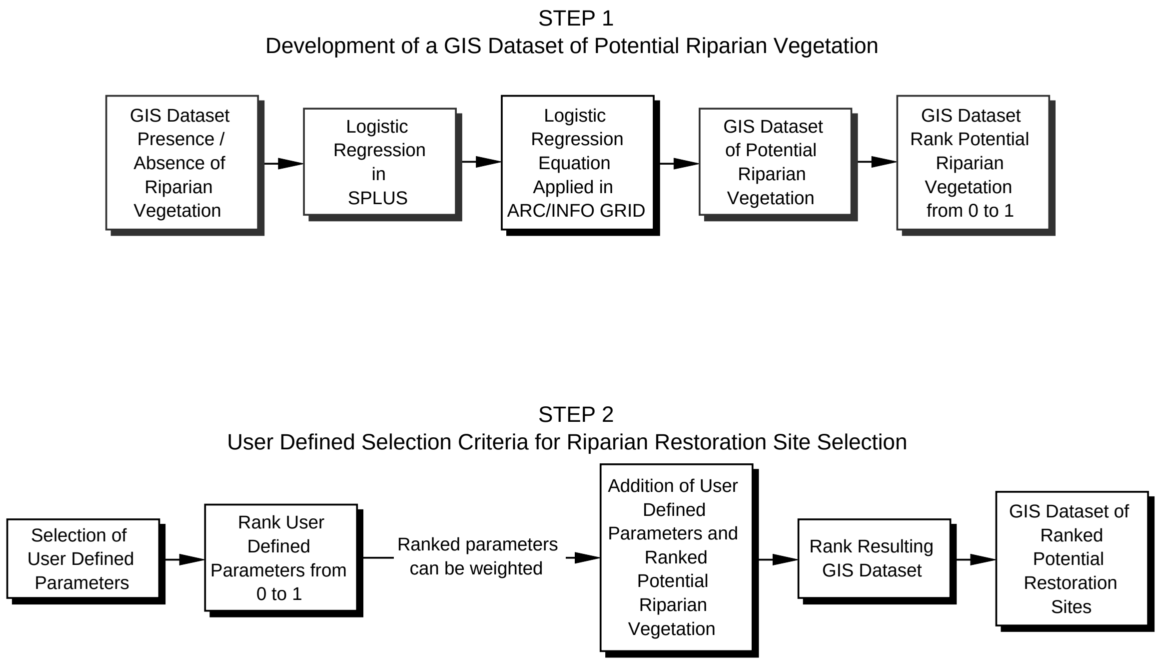
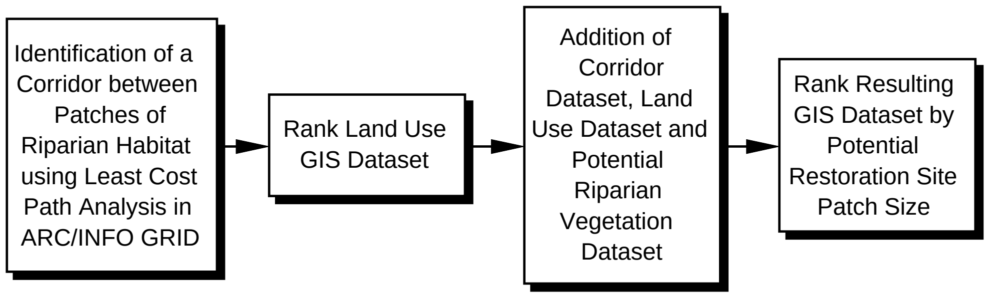


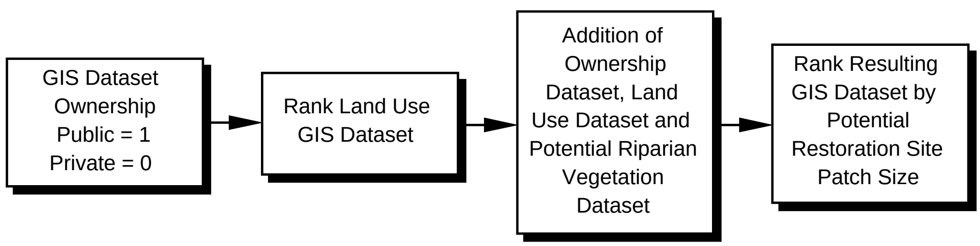
Figure 2.1: Diagram of the steps in the riparian restoration site selection model applied in the lower Cosumnes River watershed.

Corridor Criteria



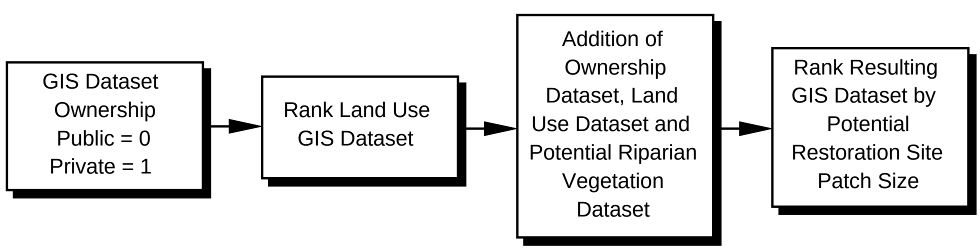
Corridor Criteria: Potential restoration sites are identified using the datasets for, Potential Riparian Vegetation, corridors connecting existing riparian vegetation patches and existing land use.

Public Land Use Criteria



Public Land Use Criteria: Potential restoration sites are identified using the datasets for, a Potential Riparian Vegetation, existing land use, and public land ownership.

Private Land Use Criteria



Private Land Use Criteria: Potential restoration sites are identified using the datasets for, Potential Riparian Vegetation, existing land use, and private land ownership.

Figure 2.2: Three different examples of user-defined site selection criteria were applied to a potential riparian vegetation dataset. The resulting maps can be used to prioritize potential riparian restoration sites.

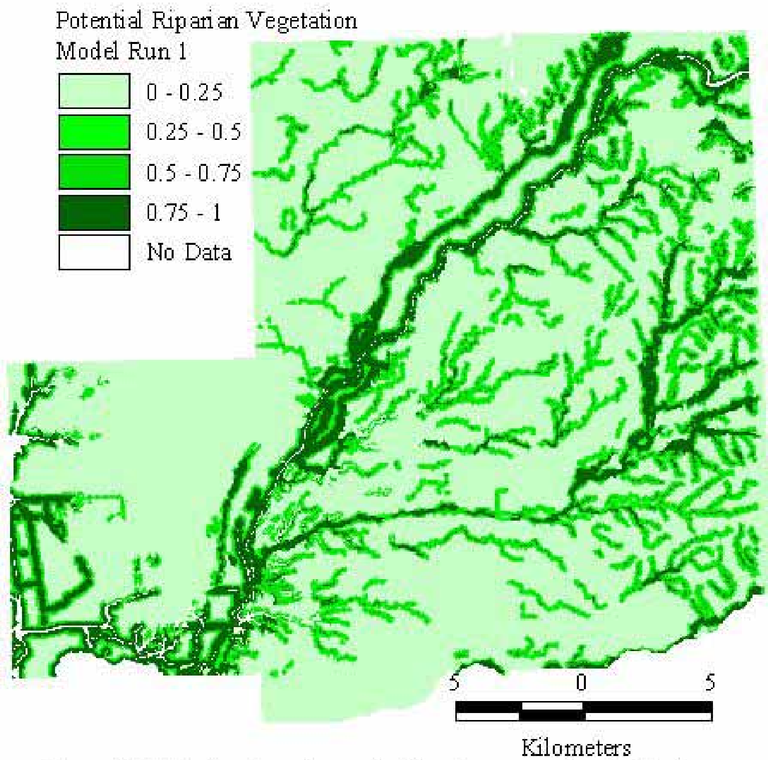


Figure 2.3: Distribution of potential riparian vegetation in the lower Cosumnes River Watershed calculated from a logistic regression analysis of presence and absence of riparian vegetation and flood frequency, maximum soil permeability, distance from the nearest body of water, change in elevation from the nearest body of water and a calculated wetness index.

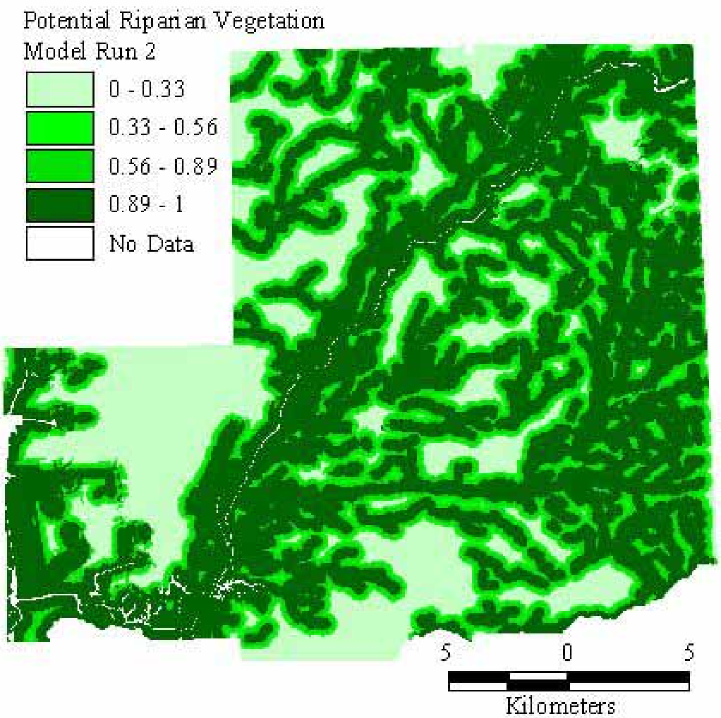
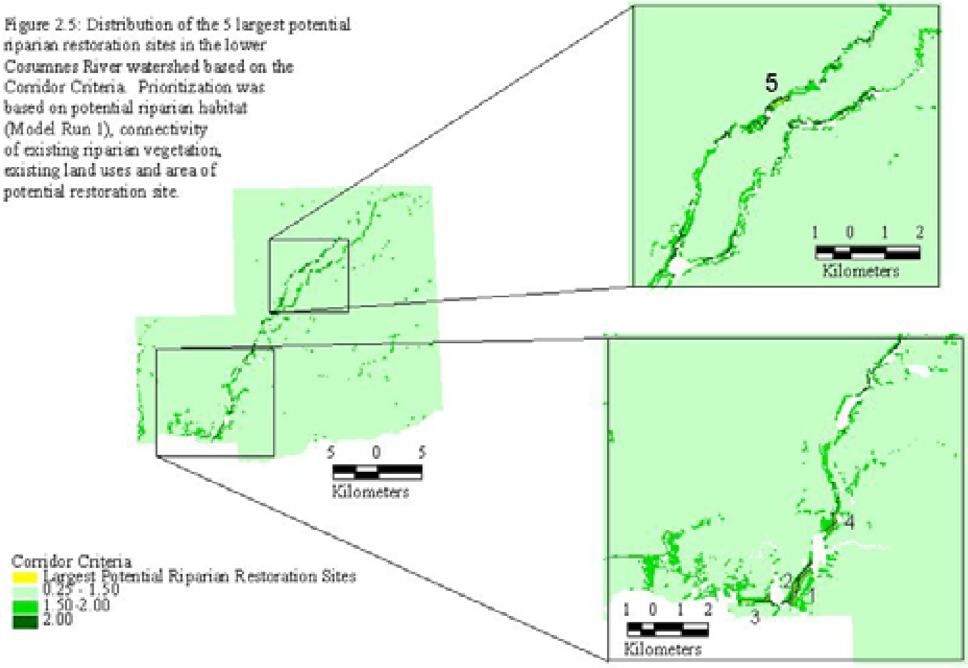


Figure 2.4: Distribution of potential riparian vegetation in the lower Cosumnes River Watershed calculated from a logistic regression analysis using the same parameters as Model Run 1 (Figure 3) and four additional presence and absence of riparian vegetation points.

Figure 2.5: Distribution of the 5 largest potential riparian restoration sites in the lower Cosumnes River watershed based on the Corridor Criteria. Prioritization was based on potential riparian habitat (Model Run 1), connectivity of existing riparian vegetation, existing land uses and area of potential restoration site.



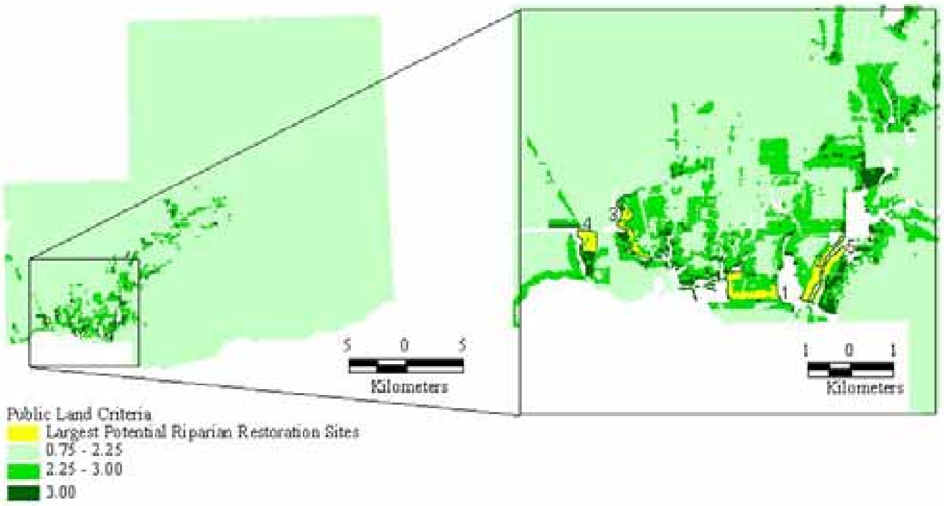
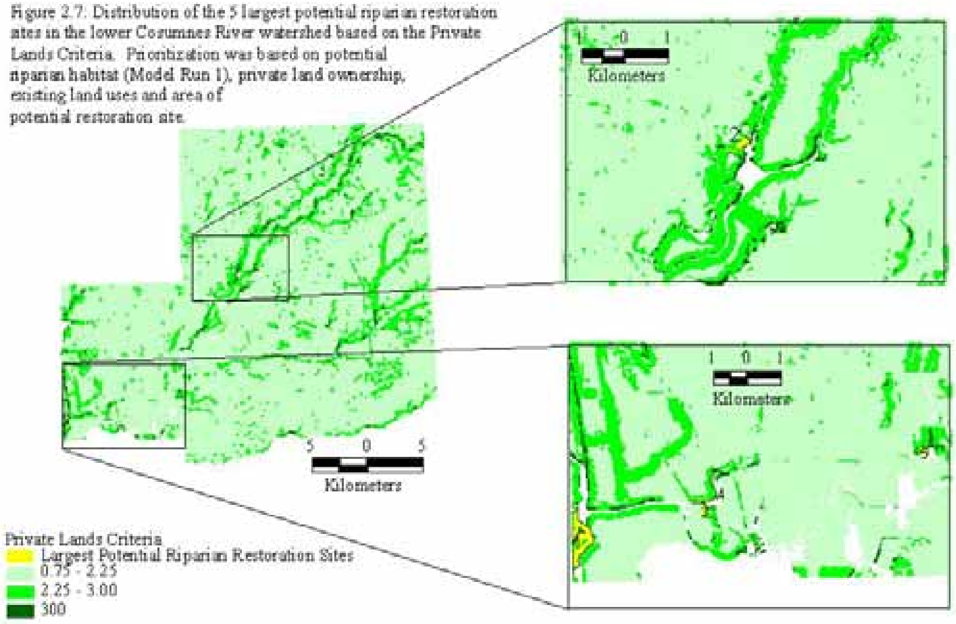


Figure 2.6: Distribution of the 5 largest potential riparian restoration sites in the lower Cosumnes River watershed based on the Public Lands Criteria. Prioritization was based on potential riparian habitat (Model Run 1), public land ownership, existing land uses and area of potential restoration site.

Figure 2.7. Distribution of the 5 largest potential riparian restoration sites in the lower Cosumnes River watershed based on the Private Lands Criteria. Prioritization was based on potential riparian habitat (Model Run 1), private land ownership, existing land uses and area of potential restoration site.



TABLES:

Environmental Variables associated with Riparian Vegetation	Russel et al watershed scale model	O'neil et al watershed scale model	Harris and Olsen watershed and reach scale model	Watershed scale GIS Riparian site selection model
Flood Frequency				SURRGO flood frequency maps
Groundwater				Unavailable
Soil moisture	Wetness Index			Surrogate measures
Soil characteristics				Maximum soil permeability
Geomorphology		Stream Power	Erosion and Deposition zones (watershed scale) Vegetation and geomorphology associations (reach scale)	Unavailable
Land Use	Land Use Map	Land Use / Vegetation	Land Use (watershed / reach scale)	Land use in site selection criteria

Table 2.1: A comparison of riparian restoration site selection models and the environmental variables associated with riparian vegetation.

Land Use	Rank
Open Water	1.00
Seasonally Flooded Estuarine Emergents	1.00
Permanently Flooded Estuarine Emergents	1.00
Tidal Estuarine Emergents	1.00
Seasonally Flooded Palustrine Emergents	1.00
Permanently Flooded Palustrine Emergents	1.00
Tidal Flats	1.00
Non-Tidal Flats	1.00
Riparian Woody	1.00
Flooded Agriculture	0.75
Seasonally Flooded Agriculture	0.75
Non-Riparian Woody	0.75
Non-Flooded Agriculture	0.50
Grass	0.50
Orchards/Vineyards	0.25
Barren	0.25
Other	0.25
Outside Study Area	0.00

Table 2.2: The categories of land use that were used in the three examples of selection criteria applied to the lower Cosumnes River watershed riparian restoration site selection model. The rank indicates the values given to each land use for the site selection model and the grouping of the different land uses.

	Probability selected for potential riparian from logistic regression results	Percent Existing Riparian Vegetation Identified
Model Run 1	>75%	85%
Model Run 2	>90%	99%
100 Meter Buffer	N/A	72%

Table 2.3: The comparison of logistic regression models (Model 1 and Model 2) and a 100 meter buffer for identification of existing patches of riparian vegetation in the lower Cosumnes River Watershed.

	Sensitivity	Specificity	Accuracy
Model Run 1	0.91	0.96	0.95
Model Run 2	0.5	0.49	0.67

Table 2.4: Results from the sensitivity, specificity, and accuracy calculations from the logistic regression model runs calculating the potential of riparian vegetation in the lower Cosumnes River watershed. The calculations were based on presence and absence data used in the logistic regression.

	High Quality Sites (Acres)	Moderate Quality Sites (Acres)
Model Run 1	282	2471
Model Run 2	328	5497

Table 2.5: Comparison between the acres of potential riparian habitat identified using the selection criteria of high restoration potential, corridors connecting existing riparian habitat and existing land use. High quality sites were the sites ranked the highest for potential riparian vegetation, potential corridor and high land use conversion potential. The moderate quality sites were ranked highly in 2 of the 3 selection criteria.

	Acres	Priority
Corridor Criteria	34	1
	25	2
	20	3
	19	4
	13	5
Public Lands Criteria	93	1
	66	2
	55	3
	43	4
	42	5
Private Lands Criteria	136	1
	27	2
	25	3
	25	4
	21	5

Table 2.6: Comparison of the 5 largest potential riparian restoration sites identified using three different user-defined selection criteria.

REFERENCE CITED

1. Adams, Dwight E. and Anderson, Roger C. Species Response to a Moisture Gradient in Central Illinois Forests. American Journal of Botany. 1980; 67(3):381-392.

2. Amlin, Nadine M. and Rood, Stewart B. Comparative Tolerances of Riparian Willows and Cottonwoods to Water-Table Decline. Wetlands. 2002; 22(2):338-346.

3. Auble, Gregor T. and Scott, Michael L. Fluvial Disturbance Patches and Cottonwood Recruitment Along the Upper Missouri River, Montana. Wetlands. 1998; 18(4):546-556.

4. Baker, Willaim L. Climatic and hydrologic effects on the regeneration of *Populus angustifolia* james along the Animas River, Colorado. Journal of Biogeography. 1990; 17:59-73.

5. Bendix, Jacob and Hupp, Cliff R. Hydrological and geomorphological impacts on riparian plant communities. Hydrological Processes. 2000; 14:2977-2990.

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

7. Burns, Russell M. and Honkala, Barbara H. Silvics of North America, Volumne 2 Hardwoods. Wahington D.C.: United States Department of Agriculture; 1990 Dec.

8. CALFED Bay-Delta Program. ERP Projects Tracking Table [Web Page]. 2001 Jun; Accessed 2002 Dec. Available at: http://calfed.ca.gov/Programs/EcosystemRestoration/Accomplishments/ERP_Projects_Tracking_Table1.pdf.

9. ---. Final Programmatic Environmental Impact Statemement/Environmental Impact Report. Sacramento: CALFED Bay-Delta Program; 2000.

10. Dunne, Thomas and Leopold, Luna B. Water in Envrionmental Planning. San Francisco: W.H. Freeman and Company; 1978.

11. Fetherston, Kevin L.; Naiman, Robert J., and Bilby, Robert E. Large woody debris, physical process, and riparian forest development in montane river networks of the Pacific Northwest. Geomorphology. 1995; 13:133-144.

12. Florsheim, Joan L. and Mount, Jeffrey F. Restoration of floodplain topography by sand-splay complex formation in response to intentional levee breaches, Lower Cosumnes River, California. Geomorphology. 2002; 44:67-94.

13. Harris, Richard and Olson, Craig. Two-Stage System for Prioritizing Riparian Restoraiton at the Stream Reach and Community Scales. Restoration Ecology. 1997; 5(4S):34-42.

14. Huggenberger, P; Hoehn, E; Beschta, R., and Woessner, W. Abiotic aspects of channels and floodplains in riparian ecology. Freshwater Biology. 1998; 40:407-425.

15. Hunter, John C.; Beardsley, Karen; McCoy, Michael C.; Quinn, James F., and Keller, Kaylene E. The Prospects for Preservation and Restoration of Riparian Forests in the Sacramento Valley, California. Environmental Management. 1999; 24:65-75.

16. Hupp, Cliff R. Riparian Vegetation Recovery patterns Following Stream Channelization: A Geomorphic Perspective. Ecology. 1992; 73(4):1209-1226.

17. Hupp, Cliff R. and Osterkamp, W. R. Riparian vegetation and fluvial geomorphic processes. Geomorphology. 1996; 14:277-295.

18. Kalischuk, A. R.; Rood, S. B., and Mahoney, J. M. Environmental influences on seedling growth of cottonwood species following a major flood. Forest Ecology and Management. 2001; 144.

19. Keller, Kaylene E. and Quinn, James F. Identification of Landscape Scale Characteristics that Impact Valley Oak (*Quercus lobata*) Growth: Cosumnes River Preserve Restoration Sites, a Case Study. 2002.

20. Kentula, Mary E. A Comparison of Approaches to Prioritizing Sites for Riparian Restoration. Restoration Ecology. 1997; 5(4S):69-74.

21. Kentula, Mary E.; Brooks, Robert P.; Gwin, Stephanie E.; Holland, Cindy C.; Sherman, Arthur D., and Sifneos, Jean C. An Approach to Improving Decision Making in Wetland Restoration and Creation. United States: C.K. Smoley, INC.; 1993.

22. Mahoney, John M. and Rood, Stewart B. Streamflow Requirements for Cottonwood Seedling Recruitment - An Integrative Model. Wetlands. 1998; 18(4):634-645.

23. Malanson, G. P. Riparian Landscapes. Great Britain: Cambridge University Press; 1993.

24. Meffe, Gary K. and Carroll, C. Ronald. Principles of Conservation Biology. Sunderland, Massachusetts: Sinauer Associates, Inc.; 1997.

25. Mitsch, William J. and Gosselink, James G. Wetlands. New York: Van Nostrand Reinhold; 1993.

26. Nanson, Gerald G. and Beach, Harry F. Forest succession and sedimentation on a meandering-river floodplain, northeast British Columbia, Canada. Journal of Biogeography. 1977; 4:229-251.

27. O'Neill, Michael P.; Schmidt, John C.; Dobrowolski, James P.; Hawkins, Charles P., and Neale, Christopher M. Identifying Sites for Riparian Wetland Restoration: Application of a Model to the Upper Arkansas River Basin. Restoration Ecology. 1997 Dec; 5(4S):85-102.

28. Pearce, Jennie and Ferrier, Simon. Evaluating the predictive performance of habitat models developed using logistic regression. Ecological Modeling. 2000; 133:225-245.

29. Pettit, N. E. and Froend, R. H. Variability in Flood Disturbance and the Impact on Riparian Tree Recruitment in Two Contrasting River Systems. Wetlands Ecology and Management. 2001; 9:13-25.

30. Phillips, Jonathan D. A Saturation-based Model of Relative Wetness for Wetland Identification. Water Resources Bulletin. 1990 Apr; 26(2):333-342.

31. Primack, Avram G. B. Simulation of Climate-Change Effects on Riparian Vegetation in the Pere Marquette River, Michigan. Wetlands. 2000; 20(3):538-547.

32. Richardson, Curtis J. Freshwater Wetlands. Barbour, Michael G. and Billings, William D., Editors. North American Terrestrial Vegetation . Second ed. United States: Cambridge University Press; 2000.

33. Russell, Gordon D.; Hawkins, Charles P., and O'Neill, Michael P. The Role of GIS in Selecting Sites for Riparian Restoration Based on Hydrology and Land Use. Restoration Ecology. 1997 Dec; 5(4S):56-68.

34. Scott, Michael L.; Friedman, Jonathan M., and Auble, Gregor T. Fluvial Process and the Establishment of Bottomland Trees. Geomorphology. 1996; 14:327-339.

35. Scott, Michael L.; Shafroth, Patrick B., and Auble, Gregor T. Responses of Riparian Cottonwoods to Alluvial Water Table Declines. Environmental Management. 1998; 23(3):347-358.

36. Stromberg, J. C. and Patten, D. T. Instream Flow and Cottonwood Growth in the Eastern Sierra Nevada of California, USA. Regulated Rivers: Research and Management. 1996a; 12:1-12.

37. Stromberg, J. C.; Tiller, R., and Richter, B. Effects of Groundwater Decline on Riparian Vegetation of Semiarid Regions: The San Redro, Arizona. Ecological Applications. 1996b; 6(1):113-131.

38. Stromberg, Juliet C. Restoration of Riparian Vegetation in the South-Western United States: Importance of Flow Regimes and Fluvial Dynamism. Journal of Arid Environments. 2001; 49:17-34.

39. Tabacchi, Eric; Correll, David L.; Hauer, Richard; Pinay, Gilles; Planty-Tabacchi, Anne-Marie, and Wissmar, Robert C. Development, maintenance and role of riparian vegetation in the river landscape. Freshwater Biology. 1998; 40:497-516.

40. Trowbridge, Wendy B. The Influence of Restored Flooding on Floodplain Plant Distributions. Davis, California: University of California, Davis; 2002.

41. Van Splunder, I.; Coops, H.; Voesenek, L. A. C. J, and Blom, C. W. P. M. Establishment of alluvial forest species in floodplains: the role of dispersal timing, germination characteristics and water level fluctuations. Acta Botanica Neerlandica. 1995; 44(3):269-278.

42. Wheeler, Richard H. and Kapp, Ronald O. Vegetational Patterns on the Tittabawassee Floodplain at the Goetz Grove Nature Center, Saginaw, Michigan. The Michigan Botanist. 1978; 17:91-99.