Title:
Monitoring Riparian Restoration: Making the most with limited data from the Cosumnes River Floodplain

Running Head:
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Abstract

Few of California's Central Valley riparian forests remain and are thus the focus of ongoing, large-scale restoration efforts. However, few formal programs are established to monitor restoration outcomes. We collected and synthesized planting and monitoring records from the last 20 years (1985-2005) of restoration actions conducted at the Cosumnes River Preserve, which has one of the largest extant riparian forest expanses in the Central Valley and has been the subject of ambitious efforts by multiple land managers to re-establish native riparian and floodplain vegetation. We cataloged and spatially indexed monitoring data from notes, reports, dissertations, publications and personal communications with reserve managers into a geographical information system (GIS). Our GIS-based retrospective analysis of restoration activities was enabled by collation of lists of species planted, methods of planting, and management methods, such as irrigation, weed control, and protection from herbivores. We analyzed germination rates, seedling survival, and growth rates for monitoring records across 76 separate restoration locations. Our results indicate that hydrologic regime, soil composition, and to a more limited degree management actions are instrumental in ensuring germination, survival, and rapid growth of riparian forests. Furthermore, the expansive effort required to capture these data retrospectively suggests that future and ongoing restoration efforts should be accompanied by robust monitoring programs with standardized data collection and storage requirements.

Introduction

Riverine floodplains and their adjacent riparian forests provide numerous ecosystem services, which, in addition to harboring native vegetation and wildlife, they include clean drinking water, ground water recharge, flood-flow mediation, recreation, and aesthetic resources. Floodplain habitats are among the most productive and diverse, and impacted, ecosystems globally (Tockner & Stanford 2002; Zedler & Kercher 2005); they are also at risk of further degradation by innumerable anthropogenic stressors. Natural floodplain ecosystems are a product of, and adapted to, highly variable hydrologic regimes – typified by droughts, catastrophic floods, and frequent periods of inundation – expressed across seasonal, yearly, and decadal timescales. This hydrologic regime drives physical and biological processes dependent upon changes in the timing, magnitude, duration and frequency of flooding (Power et al. 1995).

California's Central Valley riparian areas, of which less than 5% remain (Hunter *et al.* 1999), have been identified as priorities for conservation and restoration (CALFED 2000). Large scale restoration of California's low-gradient rivers and their floodplains has been largely semi-passive in nature – in essence, through the structural manipulation of existing levees either through setbacks or purposeful breaching. Restoration is achieved by the natural succession of flood dependent ecological communities – as it is the only cost effective means of doing so over large areas. However, past semi-passive restoration efforts have not been uniformly successful either in generating high quality, productive native-dominated vegetation or in re-establishing functioning food webs supporting floodplain sentinel species (e.g., birds, fishes, etc.). Active restoration – the direct propagation of desirable plant species – has been implemented on numerous occasions as it provides some control over the composition of resulting forests; however, it is labor-intensive and bypasses natural successional processes. Furthermore, restoration projects have generally been inadequately monitored to assess success or even judge adequacy of implementation. More specifically, to our knowledge gauging differential trajectories between active and semi-passive restoration techniques through monitoring has rarely if ever been attempted across thousands of floodplain hectares in the Central Valley region.

The lack of restoration monitoring is not unique to California's Central Valley. In fact, Berhnhardt *et al.* (2005) estimate that upwards of $15 billion has been spent on riverscape restoration with only 10% of such projects having formal assessment and monitoring programs. Their analysis revealed that most restoration projects were not designed to monitor progress, analyze monitoring results, or evaluate consequences of restoration activities. The disconnect between regulatory-funded restoration and sound science is further exacerbated by the lack of an experimental design in developing monitoring programs prior to restoration activities to address ecological success metrics. Typically, restoration projects are funded for implementation solely, without continuation funds for short or long-term monitoring (Wohl *et al.* 2005). Unfortunately, it is also recognized that initiatives for restoration are often borne more out of legal contexts than ecological ones (Zedler 2005). As Wohl *et al.* (2005) point out, there is an outstanding need for science in riverscape restoration, which in principle would embrace complexity and uncertainty, define an *a priori* theoretical framework to identify generalities across systems, conduct monitoring at appropriate scales of reference, and embed science within decision making and implementation. Zedler (2005) goes so far as to suggest 'adaptive restoration', executed as successive experiments, and hence implicit monitoring, as a means to reinforce scientific continuity in meeting restoration goals. Such an approach is complementary to 'adaptive monitoring' advocated by Florsheim *et al.* (in press), wherein the frequency and sophistication of the monitoring technique is dependent upon the measurable range of ecosystem changes required for evaluation. Foremost in improving restoration outcomes, however, is to reconcile the paradox of resource managers wanting practical guidance from scientists (Young *et al.* 2005) and scientists needing standardized and frequent data collection from managers (Holl *et al.* 2003).

There are myriad processes operating at coarse spatial scales that influence riparian restoration trajectories (Holl *et al.* 2003), including anthropogenic alterations (e.g., dams, levees, groundwater withdrawal), physical processes (e.g., floods and base flow, in terms of duration, magnitude, and frequency), and ecological processes (e.g., population-level dynamics such as dispersal and colonization, as well as community-level interactions that regulate seed dispersers, pollinators, herbivores, etc.). Effective restoration monitoring in a perfectly designed and executed research program would capture data for each of these processes and actors across a range of spatial and temporal dimensions before and after the restoration experiment is conducted. However, such programs are labor-intensive, difficult to fund for the reasons stated above, and may or may not correspond to landowners' and funding agencies needs to carry out management actions. Thus, we are often challenged with conducting retrospective analyses with limited data, and a less than ideal experimental design. That is the case in this study. Nevertheless, it represents one of the best-supported and well-regarded floodplain management programs in the Central Valley and the Sacramento Delta region, and thus provides insights not accessible through smaller, more controlled, studies.

Riparian Monitoring Framework & Analysis

Generalized Riparian Systems

Our analysis of riparian vegetation restoration monitoring is embedded within the context of generalized riparian systems ecology. Riparian and floodplain landscapes are the result of the interaction between hydrology – moving water – and landforms which create a mosaic of habitats for colonization by aquatic and terrestrial plants and their subsequent succession to other ecological communities. A major driving force in the creation and maintenance of these landscapes is the flood pulse, or fluctuation in river discharge, and its influence on connectivity between aquatic and terrestrial systems (Tockner *et al.* 2000). The mosaics of riparian habitat are created by the formation of distinct alluvial landforms, characteristically including oxbow lakes, backwater sloughs, point bars, terraces and cut-offs (Mount 1995). Natural flow regimes mobilize gravel, sand, silt and large woody debris creating physical disturbance over spatiotemporal dimensions, which sustain vegetation mosaics (Poff *et al.* 1997). Timing and magnitude of ecosystem disturbance not only depends on the magnitude and timing of flood flows, but also on underlying floodplain topography and routes of connectivity (Church 2002). Unimpeded rivers and tributaries have dynamic properties, most notably their geometry, in which active erosion and deposition form channels, point bars, and natural levees (Dollar 2004), which in turn guide the distribution of flooding events rich with nutrients and fine-grained sediments over adjacent floodplains (Tockner *et al.* 1999). These dynamic riverine processes – movement of water and sediment – have profound effects on the distributional patterns of vegetation, its structure and its composition (Stromberg *et al.* 1993; Naiman & Decamps 1997).

Within this context, we focused our study on riparian restoration efforts within the holdings of the Cosumnes River Preserve (CRP) (Figure 1), a collection of parcels covering over 18,000 hectares that are managed as working landscapes and natural habitat preservation areas by a coalition of state, federal and non-profit organizations. These lands include a lowland river - experimental floodplain, which is located on CRP lands adjacent to the Cosumnes River proper. Restoration of the agricultural fields adjacent to the river was initiated by an accidental levee breach (ca. 1985), and subsequently by intentional breaching of levees during the late-1990's. Since the restoration of floodplain connectivity, the river channel and its floodplain have undergone considerable topographic change due to localized deposition and scour (Florsheim & Mount 2002; Florsheim & Mount 2003). These geomorphic changes have increased habitat heterogeneity due to the colonization of tree and herbaceous vegetation species on floodplain sand deposits. Other parcels represent freshwater wetlands, oak woodland savannahs, and working landscapes, such as rice fields.

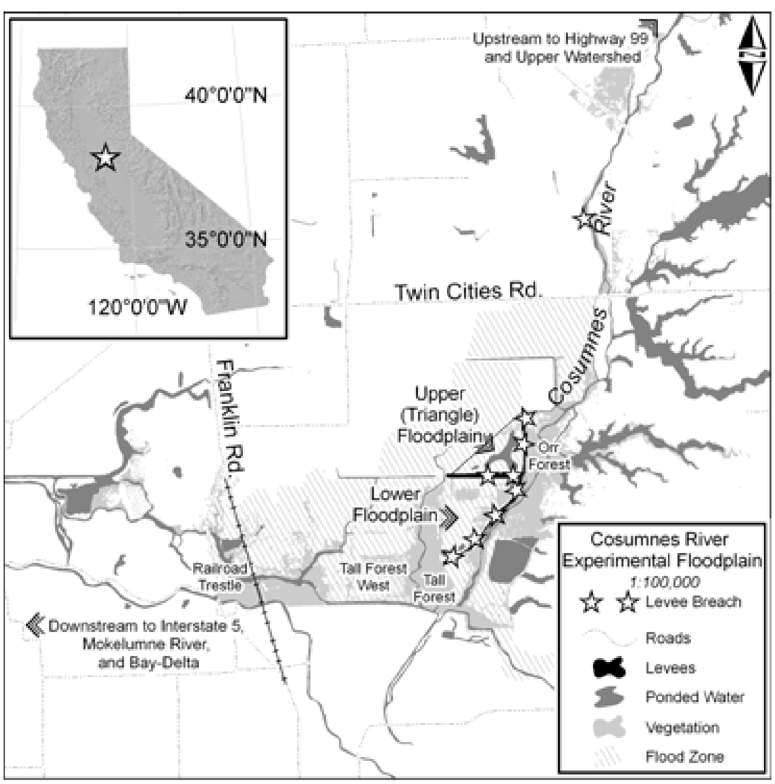

Figure 1 Site location map of the Cosumnes River Preserve. The Cosumnes River Preserve (CRP) is located in southern Sacramento County, California, USA, along the Cosumnes River. Our study included numerous restoration sites between Interstate 5 and Highway 99.

The lower Cosumnes River is considered a dynamic, low-gradient, multi-channel anastomosing system dominated by frequent avulsions and regular inundation of the floodplain during winter and spring under historic conditions (Florsheim & Mount 2002). Since the arrival of Euro-Americans in California, however, the Cosumnes River and its watershed have been impacted by a range of land use activities, including hydraulic mining, grazing, and agricultural conversion. These activities increased sediment loads and resulted in dramatic changes in the geomorphic structure of the lowland channel and floodplain. Once the hydraulic mining sediment source was eliminated in the early-1900s, channel incision, initiated by levee construction and channel constriction, occurred longitudinally throughout the previously aggraded bed (Constantine *et al.* 2003). Widespread conversion of floodplain forests and wetlands to agricultural fields also took place during the early 1900's. Today, the river is confined to a single channel and remains almost entirely disconnected from its floodplain except during high flows when levee breaches are overtopped (~25 m^3/s). Although winter floods are largely unaffected by regional groundwater withdrawals for consumptive use, late-summer flows certainly are affected (Fleckenstein *et al.* 2004); however, the diminished groundwater availability and its deleterious affect on riparian forests has been buffered by the presence of perched aquifers (Niswonger 2006).

Study Site Restoration Activities

In an effort to improve habitat conditions for a variety of sentinel species, the Cosumnes River Preserve is using two different approaches to restoring riparian and floodplain ecosystems. One method is to plant trees directly into the soil either as seeds (acorns), seedlings, or cuttings. Active restoration provides some control over the composition of incipient forests, but is labor-intensive and bypasses natural successional processes. The other is a semi-passive approach of breaching levees and returning the "natural" fluvial processes to the floodplain. Levee breaches and setbacks can cover large areas and emulate natural floodplain processes, but there is no guarantee that re-vegetation will favor native species or restore a desirable mix of habitat structures. In practice, both restoration methods have generated high productivity cottonwood and oak forests in some places, but have also resulted in high concentrations of invasive plant species and stunted trees in others. Environmental conditions resulting in productive gallery forests dominated by native trees have not been systematically examined over large areas, but flood regime, access to groundwater, and disturbance mechanisms all have been shown to play some role.

Methods

Data Compilation Methods

We collected and synthesized restoration planting and monitoring records from the last 20 years of CRP management (1985-2005). These data were in the form of notes, reports, dissertations, publications and personal communications with reserve managers. We attributed lists of species planted, methods of planting, irrigation, weed control, and herbivory protection, percent germination by species, and percent survival by species for 76 separate restoration locations.

The majority of our restoration planting and monitoring information came from year-end restoration reports written by the current or acting restoration manager at the Cosumnes River Preserve between 1991 and 1994 (Griggs 1991a; Denny & Griggs 1992; Morris 1993; CRP 1994; TNC 1994). These reports contained a combination of narrative site and restoration planting histories, tables of planting details, and graphs of monitoring results. Information on dates, methods, and earlier history of older active restoration sites was derived mostly from expert knowledge, partially because many written records were lost in a fire at CRP headquarters in 1995. There was definite evidence of institutional memory loss even within the short timeframe of these reports (1991-1994), such as inconsistencies in number of seeds planted, dates planted, as well as colloquial names of planting locations. Determining the geographic placement of restoration sites presented a constant challenge. Few maps were provided in the respective reports, and narrative descriptions of planting locations were not adequate to determine planting site boundaries. Furthermore, colloquial names have a tendency to change through time and by user. We attempted to minimize these impacts by using coarse map units, multiple source data, and cross-verification with former and current CRP managers.

Information from year-end restoration reports was supplemented by unpublished notes (Denny 1991, 1992), restoration plan documents (CRP 1991; Griggs 1991b; TNC 1991), and personal communication with past preserve managers (Denny, Griggs, Reiner). Active restoration site locations were identified and mapped primarily through electronic sketches and GIS-based digitizing.

Site management plans and reports written by independent contractors (e.g., Stanley *et al.* 1987; Vick *et al.* 1997; May 2000) were reviewed, but contained little substantive data. These reports describe site-specific current and historic conditions (vegetation, hydrology, soil characteristics), and recommend various restoration and monitoring actions. Few of these management suggestions were followed, though the overall restoration goals put forth in each plan are characteristic of ongoing restoration activities at CRP (i.e., levee breaching, tree planting and invasive species control).

Dissertations and reports by University of California, Davis graduate students evaluating vegetation patterns and restoration success at CRP contained the bulk of our monitoring information. Vegetation Patterns and Processes of Natural Regeneration in Periodically Flooded Riparian Forests in the Central Valley of California (Tu 2000) provided information on the species composition and ages of several reference forests based on tree ring analyses. In a USDA technical report on the relationship between soil moisture availability and oak seedling establishment and survival, Meyer (2002) estimated forest stand ages within one of these same reference forests (Tall Forest). While the separate analyses of tree age within Tall Forest at the Cosumnes River Preserve by Meyer (2002) and Tu (2000) both used tree ring sampling within study plots, their study sites overlap, and their conclusions on forest stand ages are not consistent with one another. Tu (2000) estimated a 1920 establishment of the central Tall Forest, and a 1965 - 1975 establishment of the lower Tall Forest. Meyer's sites are more complex and ranged in average year of establishment from 1939 to 1957. We chose to use 1920 as the most conservative estimate establishment year for Tall Forest to minimize the possibility of over-estimating growth rates.

Other theses provided additional sources of information. Landscape scale analysis of riparian restoration, site selection and adaptive management in California's Cosumnes River Floodplain (Keller 2003) provided site and planting history for fourteen restoration sites at the Cosumnes

River Preserve. Associated geodata provided by Keller assisted with locating restoration site boundaries. Oak canopy height data collected by Keller at these fourteen restoration sites contributed to analysis of oak growth rates. The influence of restored flooding on floodplain plant distributions (Trowbridge 2002), provided restoration planting and site histories for four of our restoration sites.

A report by Chirman (1993) provides a subjective description of 1993 vegetation conditions at three reference sites, including species lists, and details the restoration plan at one restoration site. No data were used from this report, but it provided useful background information and documented restoration plan rationale. Other reports included three by Swiecki & Bernhardt (1990a; 1990b; 1991), who studied minimum input techniques for oak restoration at three sites. Oak growth data from these studies were integrated with data from year-end restoration reports.

Trowbridge *et al.* (2005) monitored oak growth within four restoration sites over a three year period (1999 to 2001). Data from these monitoring efforts were unavailable, but the results and discussion of their findings contribute important knowledge to our understanding of our own research results. Specifically, they found that oak growth rates are highest at intermediate levels of flood inundation, and that young oak densities in a breached passive restoration site surpassed that of oak densities in adjacent breached active restoration sites where oaks were planted. Although oak densities were higher in the passive site, growth rates were higher in the active sites. This is attributed to the fact that canopy cover was high in the passive site, whereas, to date, the spacing between planted trees has largely prevented canopy contact and shading in the actively planted sites.

GIS Methods

We implemented a geographical information system (GIS) to house all tabular and geospatial data within a common spatial framework using a personal geodatabase in ArcGIS 9.1 (ESRI, Redlands, CA). The ArcGIS software suite contains a number of standard analysis algorithms (e.g., intersect, buffer, etc.), which we implemented to create relevant spatial data for our analyses of soils, management, infrastructure, and hydrography.

Knowledge of on-the-ground management and landscape features was used to supplement restoration analysis site data. For each restoration site, we cataloged its restoration status, levee relationship, its previous land use, history of topographic leveling and irrigation, and other ancillary data about the site, such as grazing and flooding history.
We calculated average distances and angles from the centroids of each restoration site to the nearest breach, river, or water of any kind (flowing or standing). Water and river feature locations were heads-up digitized from water bodies visible in high resolution aerial photos from May 2002. Breaches were heads-up digitized, using various underlying aerial photography, based on known breach locations.

Soils

We used Sacramento County SSURGO soil data (Version 2.0) available online from the Natural Resources Conservation Service (NRCS) Soils Data Mart website[1]. The Soil Data Viewer Extension to ArcMap, available from NRCS, was used to create soil-based thematic layers

[1] http://soildatamart.nrcs.usda.gov/

including available water capacity, depth to water table, drainage class, flooding frequency class, hand planting suitability, hydric rating, hydrologic group, irrigation capability, nonirrigated capability, suitability for mechanical site preparation, potential seedling mortality, soil map unit code, soil name and substratum type. We intersected these soil-based thematic layers with restoration site polygons, and then calculated the area and area-weighted percent of each soil-based parameter within each site.

Analytical Methods

Our analytical approach is necessarily a hybrid in that implementation of varied restoration projects, in conjunction with a monitoring methodology that was haphazard, resulted in a less than cohesive dataset. As Holl *et al.* (2003) describe, there a number of alternative approaches to analyzing restoration outcomes, which include several statistical approaches. We implement more classical methods here, in part due to their familiarity, but less so in a formal hypothesis testing structure. We use descriptive and classical statistics here to show observable trends and correlative relationships between disparately collected monitoring data and coarser landscape-scale factors. Future analyses will want to capitalize on the information-theoretic approach with its explicit model specification, in addition to employing longitudinal data analysis configured to handle repeated measures in irregularly spaced time events.

Results

We analyzed three specific phases of plant development of importance to active restoration activities: germination, survival, and growth. Germination and seedling survival was only monitored in active restoration sites; however, see Tu (2000) and Trowbridge *et al.* (2005) for a discussion of semi-passive restoration techniques and outcomes on riparian plant establishment. A total of 76 restoration sites, categorized by levee breaching, land use, and site history, were used in the analysis (Table 1). Semi-passive restoration events, while similar in number to active ones (36 vs. 40), were substantially greater in total area covered (2700 ha vs. 170 ha; Table 2).

Restoration Type	active (40) or semi-passive (36)
Success	failure (14), forest reference site (5), no goal (18), success (37), unknown (2)
Levee Breach	breach (11), unbreached (65)
Previous Land Use	animal agriculture (18), natural (3), plant agriculture (30), semi natural (22), unknown (3)
Previous Irrigation	no (36), yes (40)
Grazing History	grazed (37), ungrazed (37), unknown (2)
Level History	leveled (42), not leveled (29), scraped (3), unknown (2)

Table 1 Restoration site categorization. Restoration sites (n=76) were categorized by levee breaching, previous land use, and site history, showing the varied nature of the riparian restoration activities on CRP lands.

Vegetation Planting	Levee Status	Sites (n)	Total Area (ha)	Mean Site Area (ha)	Minimum Site Area (ha)	Maximum Site Area (ha)
Active	Breached	4	14.17	3.54	1.14	9.70
Active	Unbreached	36	154.39	4.29	0.22	20.25

Semi-Passive	Breached	7	166.38	23.77	7.36	71.09
Semi-Passive	Unbreached	29	2555.32	88.11	4.62	487.29

Table 2 Restoration sites categorized by type and levee status. Semi-passive restoration activities covered a substantially larger area than active ones.

Active Restoration

We coded restoration sites which were actively planted by CRP staff and/or volunteers since CRP acquired the property as representing 'active' restoration. Methods employed ranged from pressing acorns into the ground by boot, with no protection or irrigation, to planting of seedlings with prior site preparation, with or without some combination of herbivory protection (i.e., deer and rabbit fencing), weed control (e.g., thatch mats or black plastic), and ongoing summer irrigation. We analyzed 40 active restoration sites covering 168.5 ha. Active sites were generally small ($\bar{x}$ = 4 ha), ranging from 0.2 ha sites along irrigation ditches to a 20 ha restored floodplain site.

We found 4 active restoration sites subject to flooding due to accidental and/or intentional levee breaches. We defined these sites as 'breached active'; they ranged in size from 1.1 to 9.7 hectares ($\bar{x}$ = 3.5 ha). Two of the four sites are directly adjacent (<30 m) to the Cosumnes River, hydrologically connected via an engineered levee breach. The remaining two sites are not directly adjacent to the river, and are 500-800 m away from the nearest levee breach, but are hydrologically connected to the river due to their floodplain position.

The remaining 36 'unbreached active' sites are generally farther from the Cosumnes River channel and experience less hydrological connectivity than the breached active sites. Only 3 unbreached active sites were adjacent to the river (<30 m). There were 27 unbreached active sites containing or adjacent (<30 m) to a water feature (i.e., rivers, creeks, sloughs, lagunitas, irrigation ditches, spring-flooded rice fields and/or ponds). We identified 8 unbreached active sites protected by levees. Tthe remaining sites were hydrologically unconfined, though many sites only flood during high flow events due to channel incision, distance to channel, and changes in elevation.

Active sites were quite heterogeneous in regards to prior land use, pre-restoration grading and grazing. All four breached active sites were leveled, ungrazed agricultural fields (rice or row crops) prior to levee breaching. Past land uses of the 36 unbreached active sites include: row crop (19 sites), irrigated pasture (6 sites), grassland (5 sites), dry pasture (3 sites), fallow field (2 sites), and field edge (1 site). Thirteen unbreached active sites were historically grazed, and 27 were leveled, prior to CRP acquisition.

Semi-Passive

There are 36 sites delineated as 'semi-passive' restoration sites that have not been actively restored under CRP management (see above). These restoration sites are considered semi-passive in that they have been monitored for compositional and structural habitat changes due, in part, to changes in hydrological connectivity (levee breaches and subsequent floodplain inundation).

Seven semi-passive restoration sites covering 166 ha ($\bar{x}$ = 23.4 ha; 7.4 – 71.1 ha) are subject to flooding due to accidental or intentional levee breaches. These are defined as 'breached passive'. All breached passive sites are located within 30 m of the Cosumnes River. Three of these sites were row cropped prior to levee breaching. One site was sand farmed, meaning that floodwaters were allowed onto the floodplain to entrain large quantities of sand, which was later collected and sold for municipal works.

The remaining 29 semi-passive sites covering 2555 ha ($\bar{x}$ = 88.1 ha; 4.6 – 487.3 ha) are variably subjected to natural or managed flooding depending on their geographic relationship to levees, incised channels, and the magnitude and duration of flow events. These are defined as 'unbreached passive'. Fourteen of these sites are within 30m of a river, and all are within 30 m of a water feature (e.g., ponds or lagoons).

In general, unbreached passive sites experienced less past disturbance than other restoration sites. Four sites were already forested and ten were grassland at the time of CRP acquisition. History of grading and grazing is incomplete, but only two sites were leveled and row cropped, and only one site was used as pasture. Fourteen sites, including one of the remnant forest sites (Orr Forest), were grazed year-round prior to CRP acquisition. Currently seven unbreached passive sites are grazed in the summer, and one site (Cougar Wetlands) is mowed annually to maintain an open wetland for waterfowl habitat.

Germination

Site specific cultural factors, including herbivory protection, weeding, augering, and summer irrigation, were examined to determine which, if any, affected germination of Valley Oak acorns at 20 restoration sites within CRP. Herbivory protection alone did not provide a protective effect on germination rates (P=0.16), but did provide a protective effect against germination failure (LR χ^2= 3.88; P=0.05). Neither weed control (P=0.50), site preparation with an auger (P=0.98), nor summer irrigation (P=0.18) promoted germination rates; nor did they provide a detectable protective effect against germination failure.

We examined rates of Valley Oak germination and chose a threshold of greater than or equal to 75% germination as a suitable restoration target for success. In this regard, SSURGO data suggest that Hydric Group D soils, defined as low infiltration rates and high runoff potential, are detrimental to high germination rates. A logistic regression of Valley Oak restoration results with >= 75% germination against the percent area of a restoration site within the Hydrologic Group D soils resulted in a significant negative relationship. In other words, increasing amounts of poor infiltration soils resulted in an increased probability of having less than a 75% germination rate for acorn plantings (pseudo-R^2=0.31; P=0.0037; ROC AUC=0.75). However, our data suggest that Hydrologic Group D soils must be prevalent (>= 77.5%) to have more than a 1:3 chance of not meeting the preferred germination rate threshold (Figure 2).

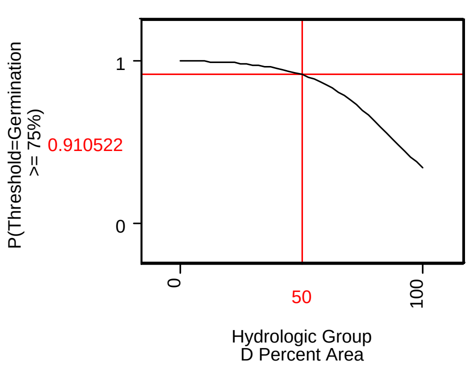

Figure 2 Logistic fit of Germination to Hydro Group D Soils. Response profile graph of germination success probability (>=75%) as a function of restoration site percent area that is in

Hydrologic Group D, which are soils that are considered to have low infiltration rates. Sites with less than 50% of its soils in Group D have greater than a 90% chance of reaching the 75% germination threshold.

The probability of Valley Oak germination failure, defined here as 0% germination, in relation to soil constituents was most marked in relation to the percent of a restoration site designated as having a flood frequency class of 'None' in the SSURGO data. A logistic regression of germination failure against this soil descriptor resulted in a significant positive relationship. That is to say that the increase in percent of soils never inundated increased the likelihood of germination failure (pseudo-R^2=0.26; P=0.0226; ROC AUC=0.77). Restoration sites with more than 50% of the area's soils free from flood inundation have a greater than 58% chance of their germination efforts not failing (Figure 3).

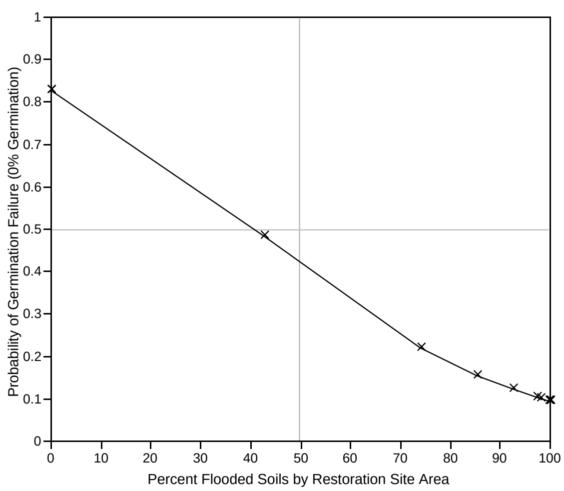

Figure 3 Fitted logistic response graph of germination failure probability against the percent of restoration site soils that are flooded. The probability function shows that as restoration sites soils are flooded, germination failure decreases accordingly.

Other soil descriptors contained in SSURGO, such as available water capacity, depth to water table, and hydric rating had no significant relationship to our measures of germination rate, failure, or success. One series of soil components, when combined, did show some relation to Valley Oak germination. Specifically, the second Eigenvector of a soil drainage class principal components analysis (PCA) was a significant factor in separating out differences in germination failure (0% germination) and germination success (>= 75% germination). The second component of the PCA had principal loadings from 'Moderately Well' (-0.57) and 'Well' (0.82) drained soils (PCA 2 = 25.8%) (Table 4). Thus, the separation of moderately well and well drained soils along the second axis significantly predicted both Valley Oak germination failure (P = 0.004) and germination success (P = 0.0015) in likelihood ratio tests, suggesting further that well drained soils are indeed important considerations.

Eigenvalue	1.9448	1.0319	0.9868	0.0365
Percent Variance Explained	48.6204	25.7980	24.6697	0.9119
Cumulative Percent	48.6204	74.4185	99.0881	100.0000

	Eigenvectors (Area-Weighted)			
Drainage Class Moderately Well	0.57569	-0.57342	0.06282	0.57950
Drainage Class Somewhat Poor	-0.70807	-0.01148	-0.08342	0.70110
Drainage Class Very Poor	-0.11742	-0.00971	0.99303	-0.00060
Drainage Class Well	0.39170	0.81912	0.05458	0.41549

Table 4 Soil drainage principal components analysis on correlations. This table shows the four principal components from area-weighted soil drainage characteristics by restoration site. The first PCA axis separates moderately well and well drained soils from somewhat poor to very poor ones. The second axis separates moderately well from well drained soils. The third axis isolates the poorest draining soils from the others.

The dominant named soil series, by percent area of restoration site, had a moderate relationship to Valley Oak germination as determined by Correspondence Analysis. Restoration germination efforts were coded as successful (>= 75% germination), failure (0%), or intermediate. There were a total of 7 named soil series across the 20 restoration sites where acorn germination was attempted. While the categorical tests were statistically non-significant (P=0.28), the CA does show the relative relationships between soil series and germination along the first Eigenvector (Figure 4), which accounted for 53% of the inertia within the model comparison. In particular, Galt Clay stands out as a particularly poor soil for Valley Oak acorn germination. Clay properties in the SSURGO data are expressed as percent clay estimates, which we used to create an area-weighted mean value of percent clay at each restoration site. While this clay estimate does covary with other soil parameters, such as drainage class and hydric soil group, it was a significant predictor of overall germination rates (R^2_{adj}=0.28; P=0.0096) with each 10% increase in clay content decreasing germination rates by 16.3% (Germination Rate = 100 – 1.63 Percent Clay).

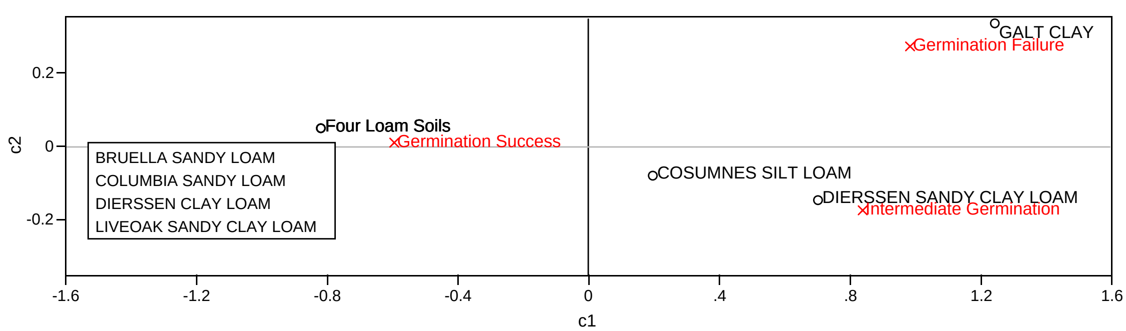

Figure 4 Correspondence analysis graph of soil series types and categorical germination response. Germination failure was defined as 0% germination, germination success was equivalent to 75% or better germination rates, and intermediate germination was greater than 0% and less than 75%.

Lastly, two land use parameters were influential in observed Valley Oak germination rates. One, grazing history had a significant negative effect on germination rate (P=0.0207; Wilcoxon χ^2 = 5.35) wherein restoration sites previously grazed had a mean germination rate of 45% versus ungrazed, which averaged 72%. Separating previous land uses into irrigated pasture, row crop, and grassland resulted in significant differences in site-based germination success (>=75%). All sites that were formerly irrigated pasture (n=3) had less than 75% germination rates, unlike the observed success ratios of grassland (3:1) and row crops (8:3). The differences among groups were statistically significant (P=0.036; LR χ^2=6.67). These results suggest that the combination of site history and soil characteristics are important in determining the success of restoration efforts relying on acorn planting as a strategy.

Forward, stepwise multivariate regression did not, however, include any land use parameters within a combined model to predict germination rates. Percent non-clay of the soil surface layer in combination with herbivory protection was the single best model (R^2_{adj}=0.52; P=0.0007), as judged by adjusted coefficients of determination and Akaike Information Criterion (AIC) scores, which lessens overfitting by penalizing the number of model parameters used.

Seedling Survival

We examined restoration planting survivorship across a range of restoration sites and planted species. These records were collected from expert opinion (n=31), field sampling (n=7) and complete field inventory (n=22) for the historical record 1998-2005. The records were predominately for Valley Oak (n=26) and generic willows (n=14), but included seven other species of shrubs and trees.

We analyzed all records across species to assess any global trends in seedling survival, which ranged from 0-100% ($\bar{x}$ =53.3%; median=61%). There were no detectable biases in method of survivorship estimation (P=0.89), number of plantings within a restoration site (P=0.51), nor year of observation (P=0.52) and thus were not considered further. Global trends in survivor class (<=25%, 26-50%, 51-75%, >75%) showed that levee breaches unsurprisingly inhibited survival (LR χ^2=10.4; P=0.015).

To account for differential effects of vegetation types, we used two Manual of California Vegetation series (MCV -- Sawyer & Keeler-Wolf 1995), to distinguish between Fremont Cottonwood – Mixed Willow series, which had a significantly lower survivorship ($\bar{x}$ = 0.36) than the Valley Oak series ($\bar{x}$ = 0.68; Wilcoxon χ^2 = 9.12; P=0.025) (Table 4).

Clay content in surface soils, as estimated from an area-weighted average of SSURGO map units within a restoration site, revealed a strong non-linear trend that differed between vegetation series. Valley oak series observations showed a negative trend (P=0.13) in survivorship when regressed against percent clay, unlike the cottonwood-willow series observations, which were significantly positive (P=0.0002) (Figure 5). A nested model with MCV class and percent clay was highly significant (P<0.0001), showing the same opposing trends between series. Two other parameters were also significant predictors when added to multivariate regression model containing MCV series nested within site percent clay (R^2_{adj}=0.36; $F_{5,54}$=7.68); breaching and distance to water feature factors showed that higher survival rates were related to unbreached sites and sites farther from water features (Table 5).

Our final analysis of seedling survival was for a limited number of restoration sites where the specific management history of site preparation and management was well-documented. We identified a total of 19 restoration site activities with detailed seedling survival information (Table 6). A forward stepwise regression model of landscape factors (e.g., site elevation, distance to water feature, soils) and site management factors (as in Table 6) resulted in a two factor model, explaining 27% of the variance (R^2_{adj}=0.27; P=0.03), which showed that herbivory protection had a positive effect on seedling survival (P=0.01) and augering a negative effect (P=0.05). However, given the non-representative locations of known augering events, the model more likely suggests no added benefit from this treatment. Neither weed control (P=0.59) nor summer irrigation (P=0.88) showed a protective effect on seedling survival for these restoration events.

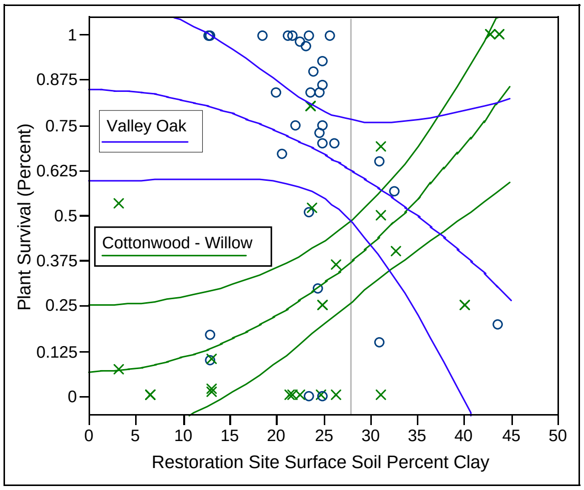

Figure 5 Graph of non-linear relationship between seedling survival rates and soil clay content by Manual of California Vegetation series. A nested model of MCV series within area-weighted surface soil content – as a quadratic term – shows the non-linear differential effects between Valley Oak and Cottonwood-Willow series. The intersection of the 95% confidence intervals of the fitted relationship show that there is no clear advantage in seedling survival rates by series when soil clay content is greater than ~27.5%.

MCV Series	Scientific Name	Monitoring Samples (n)	Seedling Survival Rate				
			Q25	Median	Q75	Mean	Std Dev
Fremont Cottonwood - Mixed Willow	*A. negundo L.* var. *californicum* (Torr. & A. Gray) Sarg.	5	0.00	0.00	0.01	0.00	0.01
Fremont Cottonwood - Mixed Willow	*Alnus rhombifolia* Nutt.	1	0.00	0.00	0.00	0.00	
Fremont Cottonwood - Mixed Willow	*Cornus sericia* ssp. *occidentalis* (Torr. & A. Gray) Fosb.	1	0.01	0.01	0.01	0.01	
Fremont Cottonwood - Mixed Willow	*Populus fremontii ssp. fremontii* S. Watson	8	0.25	0.52	0.95	0.54	0.37
Fremont Cottonwood - Mixed Willow	Salix sp. (including *S. exigua*, *S. goodingii*, *S. lasiolepis*, *S. lucida*)	14	0.09	0.38	0.80	0.45	0.36
Valley Oak	*Fraxinus latifolia* Benth.	3	0.17	0.73	0.93	0.61	0.39
Valley Oak	*Quercus lobata* Née	26	0.63	0.84	1.00	0.74	0.29
Valley Oak	*R. californica* Cham. & Schldl.	1	0.00	0.00	0.00	0.00	
Valley Oak	*Sambucus mexicana* DC.	1	0.10	0.10	0.10	0.10	

Table 4 Matrix of seedling survival rates by Manual of California Vegetation series. Two series from MCV are detailed by restoration attempts for various species by number of sites and quantiles of survivorship; mean response and its standard deviation is also shown.

Summary of Fit

RSquare	0.415667
RSquare Adj	0.361562
Root Mean Square Error	0.307037
Mean of Response	0.5285
Observations (or Sum Wgts)	60

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	5	3.6212775	0.724256	7.6826
Error	54	5.0906875	0.094272	Prob > F
C. Total	59	8.7119650		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.0456816	0.227492	0.20	0.8416
MCV[Fremont Cottonwood - Mixed Willow Series]	-0.141051	0.040893	-3.45	0.0011
MCV[Fremont Cottonwood - Mixed Willow Series]:(Pct Clay)	0.0107484	0.005696	1.89	0.0645
MCV[Valley Oak Series]:(Pct Clay)	-0.014834	0.009477	-1.57	0.1234
Breach[breached]	-0.123804	0.061717	-2.01	0.0499
LN Water Feature Distance	0.0689863	0.04051	1.70	0.0943

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
MCV	1	1	1.1216091	11.8976	0.0011
Pct Clay Nested[MCV]	2	2	0.5640077	2.9914	0.0586
Breach	1	1	0.3793504	4.0240	0.0499
LN Water Feature Distance	1	1	0.2733898	2.9000	0.0943

Sequential (Type 1) Tests

Source	Nparm	DF	Seq SS	F Ratio	Prob > F
MCV	1	1	1.4909768	15.8157	0.0002
Pct Clay Nested[MCV]	2	2	1.4593866	7.7403	0.0011
Breach	1	1	0.3975243	4.2168	0.0449
LN Water Feature Distance	1	1	0.2733898	2.9000	0.0943

Table 5 showing statistical details of multivariate regression of restoration seedling survival. A multiple factor least squares regression of seedling survival rates against a nested MCV series within percent clay content with two sequential factors (breach category and log transformed distance to water feature) shows that seedlings have a higher survival rate when they are farther from breaches and water features, such as rivers and sloughs, likely due to the disturbance processes associated with high volume floods.

Site	Species	Site Augering	Herbivory Protection	Summer Irrigation	Weed Control
Blue	QULO	unknown	no	yes	unknown
Blue	Willow	no	no	yes	yes
CASTNW	SAME	unknown	no	no	no
CW	POFR	yes	yes	yes	yes
CW	Willow	yes	yes	yes	yes
D2NORTH	QULO	no	yes	no	yes
EARTHSEA	ROCA	unknown	unknown	no	unknown
Green	ACNE	unknown	no	yes	yes
LOWWEST	QULO	unknown	unknown	no	no
NETF	QULO	no	no	no	no
Red	ACNE	unknown	no	yes	yes
STORMN	POFR	unknown	no	yes	no
STORMN	Willow	no	no	yes	no
STORMS	POFR	unknown	unknown	yes	no
STORMS	Willow	no	no	yes	no
TRAILHD	FRLA	unknown	yes	yes	yes
TWOOAKS	QULO	unknown	yes	yes	yes
Yellow	QULO	unknown	no	yes	yes
Yellow	Willow	no	no	yes	yes

Table 6 showing selected riparian restoration site activities with details in regards to site preparation and management. There were 14 sites identified with 8 target species with some level of information regarding site preparation (augering) and post-planting management such as herbivory protection, summer irrigation, and weed control.

Growth Rates

We examined growth rates of actively planted valley oak (*Q. lobata*) from synthesized monitoring reports as a function of restoration success. We calculated differences in tree heights over the range of the monitoring period to derive growth rates per year. We analyzed the averaged annual growth rates for active valley oak restoration sites in relation to irrigation schedule (number of years), soils, and site history.

Trees planted during active restoration were sampled sporadically over a period of 18 years (1987 - 2005) to obtain biometric measures of tree growth. We analyzed tree height growth measurements using two methods: absolute growth rates (*AGR*) and relative growth rates (*RGR*). Of the 82 direct observations, a total of 51 had sufficient data to calculate temporal change metrics. These observations covered 17 restoration sites across 7 combinations of land use, grading, and grazing history (Table 7).

AGR

Absolute growth rates ranged from 6 – 42 cm/yr ($\bar{x}$ = 15.6 cm/yr; sd = 10.8 cm/yr) in the 51 observations. Neither prior land use nor grazing history were significantly different in AGR; however, site grading showed a significant nonparametric difference when leveled prior to restoration (Kruskal-Wallis χ^2 = 12.4, P=0.02) where leveled restoration sites had a much greater AGR for planted valley oaks than sites either not leveled or scraped. There were no statistical differences between irrigated and non-irrigated sites (Wilcoxon Z = 0.82; P=0.41) and years of irrigation following restoration showed no significant trend either (P=0.44). Absolute growth rate did significantly vary as a non-linear function of distance from water features (P=0.0082) by showing a unimodal peak at ~500m from rivers or sloughs, suggesting positive growth as a balance of flooding disturbance and desiccation at either end of the distance spectrum (AGR = 7.7364946 + 0.0615572 distance - 0.0000572 distance m^2). There were no detectable effects from available water capacity (P=0.57), depth to ground water (P=0.16), or percent clay in site soils (P=0.38). Categorical variables, such as dominant flood class (Occasional AGR $\bar{x}$ = 20.2cm/yr; Rare AGR $\bar{x}$ = 18.2cm/yr; None AGR $\bar{x}$ = 13.5cm/yr; Kruskal-Wallis χ^2=2.37; P=0.31), showed mixed effects; in that dominant soil drainage class showed that well drained soils had a significantly lower AGR than sites with somewhat poorly drained soils (Wilcoxon Z = -2.65; P=0.0081), perhaps pointing to the presence of perched aquifers.

RGR

Relative growth rates were regressed against restoration site age to remove differential time effects (i.e., slowing). A reciprocal-linear model was highly significant ($p < 0.0001$), explaining ~96% of the variance (R^2_{adj} = 0.96).

$$\mathrm{RGR} = \frac{1}{0.2197737 + 0.1787668\,\mathrm{A_s}}$$ where A_s is restoration site age

Restoration Site	Grazing	Grading	Prior Land Use	Obs. (n)	Max. Years Irrigated	*AGR* (cm/yr)
BLUE	not grazed	leveled	row crop	1	1	7.11
EARTHSEA	grazed	leveled	irrigated pasture	2	0	13.13
GREEN	not grazed	leveled	row crop	1	3	13.25
LSE	not grazed	leveled	row crop	1	4	22.28
MACWORLD	not grazed	leveled	row crop	3	0	23.34
NBC	not grazed	leveled	row crop	1	6	6.33
NC	not grazed	scraped	fallow field	4	4	12.04
OAKISLND	grazed	leveled	irrigated pasture	4	5	48.40
RED	not grazed	leveled	row crop	1	3	12.86
SAV	grazed	not leveled	grassland	4	1	7.26
SBC	grazed	not leveled	grassland	1	6	6.33
TFWEST	not grazed	leveled	row crop	5	1	27.77
TRAILEXT	grazed	leveled	dry pasture	4	3	15.34
TRAILHD	grazed	leveled	dry pasture	7	4	25.90
TWOOAKS	grazed	scraped	dry pasture	7	3	11.09
VCN	unknown	scraped	fallow field	4	4	7.56
YELLOW	not grazed	leveled	row crop	1	3	11.59

Table 7 showing Valley Oak active restoration site land use history and absolute growth rates. Observations of tree height growth over time (n=51) were collected at 17 restoration sites with a variety of site history characteristics.

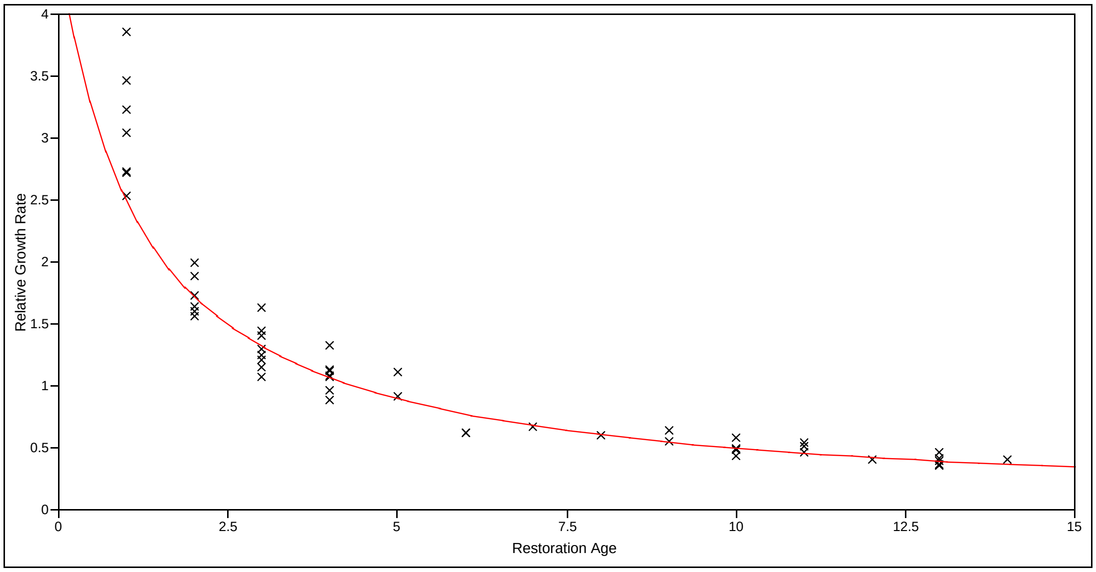

Figure 6 shows relative growth rates (RGR) for actively restored Valley Oak regressed against site restoration age. The residuals of RGR were analyzed for site specific factors predicting responses above or below this fitted model.

We examined environmental factors as predictors of RGR response adjusted for site age by testing the residuals of RGR (rRGR) as continuous and nominal (above/below fitted line) variables. Landscape factors showed varied predictive capacity for rRGR; for example, distance to water feature was significant with a unimodal response modeled as a quadratic fit (P=0.04) centered at ~475 m. However, rRGR positively increased as a function of distance away from a water source when modeled as a logistic response (P=0.0044; ROC AUC=0.72). The residual measure decreased with increasing percent clay (P=0.07) and increasing elevation variability (P=0.01), as measured by the standard deviation of restoration site elevation. Other restoration site factors that were indicative of site history, such as grazing (P=0.22), leveling (P=0.47), and previous land use (P=0.42), were not statistically significant in explaining the remaining variance in RGR from our monitoring data. Number of irrigation years following restoration had a slight negative relationship to rRGR (P=0.06), but was negligible when modeled as a logistic response (P=0.96), suggesting no growth benefit from continued irrigation.

Volunteer Growth Rates

Sampling of volunteer riparian forest trees in semi-passive restoration sites was conducted by Keller (2003), Meyer (2002), and Tu in the years 1989 – 1998. Samples were stratified across restoration site locations (n=10), observed tree species (n=5), and canopy layer (over or under story) to obtain tree height values. Each stratified sample (n=34) represents a pooled mean height (cm), which was used to calculate *AGR* and *RGR* based on age of stand establishment.

Relative growth rates (RGR) of all species combined in one analysis were regressed against stand age to remove differential effects and allow comparability of environmental effects. A reciprocal fit of RGR to stand age was highly significant, explaining ~80% of the variance ($R^2_{adj} = 0.81$, $p < 0.0001$). Model residuals were tested against species series and site history. Site history, as measured by prior land use, grazing effects, grading, and flood regime, showed no significant differences for residual growth rates using either Wilcoxon or Kruskal-Wallis nonparametric tests, for two or more levels respectively. Species series did show significant differences between groups, wherein Cottonwood-Willow samples ($\overline{AGR}$ = 41 cm/yr) had significantly higher residuals in stand age adjusted RGR than Valley Oak series samples ($\overline{AGR}$ = 7.5 cm/yr)($\chi^2 = 15.7$, $p < 0.0001$).

Discussion

We collected and synthesized CRP restoration planting and monitoring records from 1985-2005. Our data collection effort required an integration and synthesis of notes, reports, dissertations, publications and transcriptions of personal communications with reserve managers. We cataloged and spatially defined these data within a GIS, enabling further attribution of restoration events with attributed lists of species planted and management methods, such as planting details, irrigation schedules, weed control, and herbivory protection. These collated monitoring data allowed us to perform a retrospective analysis on restoration activities as measured by germination, seedling survival and growth rates for 76 separate restoration locations.

Our construction of a synthetic monitoring data repository is inferior to a programmatic data collection effort couched within a standard monitoring framework. Our data are also incomplete, but to what degree is unknown. Although our collection period spans twenty years, rarely is any one site observed more than a handful of years. We have had to pool observations from multiple sources over multiple years in some cases, which prevents informative environmental analyses such as correlating regional climatic patterns (e.g., Howell *et al.* 2006) or recorded hydrologic variability (e.g., Booth *et al.* 2006) with observed trends.

We believe that we have included the vast majority of extant monitoring data to support our analysis. Unfortunately, much is in the form of expert knowledge and unpublished notes, and there is evidence of growing institutional memory loss is in the form of missing data and inconsistencies, such as differences in recorded number of seeds planted, dates planted, and planting locations, precludes as definitive synthesis of restoration planting histories throughout CRP. Using a GIS as our data repository enabled the use of spatial analysis; however, the initial geographic placement of restoration sites presented a constant challenge as few maps were provided in the respective reports, and narrative descriptions of planting locations were not adequate to determine planting site boundaries. Colloquial place names have a tendency to change through time and by user, and we attempted to minimize these impacts by using coarse map units, multiple sources of information, and cross-verification with active CRP managers.

Each of these challenges shows the importance of creating and maintaining a standardized data framework to accompany any monitoring program. To our surprise, many manifestations of restoration monitoring (i.e., reports) were inadequate for analytical purposes in that commission and omission errors required wholesale discounting as original values, units, or methods were impossible to determine. It is for this reason and many others that we advocate standardized data frameworks and meaningful metadata – those descriptive data that detail the type, form, and nature of collected information – be required with all programmatic monitoring efforts, such as those mandated by resource agencies or funded by regional governments.

Germination

Our retrospective study of germination outcomes as detailed by restoration monitoring observations showed that many cultural factors, such as herbivory protection, weeding, augering, and summer irrigation, were largely inconsequential. Herbivory protection alone did not enhance germination rates of acorns, but did provide a protective effect against germination failure. Neither weed control, site preparation with an auger, nor summer irrigation promoted acorn germination rates or provided a protective effect against germination failure. Our analysis did show, however, that restoration site soil composition was an important environmental factor in determining germination. Our results suggest that tree plantings in areas dominated by soils with low infiltration rates and high runoff potential have a significantly reduced probability of germination. This result is bolstered by our observation that plantings have higher germination success in areas with well drained soils compared to moderately well drained soils.

Seedling Survival

Our analysis of seedling survival showed differential effects between two vegetation series. We used the Manual of California Vegetation (Sawyer & Keeler-Wolf 1995) to identify and codify our monitoring data into Cottonwood-Willow and Valley Oak series. We nested model MCV class within restoration site soil estimates of percent clay, which showed opposing trends between MCV series in that Valley Oak series seedling survival success diminished as clay content increased and Cottonwood-Willow series success rates improved with increasing clay composition. Breaching and distance to water feature were also significant predictors in this model, showing higher survival rates were related to unbreached restoration sites and sites farther from water features. Our MCV-based model of series within area-weighted surface soil clay content showed the non-linear differential effects between Valley Oak and Cottonwood-Willow seedling survival, which can be helpful for preserve managers in determining appropriate locations for future restoration. The intersection of the 95% confidence intervals of the fitted model showed that there was no clear advantage in seedling survival rates by vegetation series when soil clay content is greater than ~27.5%. Restoration sites with minimal clay content in surface soils tend to favor oak seedlings.

Growth

We used estimates of annual growth rate (AGR) and relative growth rate (RGR) to examine differential changes between restoration sites in relation to a number of landscape parameters. We found that restoration of valley oaks had significantly higher AGR on restoration sites that had been leveled prior to restoration than sites that were either not leveled or scraped prior to restoration. Leveled restoration sites were often formerly used for agricultural purposes, which means that they might be more productive generally, but most likely that breaking up of the soil produced better drainage overall. Scraping of sites and not leveling were indifferent in respect to AGR. Models of RGR showed that distance from water feature was a significant, non-linear effect growth, where rates peaked when 500m from rivers or sloughs. Relative growth rates decreased with increasing percent clay in surface soil and increasing elevation variability. Site history parameters, including grazing, leveling, and previous land use did not explaining difference in RGR across restoration sites. Surprisingly, the number of irrigation years following restoration was negligible as a potential benefit to relative growth rates.

Synthesis & Recommendations

We used landscape scale factors to determine restoration efficacy across the entire CRP, which is in contrast with many previous site specific studies (e.g., Tu 2000; Keller 2003; Trowbridge *et al.* 2005) and all sources of our monitoring information. However, we did find similar trends and results at this expanded scale. For example, Tu (2000) found that site elevation was not an adequate predictor of riparian community composition and establishment, but that soil composition was influential. Similarly, we found soil constituents, particularly the presence of clay, flood regime, and drainage to play a critical role in germination, seedling survival, and growth of restored riparian vegetation. Our observation that infrequent flooding was detrimental to restoration goals also concurs with the findings of Meyer (2002), who observed that valley oak recruitment is likely limited to years and sites with adequate soil moisture well into the growing season, sustained by geomorphically unconfined flood events.

In addition to our advocacy of standardized methods for monitoring riparian restoration, and its implementation over wide spatial scales and frequent time domains, we also advocate for continued promotion of semi-passive restoration. Not only do semi-passive techniques benefit from covering large areas at a minimum of personnel expense, many requisite ecological factors are reinforced or promoted. For example, Tu (2000) found that native woody species showed sufficient regeneration from natural inputs of seeds and vegetation growth to sustain the current composition and structure of both cottonwood-willow and valley oak forests.

Active restoration of riparian forests and floodplains is time-consuming and expensive, reliable methods are not yet established, and end results are highly variable with limited explanatory power. For this reason, we feel that riparian and floodplain restoration efforts should focus on re-establishing diverse river functions, such as ecological succession and hydrologic connectivity between surface and subsurface waters. Not only do semi-passive restoration techniques cover larger areas for far less investment, the incipient ecological processes that accompany the re-establishment of hydrological functions create habitat mosaics beneficial to many upper-trophic level species and promote staged successional trajectories that are the embodiment of structural and functional diversity. At the end of the day, biodiversity is dependent upon underlying physical complexity, which in the case of California's riverine floodplains, is created by hydrologic variability created by a natural flow regime.

Conclusion

The Cosumnes River floodplain represents one of the largest and best protected areas in the Central Valley – Sacramento Delta region in which the restoration of the greatly-diminished native riparian forests has been attempted. It is especially suitable for comparing both restoration methods and success metrics because it has one of the most extensive areas managed through semi-passive restoration (levee breaches and floodplain reconnections); it is managed by a coalition of land managers with extensive restoration goals elsewhere in the system; and it has had above-average access to both restoration funds and scientific study. In addition, the fact that the Cosumnes River is undammed provides scientists with more opportunities to study the effects of hydrological variability than in most other riparian settings in the western United States. As a result, the Cosumnes River restoration experience is certainly relevant to understanding the process of passive restoration and the additional value of active planting (if any) in creating large-scale returns to more natural riparian vegetation.

Unfortunately, our analysis shows in part that haphazard historical restoration, absent the context of a larger experimental design, adaptive management plan, or before-after-impact approach – and unaccompanied by a structured and funded monitoring effort – makes definitive assessment of restoration success problematical. This is despite the fact that many of the early active restoration efforts were specifically designed to evaluate the value of alternative methods, such as irrigation, mulching, and fencing. This is not unlike the experience in other large restoration efforts, such as the Everglades or Chesapeake Bay.

Despite the incomplete record, however, some patterns seem clear. Levee breaching is not a panacea that will effortlessly restore high quality riparian forests at will. Restoration appears most successful near channels with intermediate to high moisture – likely locations that were originally heavily forested. However, clay soils, site history (particularly irrigated grazing) and invasive species all contribute to alternate outcomes, including weed-dominated grasslands and sparse, stunted trees. Some of the causes are not yet known, but standard statistical methods applied within a GIS give some ability for managers to predict where restoration is likely to be successful, and to allocate their resources accordingly.

Ultimately, developing an effective science-based landscape-scale restoration process probably exceeds the abilities of any land manager to design an efficient field experiment up front and unambiguously determine the relative effectiveness of alternative measures after the fact. When multiple owners and investigators are jointly responsible, as is the case in the Cosumnes, the effort becomes even more challenging. We suggest that ongoing efforts provide a shared data repository which includes, at a minimum, GPS locations for all restoration sites, data dictionaries to promote shared terminology, simple registries of methods and measures used, and recommended or required shared site descriptions. All of these would have cost little, and made a synthetic assessment of restoration success much more effective.

More ambitiously, it may be desirable to try to set all restoration "experiments" in a common assessment design, such as a paired before-after-control-impact study – in in which each site has a paired unrestored location, so that differences between the two sites provide measures of the specific success of the restoration treatment. Effective adaptive management over larger landscapes might also entail improving the predictive science of riparian restoration by filling in parts of the "experimental" matrix (e.g., channel-side, irrigated, high clay, etc.) that by happenstance have not been conducted in earlier restoration efforts and monitoring in a way comparable to that used in older efforts.

Finally we should note that our inability to quantitatively measure restoration success by a synthetic analysis does not suggest that earlier restoration efforts were ecologically unsuccessful. To the contrary, the managers of the Cosumnes River Preserve continue to innovatively manage environmental recovery of an active floodplain, and the visible evolution of the experimental floodplain toward a richer community over the several years of this project has been remarkable. We trust that the analytical lessons will lead us toward more powerful methods to improve the planning and validation of riparian restoration elsewhere in the landscape so that the level of on-the-ground successes in the Cosumnes River floodplain can become more widespread.

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