Riparian Revegetation Evaluation on California's North Coast Ranches

Final Report

Prepared by

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Cover photographs: *Coastal stream on ranch along Hwy. 1 in 1994 (upper) and in 2004 (lower). Photographs are courtesy of Marin Resource Conservation District.*

EXECUTIVE SUMMARY

Overview

We conducted a retrospective, cross-sectional survey of riparian revegetation projects on north coastal California working ranches. Our goal was to determine the efficacy of riparian restoration within the working landscape of California's rangelands. Specifically, we documented plant community succession and structure, and aquatic habitat response to restoration over time. This type of information is useful in confirming the benefits of restoration and directing improvements to restoration project design, implementation, and management that can improve the success of future projects.

In a typical revegetation project scenario, monitoring has focused on survival of planted vegetation and seldom extended beyond a contracted three to five year period. Rarely have monitoring surveys attempted to quantify the resulting available aquatic habitat and plant community structure over long-term time scales over multiple decades. Ecological restoration and riparian revegetation typically received minimal systematic project monitoring, evaluation, and feedback. The result has been limited documentation of project outcomes and effectiveness. Because of the considerable amount of riparian revegetation in north coastal California since the 1970's by private landowners, restoration practitioners, and financial and technical assistance agencies we were able to fill this data gap through our survey.

We surveyed 102 sites, totaling 19.4 kilometers, along streams in Marin, Mendocino, and Sonoma Counties from 2002 to 2005. Site selection focused on revegetation projects in mixed oak woodland tributaries with alluvial, gravel substrate reaches of minimal tree and shrub cover prior to project installation. Restoration methods at surveyed project sites included riparian revegetation, bioengineering bank stabilization, and herbivore management (removal, reduced numbers, or exclusionary fencing for livestock and/or deer). Surveyed sites included 89 riparian restoration sites and 13 non-restored sites which were near projects and representative of pre-project conditions.

We have documented riparian vegetation and aquatic habitat responses at temporal stages over a thirty-year period and compared the influences of common restoration methods on these responses. We have identified critical elements to guide site-specific potential for establishing native tree populations through both passive and active methods. Our restoration trajectory analysis correlated the abundance of nine tree genera to time since project installation, site conditions and restoration treatment. Lastly, we developed practical guidelines and recommendations for monitoring riparian revegetation projects.

Findings and Discussion

Our results document significant improvements in both riparian vegetation and aquatic habitat metrics as the age of project sites increased. This confirmation of intended improvements to stream conditions should encourage the continuation of riparian revegetation projects. Our results also point to unintended outcomes resulting from such projects, such as increases in invasive plant species. This highlights the need to improve project design, implementation, and maintenance.

Outcomes from our models of individual tree genera response to restoration treatment method are useful for selecting implementation techniques. Generally, direct planting of the slower growing, late seral tree species significantly increases their abundance. By comparison, the presence of relict populations, perennial stream flow and floodplain area are more important in establishing early seral tree species.

Our results are useful for validating riparian restoration project success, improving future project designs, and guiding how to efficiently monitor program effectiveness. We recommend project planning continue to follow site-specific approaches and our results provide insight for this process. Concepts such as the relative bank height or elevation above the stream channel, stream flow regime, identification of relict seed sources of early seral tree species and soil percent clay are factors that restoration practitioners and funders should consider when adapting project designs to site-specific conditions and species-specific objectives.

In addition to providing restorationists, landowners, and funders with useful direction to improve the success of riparian revegetation projects, we have developed a document for conducting monitoring of such projects. This document has two elements: 1) Developing a monitoring program; and 2) Observations and recommendations for monitoring methodologies.

Natural resource managers and restoration practitioners should be able to use these results to set realistic and quantified project objectives for both riparian vegetation and aquatic habitat metrics. They should also be useful in site design and implementation decision making, as well as site management, including the use of efficient monitoring. Armed with this understanding, the restoration partnership between the landowner, practitioner, and funder will increase their efficiency and effectiveness, resulting in wiser uses of resources to implement even more successful stream revegetation projects.

The principal findings, considerations, and recommendations of our study are:

- Stream and river revegetation has resulted in improvements to aquatic habitat and riparian vegetation community and structure at the surveyed sites. This confirmation of long-term intended and beneficial outcomes supports the continuation of these practices to improve watershed functions.
- Passive restoration methods (controlling herbivory using livestock and/or deer exclosures, livestock removal, or managing livestock by reducing their intensity) and active revegetation techniques (planting and/or bioengineering) are both effective at bringing about beneficial responses in aquatic habitat and plant community structure at restored project sites. Active methods accelerate this response for metrics such as canopy cover and bank stability in the first ten years after project implementation. In general, the magnitude of the response from both methods for numerous metrics converges after approximately 10 to 15 years. The inference is that there is a limit, or ceiling, to rate of response and ending value for studied metrics over time regardless of the restoration method employed.
- The one notable exception or difference between active and passive revegetation methods is the increase in tree species diversity achieved consistently through time with direct planting methods.
- Both active and passive revegetation methods are viable tools for the restoration partnership to use. Selection of restoration techniques should be based upon a balance between site-specific objectives, programmatic goals and resource allocation. An accelerated rapid response may be desired and can be achieved through active methods, but with an associated higher project budget. Alternatively, a program may place a premium on treating the greatest length of stream per restoration dollar spent, which favors the use of passive methods and requires a longer time horizon to achieve project site response. Certain sites require active methods to address acute bank stability issues, provide a seed source, or develop an active floodplain that contribute to the establishment and continued propagation of riparian vegetation. Our general recommendation is that project design should be guided by site-specific potential for passive revegetation and active methods should be used to enhance that potential.

- Early seral, fast growing tree species recovery is accelerated in the presence of relict populations at or near the site. Project design that accounts for the presence and location of seed source for either desired or invasive species will be able to capitalize upon or prevent their influence on project site response.
- Planting is generally required for the recovery of late seral, slower growing tree species within 30 years. Furthermore, survival and establishment is related to soil texture - oaks (*Quercus sp.*) and Douglas-fir (*Pseudotsuga menziesii*) have greater densities in high percentage clay soils and California Buckeye (*Aesculus californica*) having greater densities in low percentage clay soils.
- Resulting riparian forest composition and structure is related to geomorphology at project sites. Accordingly, landform distribution should be used in decisions regarding where to plant which species.
- There is a consistent transition in the understory plant community from annual to perennial herbs to shrubs over time. This transition appears to culminate in sites dominated by shrub and vine species, with Himalayan blackberry (*Rubus discolor*) as the most common component. There is also a corresponding decrease in sedges (*Carex sp.*) and rushes (*Juncus sp.*).
- The change in understory plant community composition points to the need for vegetation management at project sites, including the identification of appropriate weed control methods and a funding process to support this long-term project maintenance task.
- Recommendations for improving project design and implementation include:
    - Delay planting for one to two years post project site fencing, to learn where and what plant species will colonize through natural regeneration. The potential for natural regeneration, and thus this recommendation, to be effective is greatest at sites with floodplain access, relict species, and perennial stream flow.
    - Planting more tree willow species such as red and/or shining willow where appropriate.
    - Early seral species will have to be planted if they are desired at the site above frequently flooded locations. Below that flood stage, project design can seek to capitalize on the sites natural regeneration potential.
    - Where streambanks are unstable, bioengineering and other bank stabilization methods are needed to facilitate streambank revegetation.

- Qualitative implementation and effectiveness monitoring with photo-point methods is useful to document site response following project implementation and should be continued.
- Quantitative effectiveness monitoring is needed for a select number of site response metrics - canopy cover, width-to-depth ratio, maximum pool depth, and tree/ shrub composition by cover. Baseline values for these metrics can be collected during the project implementation phase if the appropriate expertise and technical support needed to conduct the monitoring is available.
- Future monitoring visits to project sites should be timed appropriately to guide decisions about adaptive management and strategic intervention. For holistic plant community management and controlling invasive, non-native species, project sites should be evaluated at approximately five to ten years post project implementation.

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INTRODUCTION

Riparian corridors provide critical habitat and hydrologic functions, while contributing to viable agricultural production systems and recreational opportunities (Hobbs 1993). California ranchers and farmers, working with resource agency staff and restoration practitioners, have implemented revegetation efforts for more than four decades to meet these resource management objectives.

Billions of dollars have been spent in the United States on stream and river restoration (Palmer et al. 2005). The number of riverine restoration projects in the United States has steadily increased, since the 1980's, from 100 to over 4,000 projects per year by 2001 (Bernhardt et al. 2005). California was third in spending on stream restoration efforts, with $3,699,785 per 1,000 miles of stream compared to $17,312,928 and $11,358,472 in Washington and North Carolina, respectively. These funds have been used on 13 identified project types that include riparian management, bank stabilization, floodplain reconnection, instream habitat improvement, and water quality management. Revegetation was a common objective towards achieving the goals of each project type.

In a typical revegetation project scenario, monitoring has focused on survival of planted vegetation, and seldom extended beyond a contracted three to five year period. Rarely have monitoring surveys attempted to quantify the resulting riparian forest structure, community composition, and ecosystem functions. Ecological restoration has typically received minimal institutionalized, systematic project monitoring, evaluation, and feedback. The result has been limited documentation of project outcomes and effectiveness.

Post project analysis can provide valuable feedback for the design, installation, and management of future projects (Kondolf 1995, 2001, 2004). Existing projects offer opportunities to learn about resulting community structure, spatial arrangement, and ecosystem processes that drive these results (Jelinski and Kulakow 1996). For example, Frissell and Nawa (1992) documented that streams carrying high amounts of coarse bedload in alluvial reaches had low success of active instream enhancement 20 years after revegetation implementation. Numerous studies have found rapid riparian vegetation recovery resulting from passive revegetation methods - the removal of ongoing stressors or degrading agents (Platts 1981, Kauffman et al. 1997, Opperman and Merenlender 2000). And the restoration of instream fish habitat using exclusionary fencing methods has been documented (Opperman, 2004). Few studies, however, have compared long-term results from active and passive revegetation (Thayer et al. 2005).

Realistic and quantifiable expectations of project outcomes are needed by landowners, government agencies, and consultants to inform decisions about resource allocation for future riparian restoration and management. Recognizing the need for quantitative documentation of ecological outcomes and feedback, we conducted a retrospective, cross-sectional survey of north coastal California riparian revegetation projects in Marin, Mendocino, and Sonoma Counties (Figure 1). Our goal was to determine the efficacy of riparian restoration by further understanding plant succession, community dynamics, and site potential or restoration trajectory, within these working landscapes. The on-the-ground work by private landowners, restoration practitioners, and technical and financial agency assistance to implement riparian revegetation efforts over multiple decades in north coastal California made this survey feasible.

This report provides a summary of this study including descriptions of methods used for restoration project characterization and data analysis, presentation of results, formation of considerations and recommendations for future project design, implementation, management, and monitoring. It also provides preliminary guidelines for monitoring revegetation projects and a summary of outreach activities conducted during the project.

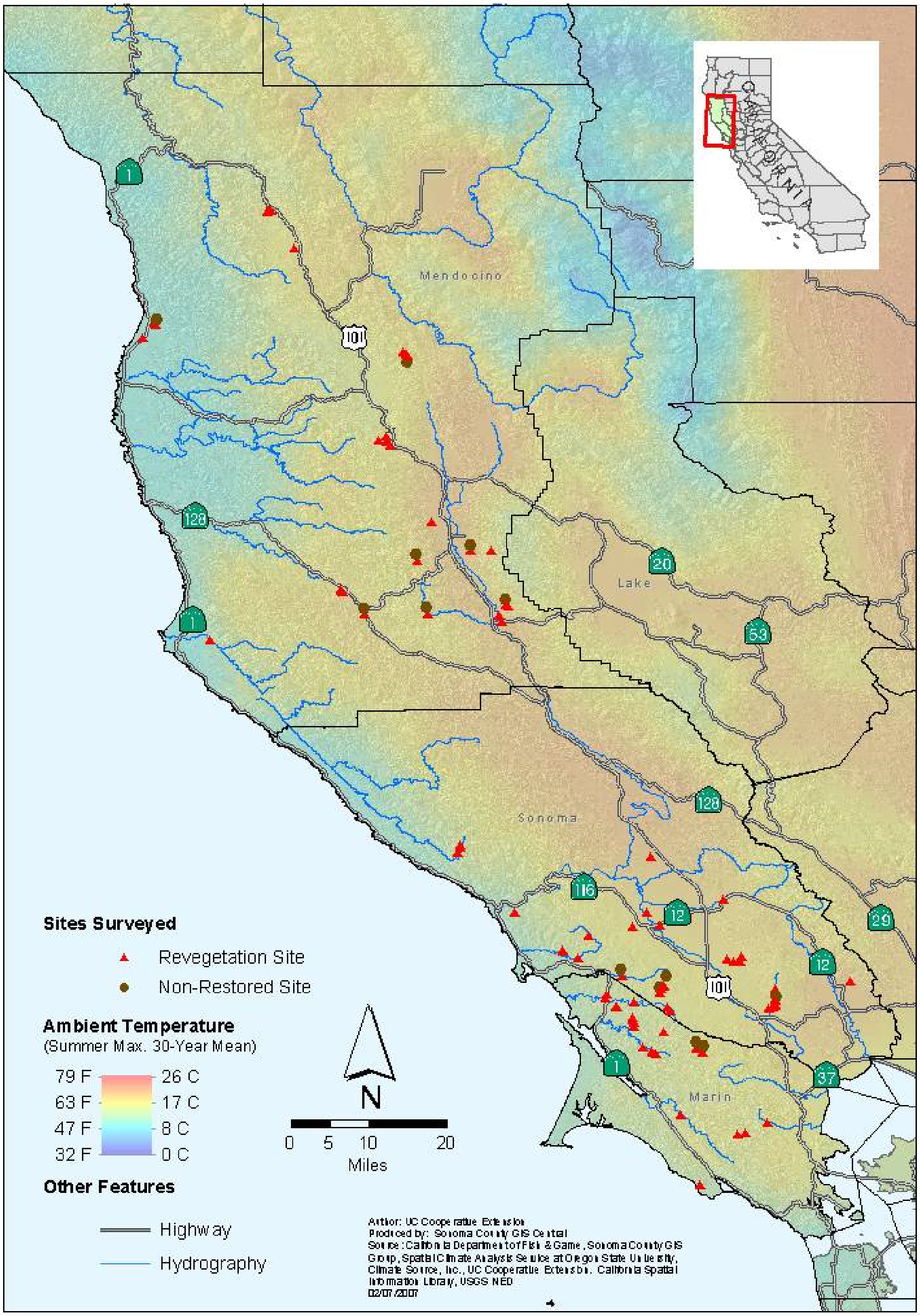

Figure 1: Study area including surveyed restoration projects (red triangles) and non-restored sites (brown circles) with mean summer maximum temperature (image courtesy of Sonoma County GIS Central).

METHODOLOGY

Project Identification

From 2003 to 2005, we surveyed 102 sites during summer months. Landowner permission to access project sites was 100% voluntary. Collaboration between consultants, agencies and landowners was crucial in completing this survey.

Table 1: Summary statistics for survey sites.

Variable	Mean	(Min - Max)
Watershed Area (km.^{2})	23.5	(0.2 - 133.1)
Elevation (m.)	145.3	(3.7 - 656.4)
Annual temp. (C.)	13.7	(12.0 - 15.1)
Annual precip. (mm.)	1,019.0	(679 - 1,629)
Forested (%)	21.9	(0 - 100)

The three-county study area is dominated by oak woodlands and annual grasslands that typify California's rangelands. As a northern California coastal region, our study location and survey sites have relatively cooler temperatures and higher rainfall than much of the state's rangelands (Table 1). Understanding this climatic difference, our results from this survey are applicable to stream revegetation efforts in rangeland throughout California.

Project cooperators identified both "successful" and "unsuccessful" projects to be included in the study. Site selection focused on projects in alluvial, gravel substrate reaches of mixed oak woodland tributaries, with minimal tree cover prior to project installation. Non-restored sites were surveyed opportunistically where local experts knew that a particular stream reach had similar vegetation structure as the project site before revegetation occurred.

Surveyed project sites were primarily on first, second, and third order streams, and had a range of project age from 4 to 39 years since restoration (Figures 2 and 3). This range in project age represented the continuum needed to quantitatively document restoration trajectory outcomes beyond the three to five years of typical monitoring conducted at project sites.

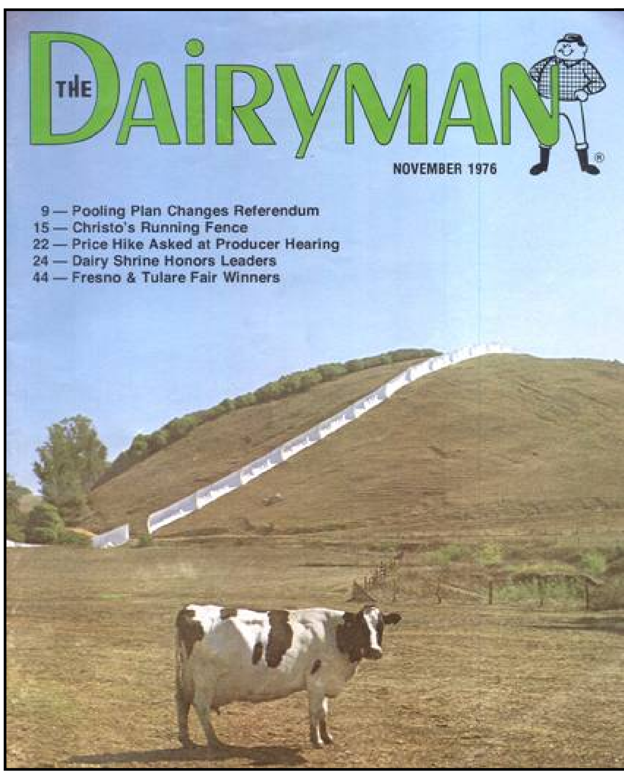

Figure 1: Example of survey site in 1976 with Christo's Fence behind the newly fenced stream (left) and 2002 (above) (images courtesy of Tresch Family Dairy).

Figure 3: Example project site in Chileno Creek. Photographic sequence documents vegetation response at zero, two, and eight years post restoration (images courtesy of Marin Resource Conservation District).

Site Characterization

We characterized riparian restoration project sites in three broad categories: 1) site revegetation goals, design, and maintenance activities; 2) site physical conditions and aquatic habitat; and 3) plant community composition and structure. Historic site information and project goals were summarized from past reports and anecdotal surveys of landowners and restoration practitioners.

Project goals, design, implementation, and maintenance were researched to document management and revegetation variables such as species planted, bioengineering structures installed, and relict plant populations present. The variables were combined with landscape and watershed scale information to provide context and serve as predictors of restoration outcomes or metrics.

We collected plot, cross-section, and reach-scale instream habitat data at each site. Stream width and depth were documented using bankfull width-to-depth ratio and entrenchment (Rosgen 1996). At the reach scale, data collected included small woody debris (diameter < 12 in), large woody debris (diameter > 12 in), wood aggregates (clumps of 4 or more pieces), mean pool depth, maximum pool depth, and percent pool to riffle habitat types (Flosi et al. 1998). We measured riparian shade cover over the thalweg at each site using two cross-section scale protocols and one reach-scale protocol. Canopy density (Spherical Densiometer) and solar radiation (Solar Pathfinder) were measured from the thalweg at three cross sections per site. The Densiometer data was collected following CDFG protocols (Flosi et al.1998) while we adapted our use of the Pathfinder by converting the measurement of solar radiation in the month of August to riparian shade. Lastly, the linear distance of riparian shade over the thalweg was recorded at intervals with a hip chain as *linear channel cover*.

Plant community data was collected from plots within transects perpendicular to the channel at each cross-section. Plot location was based on channel morphology at the lowest possible *bankfull* location and *floodprone* elevation (2 x bankfull depth) using three independent cross-sections per site (Rosgen 1996). We defined *bankfull* as the break in slope of a flat depositional surface flooded every 1-2 years on average. At each cross-section, two belt transects, both eight yards wide, continued up left and right

Figure 4: Belt transect depicted for 2 vegetation plots.

stream banks from the thalweg (Figure 4) until the upper bank was sampled. Plot length was variable and based upon the extent of the landform class for each plot.

We adapted Harris (1987, 1999) geomorphic classification of plots to form landform class designations which included the *active channel* (C), *erosional flood plain* (E), *depositional flood plain* (D), and *upper bank* (U) (Figure 5). Designations for each plot were based upon field observations of channel morphology and features of aggradation and erosion. Channel plots were considered the active channel from the thalweg up to the bankfull location (Rosgen 1996). Erosional plots had evidence of stream bank cutting. Depositional plots were young and old terraces with flotsam or general evidence of aggradation. Upper bank plots were furthest from the water table and received the least amount of hydrologic disturbance. They extended from the top-of-bank to the fence or field edge and may represent alluvial valley, terrace or upland hillside geomorphic features. These landform categories allowed vegetation data to be linked to specific cross-section morphology given the degree of channel incision.

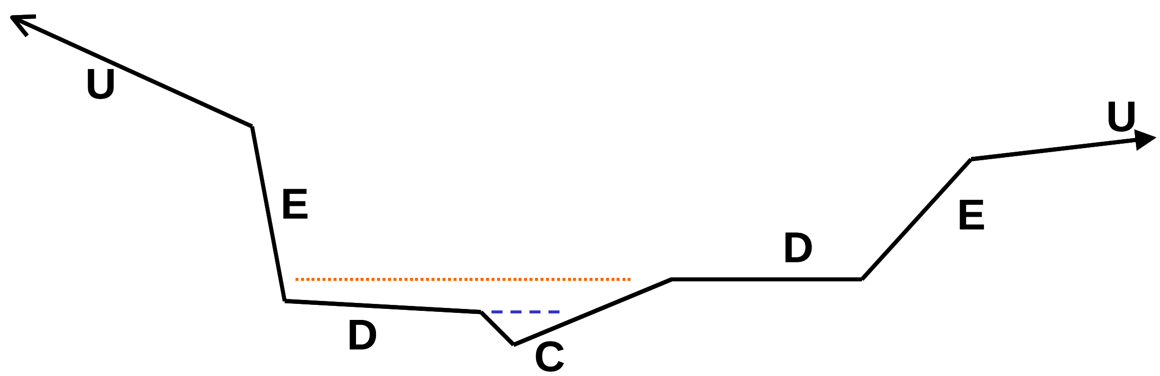

Figure 5: Idealized stream channel cross-section depicting landform class (letters), bankfull elevation (lower dashed line), and floodprone elevation (upper dotted line). Landform class designations include *active channel* (C), *erosional flood plain* (E), *depositional flood plain* (D), and *upper bank* (U).

Data gathered within each plot included species composition (Hickman, 1993), age-form class, canopy composition, slope, particle size, and landform class (Harris 1999, Thayer et al. 2005). Ground cover was assessed with three quadrats per plot using a modified Daubenmire Frame (20 x 50 cm) placed perpendicular to the stream channel (BLM 1996). The height, or elevation, of each plot above the thalweg was recorded and used to calculate a relative plot height as the number of bankfull heights at the plot's vertical midpoint. Site characterization also included soil particle size analysis by landform class. Summer flow was characterized as perennial, no flow with standing water in pools, or completely dry.

With Geographic Information System (GIS) software (ArcGIS 9.1, County of Sonoma's GIS Central) we were able to make landscape scale visual comparisons of project and stream reach vegetation response to restoration over time. For example, in the Adobe Creek watershed surveyed project site boundaries were delineated on aerial photographs taken in 1971 and 2004 (Figure 6). Coarse spatial data was also collected using the intersect tool available in ArcGIS Spatial Analyst. We gathered mean maximum summer temperature for each survey site (Figure 1) from Parameter-elevation Regression on Independent Slopes Models (PRISM) of 1971 to 2000 data (Daly 1997, Climate Source 2001). Other data sources included 30-year mean precipitation (Climate Source 2001), total canopy cover (Table 1) and cover type (CDF 2005) were provided for an understanding of the spatial variability of surveyed sites (Appendix A).

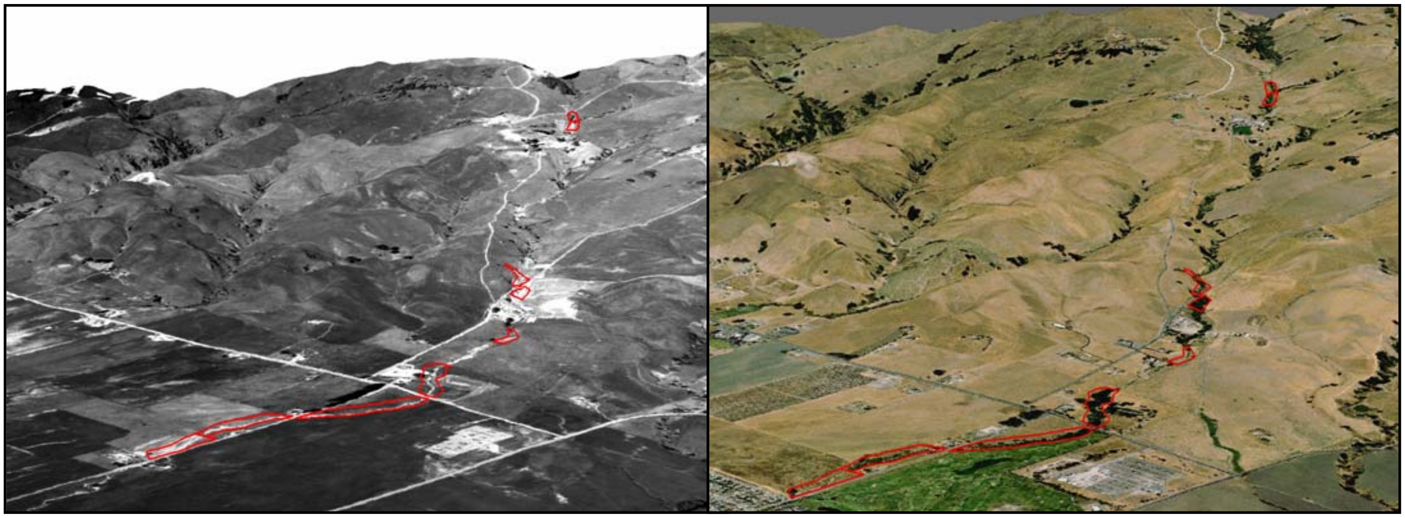

Figure 6: The Adobe Creek watershed with surveyed site boundaries in 1971 on the right and 2004 on the left. The oldest revegetation project site characterized in this watershed was implemented in 1972. In the 1971 photographs the surveyed sites generally have sparse riparian vegetation cover compared to the continuous dark green corridor documented in 2004 (images courtesy of Sonoma County GIS Central).

Analysis

Our primary focus in analyzing the collected data was the response over time or trajectory of measured aquatic habitat and riparian vegetation metrics. A restoration trajectory assumes project sites "follow a gradual path of development" towards natural and undegraded conditions similar to a reference site or ideal goal that is project success (Hobbs 1993, Hobbs and Norton 1996, Zedler and Callaway 1999, Choi, 2004, Ruiz-Jaen and Aide 2005). The trajectory concept has been used to represent a predictable guaranteed outcome. This type of analysis involves the quantification of specific restoration metrics for adaptive management purposes (Falk et al. 2006). For example, active rehabilitation methods may be implemented when passive ones have not produced satisfactory results (McIver and Starr 2001).

We developed our restoration trajectories by first designating a project age for each surveyed site as the duration of time since project implementation. We formed categorical age groups based on documented time durations required for site response to restoration. These groups are zero years or non-restored (n=13 sites), 4-7 years (n=38), 8-11 years (n=18), 12-19 years (n=14), and 20-39 years (n=19). The goal was to characterize site change over time for numerous restoration effectiveness metrics in order to further understand expected and unintended project outcomes. Statistical analysis was performed to test for differences in the metric means between age groups using a Tukey multiple comparisons test of Analysis of Variance (ANOVA) with JMP software (version 5.1).

In addition to the age group analysis, we explored the plant community response in more detail. This included analyses of the response of the riparian vegetation metrics and specific tree genera to different restoration methods.

RESULTS & DISCUSSION

Each of the three following results sections are being prepared as independent, peer-reviewed journal articles. The first provides insight into long-term project performance by using a descriptive approach to summarize the trajectory results for the restoration metrics. The second section assesses indirect effects of projects on plant community dynamics, especially the herbaceous layer composition and diversity. The last section presents results from analyses of how the density of common riparian trees was affected by revegetation methods.

Restoration Metrics

Riparian Vegetation

The riparian restoration metrics indicate how woody vegetation attributes respond over time (Table 2). The far right "ANOVA" column summarizes the statistical tests with different letters indicating significant differences between project age groups ($p<0.05$). For example, mean native tree density at 4-7 year old project sites was greater than at non-restored sites but similar to that at 8-11 year old sites. The majority of metrics increased in value, representing a positive trajectory, as demonstrated by total shade by plot. Other metrics decreased significantly such as vegetative cover. The metrics are presented in descending order based on their magnitude of change, with metrics that had no significant change across all age groups listed at the bottom of the table.

Table 2: Riparian vegetation metric mean values with standard error by project age group (differing letters in ANOVA denote statistically significant differences between age groups).

Restoration Metric	Non-restored Mean ± SE	4 - 7 yrs. Mean ± SE	8 - 11 yrs. Mean ± SE	12 - 19 yrs. Mean ± SE	20 - 39 yrs. Mean ± SE	ANOVA (p<0.05)
Native tree density (ind./hectare)	60.8 ± 32.43	431 ± 55.51	525 ± 75.70	723 ± 120	496 ± 69.1	a-b-bc-c-bc
Native shrub density (ind./hectare)	93.1 ± 35.1	456 ± 84.3	297 ± 63.9	729 ± 196	719 ± 105	a-ab-ab-b-b
Exotic shrub density (ind./hectare)	138 ± 47.4	457 ± 86.9	772 ± 170	909 ± 184	1,054 ± 170	a-ab-bc-bc-c
Total shade by plot (%)	12.9 ± 2.37	34.6 ± 2.27	40.4 ± 3.38	71.3 ± 3.41	68.5 ± 3.07	a-b-b-c-c
Woody veg. density (ind./hectare)	446 ± 95.7	2,088 ± 172	2,840 ± 323	3,632 ± 370	3,131 ± 285	a-b-bc-c-c
Native tree canopy cover (%)	10.6 ± 2.01	33.1 ± 2.20	37.8 ± 3.21	67.3 ± 3.27	60.6 ± 2.99	a-b-b-c-c
Root cover (%)	0.70 ± 0.3	2.21 ± 0.33	3.56 ± 0.65	5.72 ± 1.00	4.86 ± 1.01	a-a-ab-b-b
Tree richness (sp./plot)	0.65 ± 0.07	1.46 ± 0.05	1.98 ± 0.08	2.49 ± 0.10	1.84 ± 0.07	a-b-c-d-c
Shrub richness (sp./plot)	0.47 ± 0.07	0.90 ± 0.04	1.42 ± 0.08	1.27 ± 0.08	1.57 ± 0.07	a-b-cd-c-d
Litter cover (%)	18.7 ± 1.5	23.2 ± 0.92	23.7 ± 1.26	26.9 ± 1.49	29.5 ± 1.43	a-ab-ab-bc-c
Ground cover (%)	84.7 ± 0.85	88.5 ± 0.45	87.9 ± 0.55	88.3 ± 0.71	86.3 ± 0.71	a-b-bc-bc-ab
Veg. cover total (%)	44.4 ± 1.43	42.3 ± 0.82	38.7 ± 1.18	40.9 ± 1.65	35.5 ± 1.13	a-ab-bc-ab-c
Exotic tree density (ind./hectare)	0 ± 0	0.75 ± 0.75	0.54 ± 0.46	28.1 ± 25.3	3.69 ± 2.33	a-a-a-a-a

To facilitate interpretation of the magnitude of response to restoration, we graphed the relative percent change for each metric (Figure 7). The metrics that did not demonstrate a significant change over time were not graphed. We calculated the relative change using the mean values from Table 2 and the following equation:

$$\text{Relative \% Change} = \frac{\text{Restored - Nonrestored}}{\text{Nonrestored}} \times 100$$

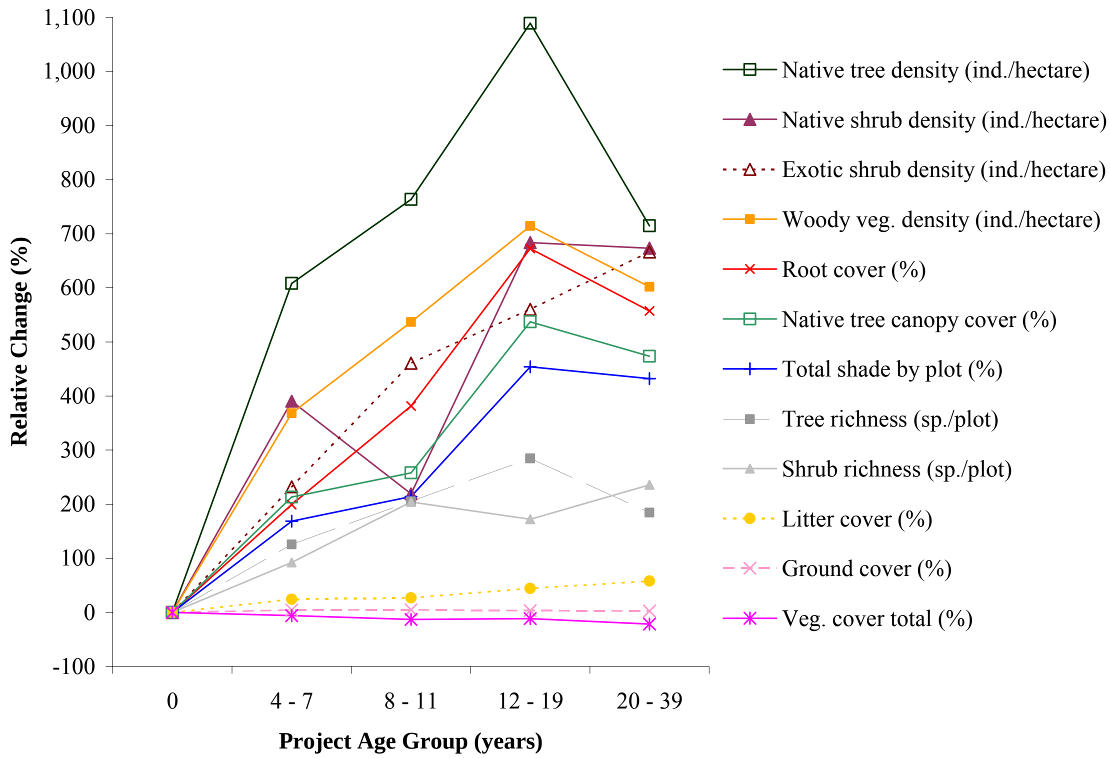

Figure 7: Relative percent change of riparian metrics over time.

The intended result of greater native tree abundance was successful in this region with density increasing by over 1,000%. The decrease in density in the 20-39 year old projects was not significant. An unintended and potentially undesirable result of projects was the significant increase in exotic shrub density over time. Unlike the native shrub density, which also increased over time, the exotic shrubs continued significant population growth into the over 20 year age group. The implication is that this density and pervasiveness may continue, thus calling for vegetation management throughout the life of a project. This is particularly true at project sites where relict populations of exotic shrubs before large herbivore access was altered.

Aquatic Habitat

The instream restoration metrics characterized the aquatic habitat available. We analyzed and summarized the results in the same manner that we did for the riparian vegetation metrics. Metric means by project age group are presented in Table 3 and the relative changes are graphed in Figure 8. In general, these metrics document a positive or improving trend in habitat conditions that parallels the increases and improvements in the riparian vegetation metrics. For example, the statistically significant increases in canopy density and woody aggregates are outcomes that would be hoped for in improving instream habitat through riparian revegetation. Similarly, the decrease in bankfull width-to-depth ratio was an improvement in habitat quality and an intended outcome from revegetation because stream channels tend to deepen and narrow as complexity increases with tree establishment. Other metrics did not improve over time such as embeddedness and fine sediments in the channel, which are most likely influenced by larger scale watershed factors that override any beneficial impacts that the project would have.

An unexpected result we found was the significant increase in pool depth metrics. Though a theoretical purpose of riparian restoration is to improve pool depth, we were not sure how the retrospective survey design would be able to document changes to channel morphology. Pool depth is one of the best indicators of aquatic habitat quality, especially for salmonid species. We found a near 100% improvement in maximum pool depth, from 0.62 m at non-restored sties to 1.12 m at 20-39 year old project sites, which is a biologically relevant improvement for fisheries management.

Table 3: Instream metric mean values with standard error by project age group (differing letters in ANOVA denote statistically significant differences between groups).

Restoration Metric	Non-restored Mean ± SE	4 - 7 yrs. Mean ± SE	8 - 11 yrs. Mean ± SE	12 - 19 yrs. Mean ± SE	20 - 39 yrs. Mean ± SE	ANOVA ($p<0.05$)
Linear channel cover (%)	5.51 ± 2.68	32.7 ± 4.71	34.9 ± 6.69	76.0 ± 7.07	75.9 ± 6.04	a-b-b-c-c
Aggregate woody debris (#/100m)	0.19 ± 0.10	0.32 ± 0.09	0.44 ± 0.15	1.18 ± 0.24	2.17 ± 0.35	a-a-a-b-c
Small woody debris (#/100m)	1.03 ± 0.37	2.36 ± 0.40	3.57 ± 0.89	5.58 ± 0.78	10.1 ± 0.96	a-a-b-c-d
Canopy density (%)	13.2 ± 2.92	40.9 ± 3.29	48.8 ± 3.63	74.6 ± 1.72	81.8 ± 2.54	a-b-b-c-c
Intercepted solar radiation (%)	18.5 ± 6.40	45.9 ± 2.52	57.4 ± 2.25	78.4 ± 5.11	82.8 ± 2.55	a-b-c-d-d
Large woody debris (#/100m)	0 ± 0	0.53 ± 0.19	0.62 ± 0.18	1.53 ± 0.24	2.14 ± 0.33	a-b-b-c-d
Max. pool depth (m)	0.62 ± 0.09	0.83 ± 0.05	0.95 ± 0.09	1.05 ± 0.10	1.12 ± 0.08	a-b-bc-cd-d
Mean pool depth (m)	0.42 ± 0.05	0.52 ± 0.03	0.67 ± 0.07	0.68 ± 0.06	0.66 ± 0.04	a-b-c-c-c
Pool habitat (%)	31.7 ± 4.88	38.7 ± 3.02	40.8 ± 3.62	46.2 ± 3.95	43.5 ± 4.16	a-ab-b-b-b
Pool density (#/100m)	3.08 ± 0.34	2.99 ± 0.22	3.27 ± 0.26	4.15 ± 0.79	3.59 ± 0.30	a-a-a-b-ab
Bankful width:depth	43.3 ± 5.57	30.2 ± 3.90	26.4 ± 5.79	25.4 ± 4.29	21.0 ± 3.47	a-b-bc-bc-c
Embeddness (%)	42.7 ± 7.91	39.5 ± 3.03	44.6 ± 3.15	40.7 ± 2.30	38.5 ± 4.83	a-a-a-a-a
Fines in channel (%)	13.2 ± 5.59	15.3 ± 3.96	10.7 ± 3.31	24.8 ± 8.28	16.2 ± 3.79	ab-ab-b-a-ab
Bank slope (degrees)	18.7 ± 0.99	16.1 ± 0.78	17.3 ± 0.84	17.3 ± 1.65	15.7 ± 0.88	a-a-a-a-a

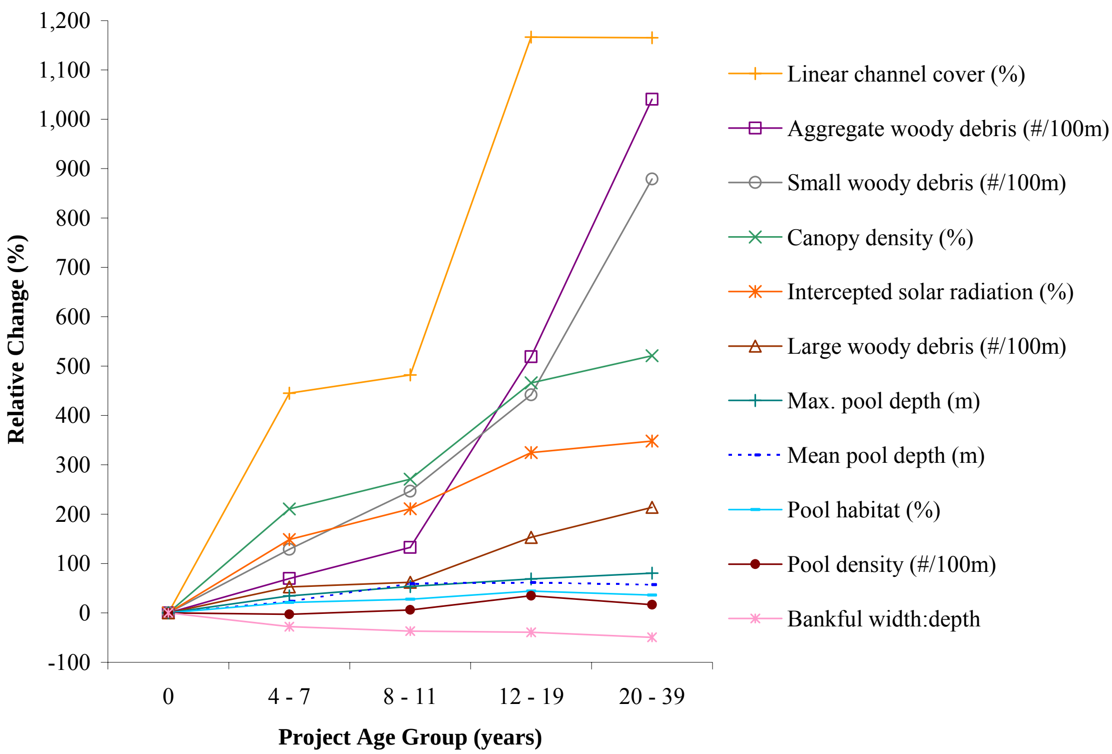

Figure 8: Relative percent change of instream metrics over time.

Plant Community Response

A fundamental transition in plant community structure and composition was observed over multiple decades as woody species established and dominated sites (Figure 7). The frequency of woody species observed at project sites was calculated along with the mean density for each species (Appendix B). Arroyo willow (92.0 % of sites) and Himalayan blackberry (88.6% of sites) were the most common species identified at surveyed project sites.

Because dominance by invasive species is an ongoing concern for land managers across California, we assessed the response of common native and exotic blackberry species over time. We calculated the relative cover of Himalayan blackberry (*Rubus discolor*) and California blackberry (*R. ursinus*) to quantify the colonization and development patterns.

A significant increasing trajectory in cover was documented for multiple species that is dependent upon landform class, or plot location. The exotic Himalayan blackberry colonized the floodplain landforms fastest (Figure 9a). This species was observed to dominate mesic riparian environments, rarely co-occured with other understory species once established, and spread by vegetative production to xeric locations. In contrast, the native California blackberry was observed to co-occur with multiple herbaceous and woody species and had the greatest potential for cover on the erosional floodplain landforms (Figure 9b).

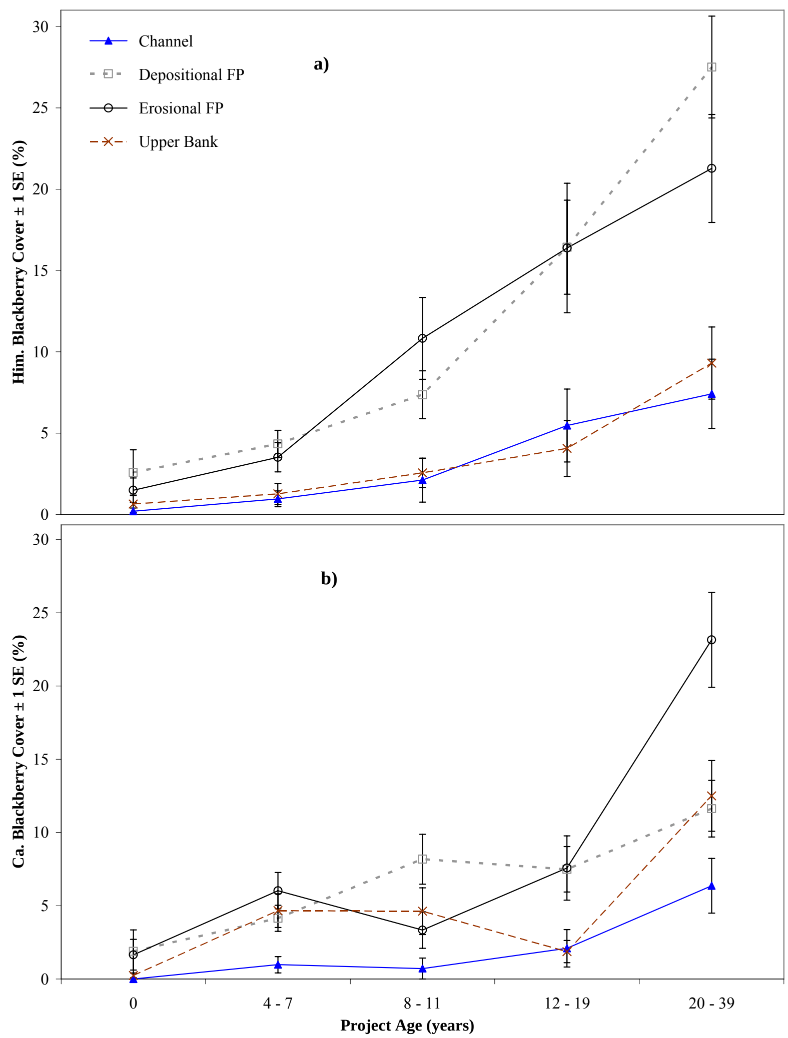

Figure 9: a) Himalayan and b) California blackberry cover over time by landform class.

The response of forb and grass species to restoration is an important outcome for ranch managers considering future projects. We summarized the mean values (Table 4) by functional group and calculated their relative percent change (Figure 10). These results were highly variable, with no obvious trajectory. However, patterns of herbaceous species response indicated several interesting trends.

Table 4: Herbaceous riparian metric mean values with standard error by project age group (differing letters in ANOVA denote statistically significant differences between age groups).

Restoration Metric	**Non-restored** Mean ± SE	**4 - 7 yrs.** Mean ± SE	**8 - 11 yrs.** Mean ± SE	**12 - 19 yrs.** Mean ± SE	**20 - 39 yrs.** Mean ± SE	ANOVA ($p<0.05$)
Exotic per. grass cover (%)	3.20 ± 0.69	5.95 ± 0.56	4.90 ± 0.64	9.59 ± 1.15	6.28 ± 0.77	a-a-a-b-a
Exotic per. forb cover (%)	2.47 ± 0.39	5.16 ± 0.44	3.31 ± 0.47	3.07 ± 0.65	4.18 ± 0.58	a-b-ab-b-ab
Native per. forb cover (%)	5.27 ± 1.03	4.51 ± 0.44	8.99 ± 0.91	7.12 ± 0.99	7.40 ± 0.85	ab-b-c-abc-bc
Per. herb. richness (sp./plot)	2.11 ± 0.15	2.67 ± 0.08	3.77 ± 0.49	5.08 ± 1.81	2.45 ± 0.11	a-a-ab-b-a
Native per. grass cover (%)	8.16 ± 1.18	9.81 ± 0.66	7.23 ± 0.79	9.42 ± 1.12	8.58 ± 0.96	a-a-a-a-a
Ann. herb. richness (sp./plot)	4.66 ± 0.38	3.87 ± 0.12	3.99 ± 0.19	3.25 ± 0.43	2.22 ± 0.12	a-ab-ab-b-c
Annual grass cover (%)	37.0 ± 1.86	23.6 ± 0.88	22.8 ± 1.31	13.2 ± 1.19	13.8 ± 1.12	a-b-b-c-c
Annual forb cover (%)	17.1 ± 1.29	19.1 ± 0.85	12.1 ± 0.94	10.0 ± 1.07	4.78 ± 0.59	a-a-b-b-c

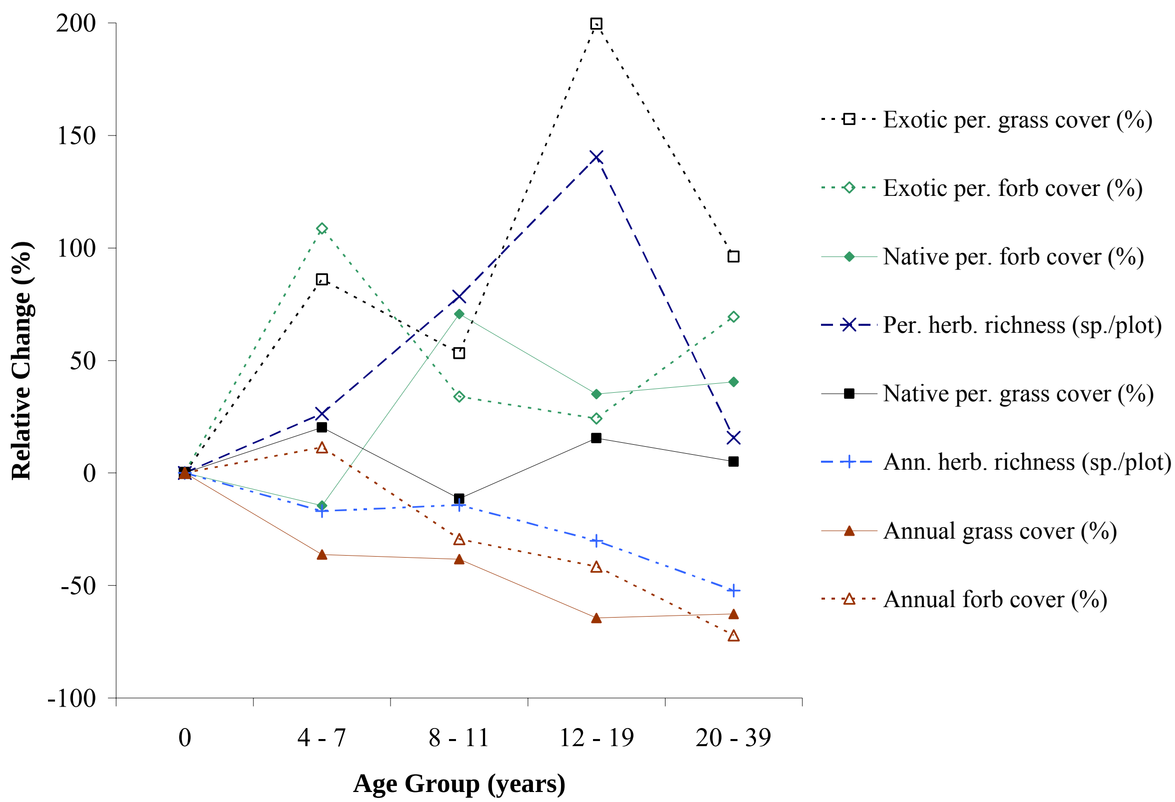

Figure 10: Relative percent change of herbaceous species metrics over time.

The results showed no response for native perennial grass. In comparison, cover of the three other perennial functional groups - exotic perennial grass, exotic perennial forb, and native perennial forb increased and decreased with project age. Exotic perennial grass cover was the first to increase and peaked between 12 and 19 years, similar to the perennial herbaceous species richness. The annual species cover and species richness (includes biennial spp.) significantly decreased over time. These opportunistic annual species benefit from disturbance and resulting bare ground patches and the observed decline may be caused by the increase in shade, increase in liter, and/or competition. This negative trajectory indicates a potential decline in rare plant habitat because of the reduction in cover of annual forb species. These results warrant further research since our single visit at each site over the entire summer limited identification of annual flora to genus level and functional groups.

It is often assumed the native herbaceous species would benefit indirectly from exclusion of herbivory. Our results indicate that the effect of restoration on non-woody plant species is more complex. *Juncus* species generally grow in full sun habitat. *Carex* are more shade tolerant and the most diverse riparian plant genus in California. Results indicated a negative trajectory on certain landform classes for these two genera (Figures 11 a and b). This may be considered an undesirable outcome by some botanists and plant ecologists. It is important to note that more recent revegetation projects have been implemented using planting palates that incorporate herbaceous species. This was not a common practice at the projects sites we evaluated, thus limiting our ability to evaluate specific correlations to revegetation methods.

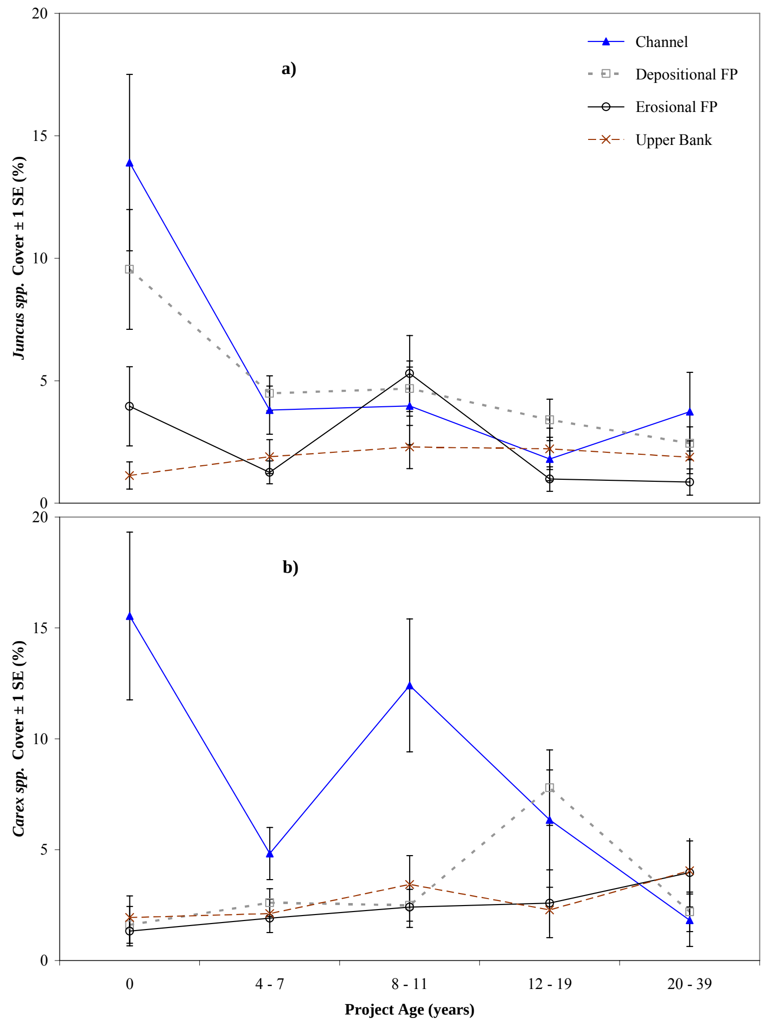

Figure 11: a) *Juncus spp*. and b) *Carex spp*. cover over time by landform class.

Annual weedy species are a concern on agricultural fields and riparian areas can be sources. Some landowners are unwilling to implement riparian fencing because of these issues. We analyzed thistles (Italian, yellow-star, purple-star, distaff, etc.) and poison hemlock for response over time by landform class (Figures 12 a and b). In some locations, these species increased rapidly during the first three years after project implementation, which we did not investigate. However, the overall long-term trend for these species is decreasing. This could be due to shade, competition, and similar interactions influencing annual grass cover.

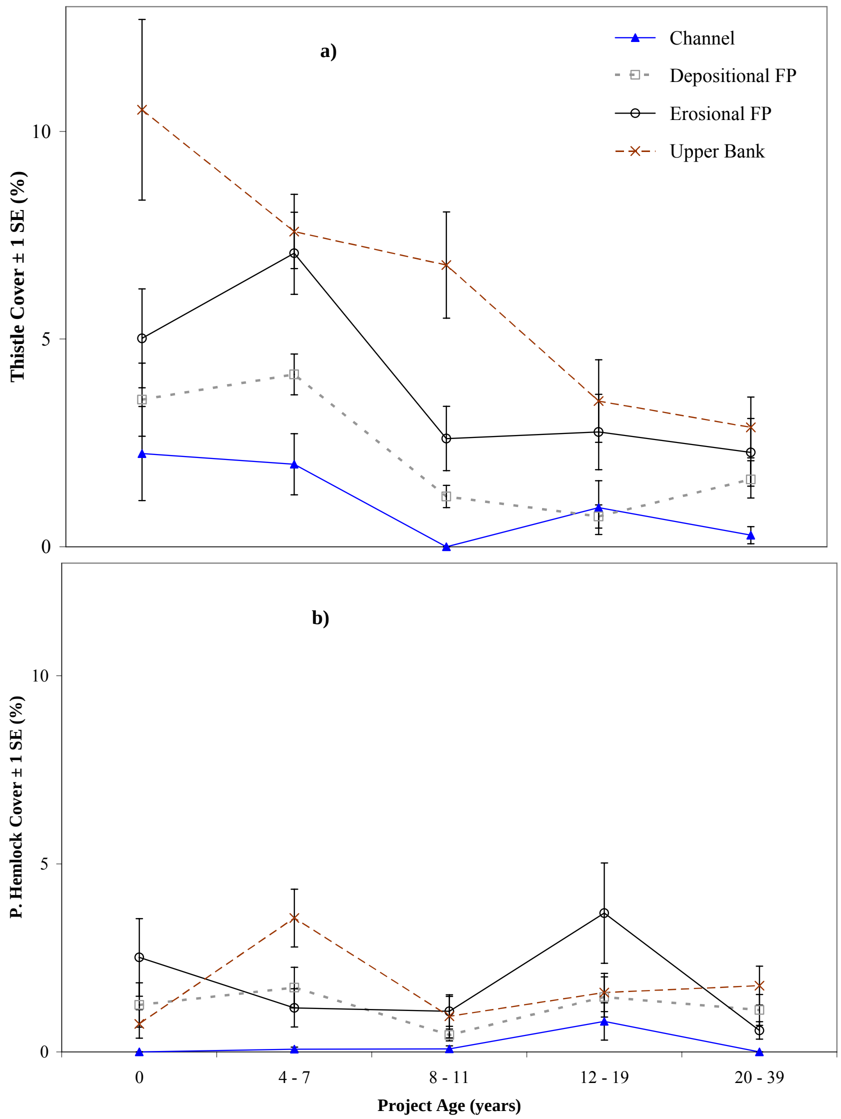

Figure 12: a) Poison hemlock and b) thistle cover over time by landform class.

Vegetation management options depend on the invasive population autecology and abundance. Planning resources to account for spatial and temporal patterns is difficult over multiple decades given site-specific concerns. We have documented succession of the plant community on a regional scale as woody species replaced herbaceous species. The basic issues and concerns at project sites changed as project sites aged over multiple decades. Simultaneously managing both annual and woody invasive species may not be feasible; however, providing options for management at critical moments may be a realistic alternative. For example, fences along streams do not last forever and we observed them failing after twenty years, especially.

Fences may be relocated further from the stream where riparian pastures are an option. When revegetation objectives are accomplished, shrub cover may be sustained at moderate levels with controlled disturbance including herbivory (Ward et al. 2003a and 2003b, Allen-Diaz et al. 2004).

Restoration Practices

Metric Trajectories

Determining the effects of a specific restoration method is challenging but the retrospective study design offers a valid approach for this evaluation. This component depended upon the information obtained from both landowners and restoration practitioners regarding a complete species list of what was planted at each site. Collecting specific and comparable data was problematic given how different groups approached record keeping in the past. Despite this, we were able to analyze available information and field data for correlations between particular revegetation methods utilized at project sites and the responses of restoration metrics and tree species density. In this way, we generated trends for regional project site response to project implementation method.

Effect on Metrics

We analyzed specific metrics which were expected to improve as a result of restoration efforts for correlations to planted and non-planted revegetation practices over time. The non-planted sites were allowed to revegetate on their own through herbivore exclusion or management and without the introduction of plant species. The planted sites had an assortment of species planted, with willow sprigging as the most commonly used method of planting.

No effect from planting was observed on total native tree density (Figure 13) while the greatest effect of planting was to increase tree species richness (# of species) across all age groups (Figure 14). For native tree cover (Figures 15), intercepted solar radiation (Figure 16), and relative bank stability (Figure 17), the planted sites had a significant improvement at 4-7 year old project sites. Values for these three metrics at non-planted and planted sites converged in the 8-11 year old project sites. The implication is that direct planting of trees can speed the recovery of riparian function relative to passive revegetation approaches. However, the result following 40 years since project implementation is generally the same for both methods. This should give the resource manager useful information for setting site-specific project goals and making decisions about resource and funding allocation for active versus passive revegetation.

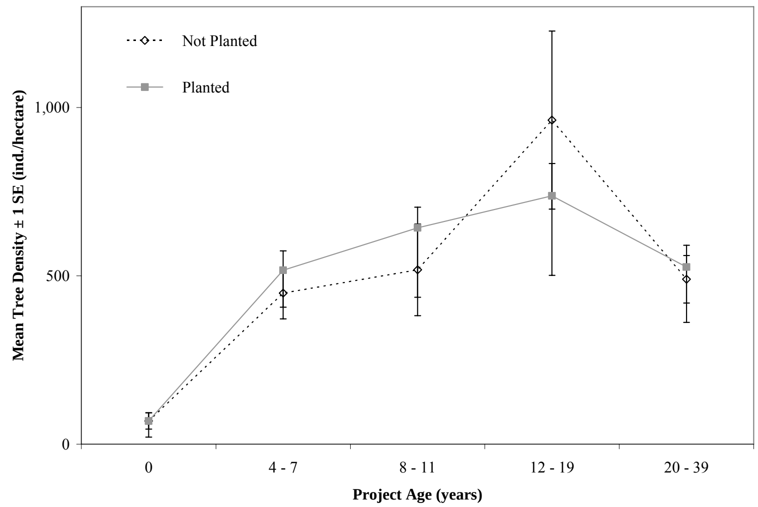

Figure 13: Native tree density over time by revegetation method.

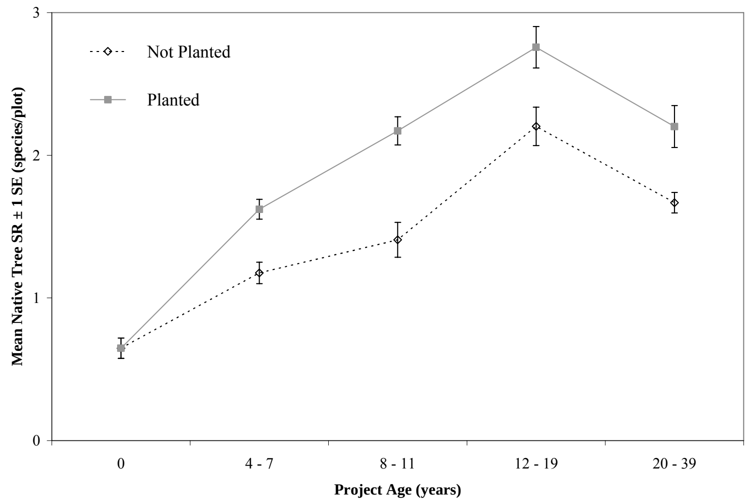

Figure 14: Native tree species richness (SR) over time by revegetation method.

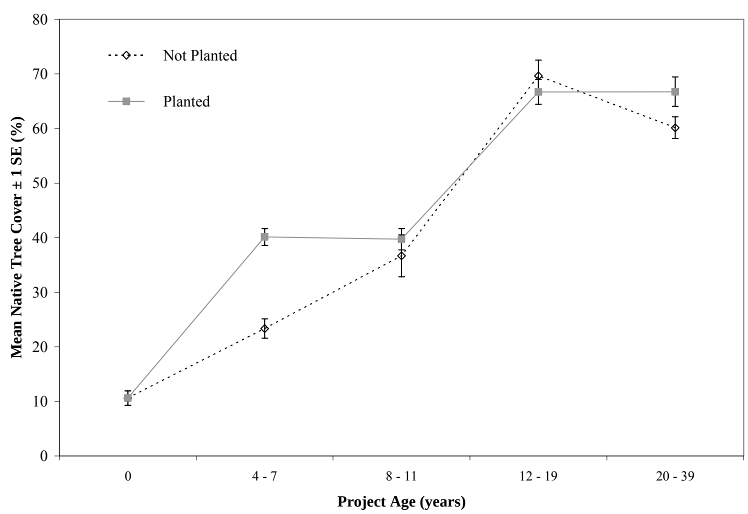

Figure 15: Native tree canopy cover over time by revegetation method.

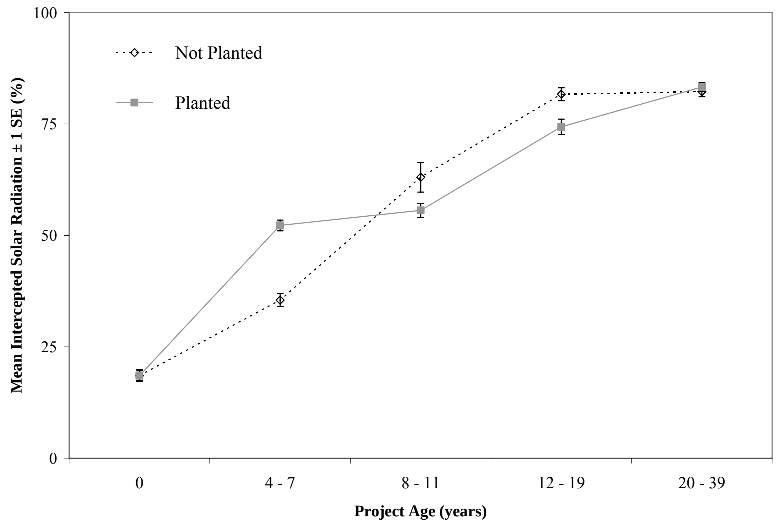

Figure 16: Intercepted solar radiation over time by revegetation method.

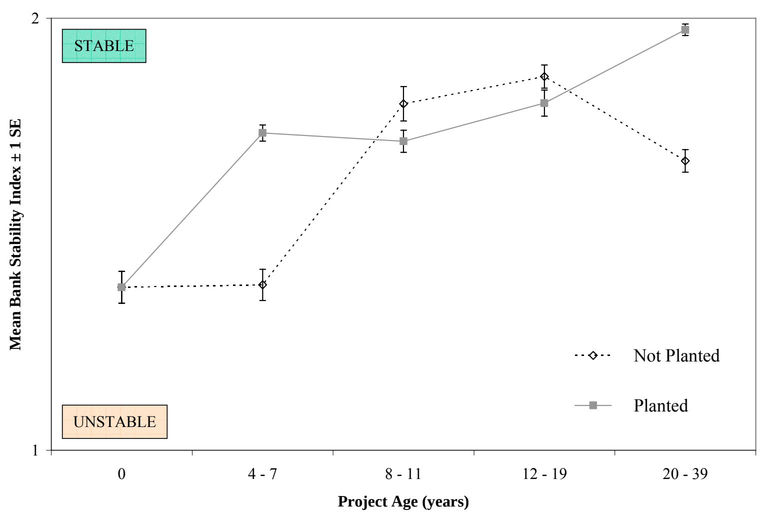

Figure 17: Stream bank stability over time by revegetation method.

Effect on Specific Tree Genera

We were interested in explaining the difference in our results between tree density and tree species richness discussed above (Figures 13 and 14). We expected that the less frequently occurring tree species may be driving the significant effect on richness observed at planted project sites because the common species are more successful at natural regeneration generally. To understand the intricacies of tree response to revegetation methods, we assessed the density of each dominant tree taxa using two sets of data driven models and identified restoration treatments as the predictor variables. The treatments included:

1) Non-restored sites (HM-, P-, B-);
2) Herbivore management, genus not planted, not bioengineered (HM+, P-, B-);
3) Herbivore management, genus planted, not bioengineered (HM+, P+, B-);
4) Herbivore management, genus not planted, bioengineered (HM+, P-, B+); and
5) Herbivore management, genus planted, bioengineered (HM+, P+, B+).

Bioengineering techniques included in the analysis were bioengineered bank stabilization projects, such as willow wall and/or deflector/baffle construction designs, which utilized live plant material and intended to effect vegetation dynamics (Flosi et al.1998, Wehren et al. 2002, Gerstein and Harris 2005). Early seral genus groups analyzed were shrub willow (arroyo, narrow-leaved), tree willow (red, shining), cottonwood (Fremont's, black), and alder (white, red). The late seral genus groups analyzed were Oregon ash, maple (box elder, big leaf), bay, live oak (coastal, canyon, interior), deciduous oak (valley, Oregon, black), buckeye, and Douglas-fir. These were chosen based upon their wide distribution in north coast riparian areas, frequent utilization in revegetation efforts, and sample size across the treatments. The response variable was the number of established individuals per plot for each of the above genus groups. This count data was dominated by zero values when analyzed by genus so a negative binomial regression was performed using Intercooled Stata 7.0 (Long and Freese 2006).

The first set of models compared all four restoration method treatments to non-restored sites (HM-, P-, B-) for each genus. The complete summary of regression coefficients and probability values is provided in Appendix C. Given the variability between and within sites, other predictor variables were included in the models using backward step-wise regression ($p<0.10$) in order to reduce the variability from spatial and temporal influences. They included: 1) project age, 2) summer stream flow, 3) maximum summer ambient temperature, 4) landform class, 5) relative height above thalweg, and 6) soil percent clay. Plot size was utilized as an exposure variable. Site category was included as a cluster variable in the model to account for spatial autocorrelation. The soil and landform types were formed by the hydrologic processes that drive riparian plant communities. Incorporating these environmental data is important for increasing the confidence in final model results (Thayer et al. 2005).

The second set of models compared the effectiveness of active restoration techniques. The regression coefficients quantify the effect of revegetation method compared to the passively revegetated sites, which did not receive planting or bioengineering (HM+, P-, B-) for each genus (Appendix D). The non-restored sites were removed from the database for this analysis. In this model we added two more predictor variables to the above six: 1) relict population presence, indicating that the genus was present at the site prior to the project; and 2) herbivore access, representing the long-term management of livestock and/or deer at the site. Similar backward regression, exposure, and cluster variables were utilized.

The statistical results from both models were summarized graphically with mean tree density values by treatment level (Figure 18 and 19). Each early seral group showed greater density at projects sites, regardless of treatment group, than non-restored sites. The exception was cottonwood at the bioengineered, non-planted sites. Shrub willow and alder density was the greatest at bioengineered sites where they were also planted (HM+, P+, B+). Tree willows showed a similar trend but this was not significant ($p=0.155$). Non-planted sites with bioengineering showed a trend of greater shrub willow and alder density than planted sites without bioengineering. Cottonwood response was different and natural regeneration was less compared to other early seral species since the planted sites had significantly greater density than the non-planted sites. Tree willow results did not show a greater effect of planting the genus than passive restoration, which may be due to tree willows being planted less frequently than the common shrub willows. The tree forms are harder to find at most degraded riparian corridors, but they are preferred by many ranch managers and flood control engineers because of their upright form. Thus, potential opportunities for improving future project design include the planting of more tree willow species where appropriate.

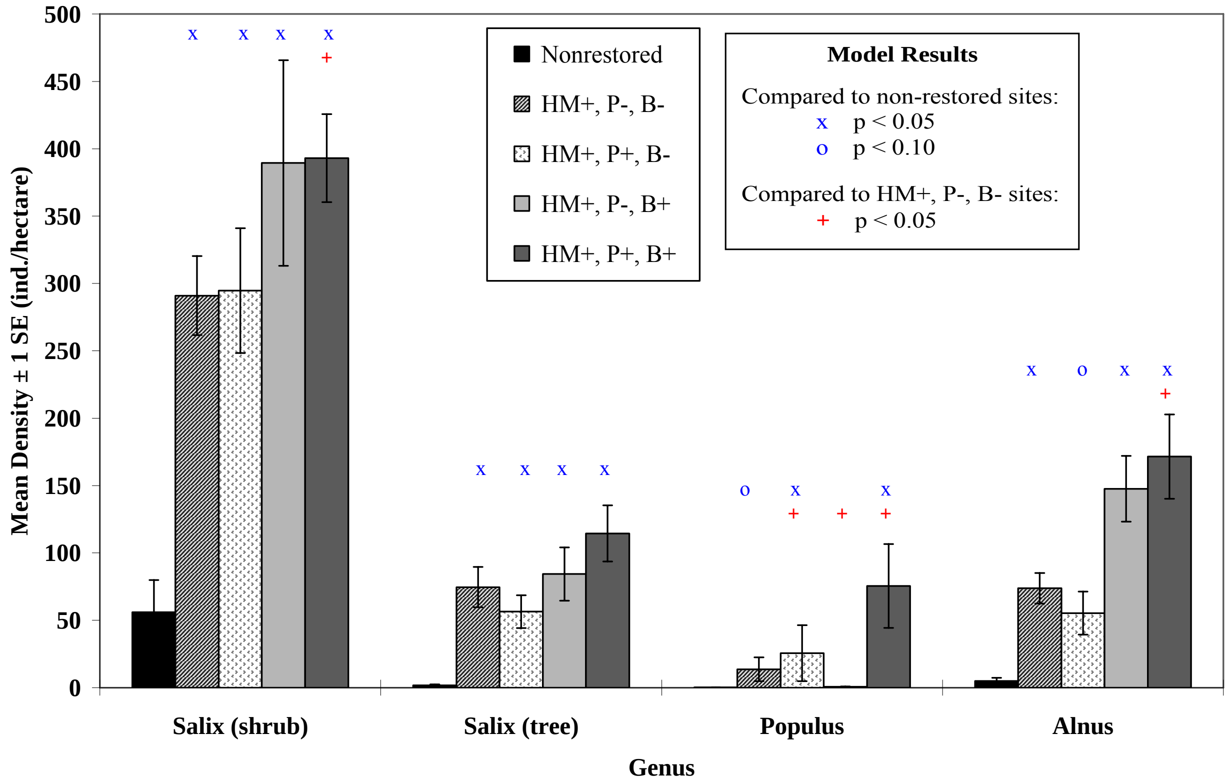

Figure 18: Early seral tree density response to revegetation method.

In general, our results showed that managing livestock or deer using fencing or other options increased the abundance of the common native early seral tree species. A simple recommendation is to wait for a few years to see where natural regeneration is occurring unless a site has minimal floodplain access for colonization and no perennial flow, or groundwater available, for establishment (Opperman and Merenlander 2003). If early seral species are desired on stream banks above the 2 x bankfull (floodprone) elevation, then planting would be recommended. If stream banks are unstable, bioengineering structures are clearly recommended before planting early seral species. Where alder is desired and no relict population is present, the objective of creating seed source for future natural regeneration should result in more alders than planting each location where a tree is desired (Appendix D).

The slow growing late seral genera demonstrated a different pattern in their response to revegetation than early seral taxa (Figure 19). All late seral genera had the greatest increase in density where each was planted, regardless of whether bioengineering was utilized. Most genera showed no significant evidence of natural regeneration. Exceptions included maple, live oak, and buckeye, which had a greater density at non-planted sites than non-restored sites. This indicates successful colonization and establishment similar to the early seral species; however abundance was considerably less where they were not planted. Ash was nearly significant for colonizing passively restored sites but was not significant (p=0.150). Both live oak and deciduous oak had a greater density at bioengineered sites where they were not planted than the non-planted, non-bioengineered sites. Bioengineering structures most likely provided suitable habitat for oaks to colonize and establish, though their abundance was significantly less than at sites where they were planted.

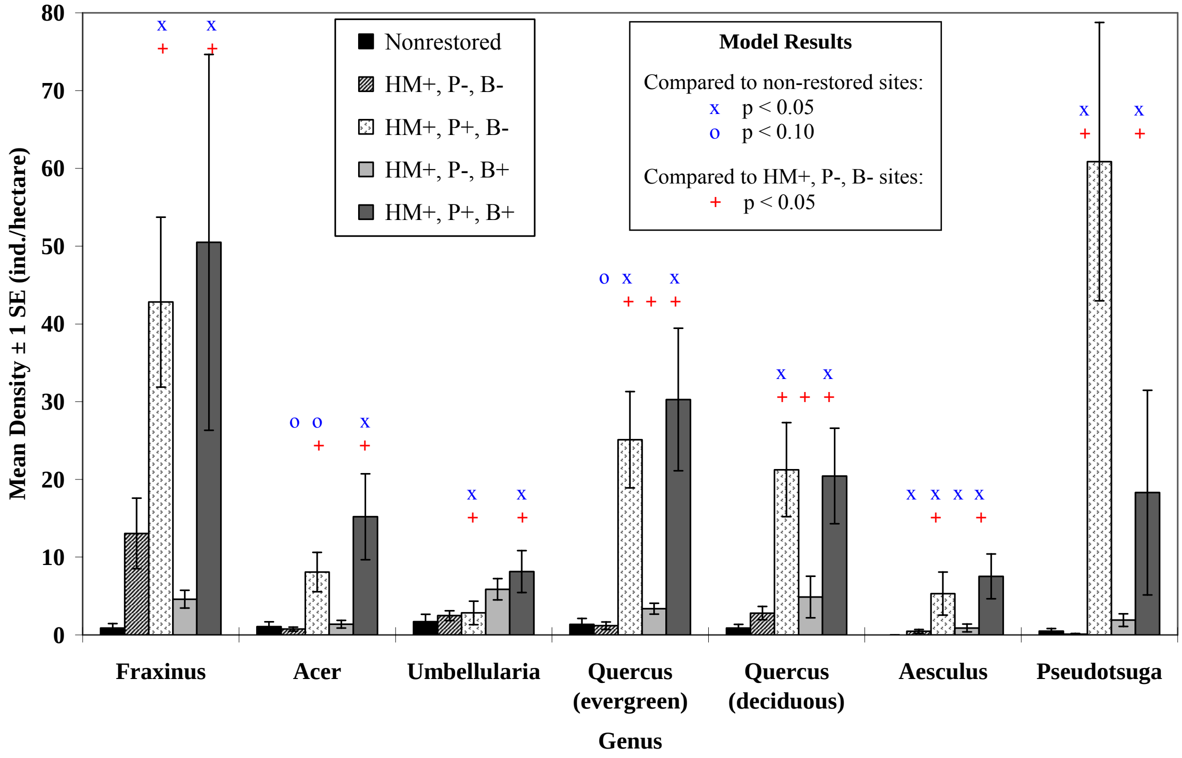

Figure 19: Late seral tree density response to revegetation method.

GUIDELINES FOR RIPARIAN REVEGETATION MONITORING

In addition to providing restoration practitioners, landowners, and grantors with useful direction to improve the success of riparian revegetation projects, we are currently developing guidelines to assist identified users in monitoring their revegetation projects. In this separate and pending document, we will present a set of tools that can be used at the initial stage of project design, post project implementation, or, ideally, over a long-term period to track changes as a result of restoration treatments. By following the process outlined in this document, the user will develop a monitoring program complete with objectives and identified monitoring methods. All methods listed in this document will be appropriately referenced for their easy retrieval.

Monitoring vegetation change at multiple scales is a well-established discipline, complete with time tested methods and protocols (Harris et al. 2005). If correctly selected and adapted to suit specific project needs, these methods are appropriate and effective in monitoring riparian revegetation projects. Because there is no limit to the number of monitoring handbooks and references, our intent is not to reiterate the step-by-step instructions for these methods. Instead, we will guide the reader through critical steps in developing a monitoring program. This will include establishing a monitoring object that is compatible with the restoration project goals and objectives. Additionally, we will direct the user to a list of possible methods to employ complete with the primary reference for each method. In this way we are forming a link for the user between their objective and the appropriate monitoring method, which was unavailable up until this time. The following is a condensed preliminary draft of this document that we will expanded upon in the complete document by December 2007.

Developing a Monitoring Program

Establishing Monitoring Objectives

By first establishing appropriate monitoring objectives and then selecting the correct monitoring method, the user will be able to document project outcomes. Accordingly, the guidelines we are drafting are intended to be used as a planning tool in conjunction with project documents including maps, design plans, and contracts.

Revegetation project objectives should form the foundation of project design. Ideally, project objectives will be stated in the initial project proposal and associated contract with the funder. Monitoring objectives are directly connected to the goals and objectives of the revegetation project and starting from the project design stage the two should be integrated. Understanding this connection and forming the integration between the two will increase the restorationists' ability to use monitoring effectively as a management tool. This will be achieved in the monitoring guidelines we are developing through a series of questions and a worksheet. The questions will direct the user to document the revegetation project goals and objectives, and contract details including contract timeline, duration of time and funding allocated for monitoring. They also guide the user to make decisions about what type of monitoring to conduct. With this context established, the user then drafts a monitoring objective.

Types of Monitoring

The type of monitoring an individual user will conduct will be based on several factors, including monitoring objectives, time and resources allocated to the monitoring effort and the time frame over which the monitoring is anticipated to occur. The four basic types of monitoring include implementation monitoring, effectiveness monitoring, validation monitoring and trend monitoring. The guidelines we are drafting will focus on site and reach scale implementation and effectiveness monitoring, since these are the most feasible to conduct and the most likely to document changes associated with a particular treatment or series of treatments.

Implementation monitoring generally consists of a qualitative assessment of whether specific aspects of the revegetation treatment were implemented as planned and should be conducted within a short period after project completion. Effectiveness monitoring is an assessment of whether a treatment is having the desired effect. It is best to conduct effectiveness monitoring prior to treatment, post implementation, and at set time intervals thereafter, for as long as resources allow. Specific sampling intervals will be determined based on project objectives, associated parameters and the time expected before changes in those parameters might be exhibited. Effectiveness monitoring can be qualitative or quantitative and should document both intended and unintended outcomes of the revegetation treatment. Users who choose to employ qualitative revegetation monitoring will be directed to California Department of Fish and Game's (CDFG) qualitative protocols (Harris et al. 2006). Since Harris submitted these protocols in 2006, CDFG has made important revisions based upon staff testing in the field.

Selection of quantitative effectiveness monitoring methods will depend on what parameters will be examined. The attributes that are anticipated to change over time as a result of the revegetation treatment are the logical parameters to focus on monitoring.

Selecting Parameters and Specific Methods

First and foremost, selection of a parameter to be sampled, and determining the timing and frequency of measuring at a project site, should be driven by the project's goals and objectives. If the primary goal of a project is to increase native woody cover on the target stream bank, then the parameters to be sampled would be native tree and shrub cover and composition. Selecting those parameters would direct users of our guidelines to the Line Intercept Transects protocol developed by Harris et al. Table 5 is a list of common parameters that could be expected to change over time as a result of riparian revegetation treatments and the preferred methods, and method source, for sampling those parameters.

Table 5: Monitoring methods based on parameters sampled.

Parameter Monitored	Method (Source)
Canopy cover	Spherical Densiometer (Flosi et al. 1998)
Width-to-depth ratio	Width/Depth Determination (Rosgen 1996, Flosi et al. 1998)
Maximum pool depth	Habitat Inventory (Flosi et al. 1998)
Tree and shrub cover	Line Intercept Transects (Harris et al. 2005)
Tree and shrub composition	Line Intercept Transects and/or Floodplain Forest Composition Plots (Harris et al. 2005)
Bank stability	Line Intercept Transects Along Banks (Gerstein and Harris 2005)
Survivorship	Modified Census Survey (Nossaman et al. 2007)

Note: It is recommended that all users referring to the Harris and Harris et al. protocols consult Nossaman et al. 2007 for modifications made based upon additional field testing.

We will recommend that all monitoring occurs in conjunction with proper project location documentation techniques (Gerstein et al. 2005) and photopoint monitoring (Gerstein and Kocher 2005).

While it is crucial that parameter and method selection be guided by revegetation project objectives, additional factors such as the time and level of expertise required must also be considered. We measured 36 parameters at either the reach, transect, or plot scale at each of the 102 studied riparian revegetation projects. This comprehensive approach required a minimum of 3 staff days per site to conduct the monitoring as described in the methods section of this report. It is impractical to expect that a restorationist will develop and implement a monitoring program that will include all of these parameters and methods. It is also unlikely that there will be sufficient funding to support the staff time needed to carry out this level of effort.

Some monitoring methods consist of site or reach scale measurements like canopy density and width-to-depth ratio. Other parameters, like tree density by species and tree species richness are measured through plot or line intercept methods. Generally, site or reach scale parameters require less time than the plot based parameters.

It is our intent to present users with a selection of methods that require only basic training and can be implemented within a reasonable budget and timeframe.

Additional Monitoring Considerations

Crafting Quantitative Project Goals and Objectives

Increasingly, the restoration practitioner and associated conservation organization implementing restoration projects, and even grantors, are striving to set quantifiable project goals and objectives. Realistic goals or objectives can often be difficult to identify and verbalize. This involves an estimate of response duration and magnitude of a particular project site characteristic. A good example is canopy density.

In the case of canopy density, we observed a gradual increase over a 40-year time span up to a value of 81.8 percent (Table 2) or a relative percent change of 520 percent. The relative percent change between the mean of 13.2 of non-restored sites and 40.9 of the 4-7 year old sites was a relative percent change of 210 percent (Figure 6). These magnitudes of change in canopy density and corresponding durations for their occurrence can be used to write a quantitative restoration project goal and objective that would read, “The project will increase site canopy density from zero to 80 percent over a 40 year time frame resulting in a relative percent change of 520 percent.” Because it is unlikely that monitoring will be carried out over a 40 year time span it may be more realistic to set a short-term goal that states, “An initial project goal is to increase site canopy density from zero to 40 percent over a 7 year time frame, resulting in a relative percent change of 210 percent.” The values provided for other parameters in Tables 2 and 3 and Figures 6 and 7 can be used in the same manner to set quantitative project goals and objectives for future revegetation projects in the study area.

Stream Shade

Two current field methods for measuring stream shade are Solar Pathfinder® and Spherical Densiometer. Solar Pathfinder method measures intercepted solar radiation while the Densiometer method measures canopy cover. The relationship between both stream shade methods is highly significant ($R^2 = 0.92$, $p<0.0001$) as shown in Figure 20. Though the Densiometer method appears to produce slightly greater variability, the data may represent riparian vegetation to a greater degree than the Solar Pathfinder method, which includes greater canyon slopes and upland vegetation. Given the power of the correlation between both methods, restoration project monitoring programs should utilize the method that is convenient and consistent with previous data collected.

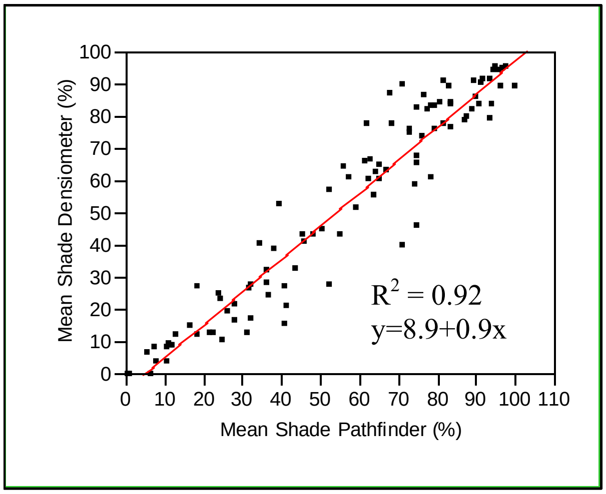

Figure 20: Relationship between stream shade Solar Pathfinder (intercepted solar radiation) and Densiometer (canopy density).

OUTREACH & EDUCATION

The uniqueness and practical importance of this survey was our ability to quantify the response of project site conditions over time since project installation. This intensive effort also gave us the opportunity to provide direction in forming project monitoring guidelines. We have iteratively shared and communicated preliminary results over the course of this study to project partners and the larger restoration community. We have refined our analysis based on the feedback we received from this exchange. This process was essential in order to ensure this applied research effort would remain on target to achieve its goals. Another benefit of this outreach and education included furthering regional restoration community's ability to set quantified project objectives, explain the projects benefits using a scientific approach, and monitor project performance over time.

We presented preliminary project results at six workshops and meetings to the local and statewide watershed restoration community (Table 6).

Table 6: Workshops provided to share project results.

Workshop Title	Date	Attendees
Cooperators Feedback	05/04/2004	23
Master Gardeners Training	06/09/2004	18
Riparian Management	06/01/2005	24
Bioengineering	10/06/2005	17
Stream Restoration Success	07/07/2006	87
Sonoma County GIS Day	11/15/06	28

Annual conferences sponsored by professional societies also offered a means for sharing the results through poster and oral presentations. They included:

1. Lennox, M.S., D.J. Lewis, R. Jackson, C.F. Battalgia, K.W. Tate, B. Allen-Diaz, S. Larson, J.M. Harper. 2002 University of California Riparian Revegetation Evaluation. pgs. 380-381. In: Proceedings of the Ecological Society of America 87th Annual Meeting and Society of for Ecological Restoration 14th Annual International Conference. http://abstracts.co.allenpress.com/pweb/esa2002/document/?ID=18174

2. Lennox, M.S., D.J. Lewis, R. Jackson, C.F. Battalgia, K.W. Tate, B. Allen-Diaz, S. Larson, J.M. Harper. 2002 University of California Riparian Revegetation Evaluation. pgs. 16-17. In: Proceedings of the California Society for Ecological Restoration, SERCAL's Ninth Annual Conference.

3. Katz, R.; M. Lennox; D. Lewis; R. Jackson; J. Harper; B. Allen-Diaz; S. Larson; K. Tate. 2004. Riparian Flora Observed at Riparian Revegetation Projects in North Coastal California. Poster abstract for the Redwood Region Forest Science Symposium. Rohnert Park, California. Sponsored by University of California Center for Forestry, Division of Agriculture and Natural Resources, and College of Natural Resources, Berkeley Campus. http://nature.berkeley.edu/forestry/redwood_poster06-katz.html.

4. Katz, R.; M. Lennox; D. Lewis; R. Jackson; J. Harper; B. Allen-Diaz; S. Larson; K. Tate. 2004. Riparian Flora Observed at Riparian Revegetation Projects in North Coastal California. Abstract in: Salmonid Restoration Federation's: 22nd Annual Salmonid Restoration Conference & 14th

International Salmonid Habitat Enhancement Workshop Conference Proceedings. Davis, California. Sponsored by American Fisheries Society and partners. Page 71.

5. Lennox, M.S., D.J. Lewis, R. Katz, R. Jackson, J. Harper, B. Allen-Diaz, and K. Tate. 2004. Riparian Revegetation Evaluation in North Coastal California. Abstract in: The Changing Landscape of Wildlife Management: 2004 Annual Conference of the Western Section of the Wildlife Society Program and Abstracts. Rohnert Park, California. Page 31.

6. Lennox, M., D.J. Lewis, R. Jackson, J. Harper, R. Katz, S. Larson, B. Allen-Diaz, K. Tate. 2004. Riparian Revegetation Evaluation in North Coastal California. 7 pages. In: Lowrance, Richard (Editor), 2004. AWRA's 2004 Summer Specialty Conference "Riparian Ecosystems and Buffers: Multi-Scale Structure, Function, and Management." American Water Resources Association, Middleburg, Virginia, TPS-04-2, CD-ROM.

7. Lennox, M.S., D.J. Lewis, S. Larson, J. Harper, R. Katz, R. Jackson, B. Allen-Diaz, K. Tate, and D. Stokes. 2005. Riparian Trajectory and Revegetation Effectiveness in North Coastal California. Oral presentation abstract In: Salmonid Restoration Federation's 23rd Salmonid Restoration Conference. Fortuna, California. Page 116.

8. Lennox, M.S., D.J. Lewis, D. Stokes, R. Jackson, J. Harper, B. Allen-Diaz, S. Larson, and K. Tate. 2006. Quantifying Outcomes at Riparian Restoration Project Sites on Coastal Ranches. Oral presentation abstract In: Salmonid Restoration Federation's 24th Salmonid Restoration Conference. Santa Barbara, California. Page 105.

9. Lennox, M.S., D.J. Lewis, K. Tate, R. Jackson, Larson, S., J. Harper, and R. Katz. 2006. Riparian Revegetation Outcomes in California North Coastal Ranches. Poster presentation abstract In: Sixth California Oak Symposium: Today's Challenges, Tomorrow's Opportunities. University of California Integrated Hardwood Range Management Program. Page 40.

10. Lennox, M.S., D.J. Lewis, K. Tate, R. Jackson, S. Larson, J. Harper, and R. Katz. 2006. Riparian Revegetation Outcomes in California North Coast Ranches. Poster presentation abstract In: California Invasive Plant Council 15th Annual Symposium Research and Management Bridging the Gap. Rohnert Park, California. Page 28.

11. Lennox, M.S., D.J. Lewis, J. Harper, R. Jackson, D. Stokes, and K. Tate. 2006. Riparian and Aquatic Habitat Trajectory on North Coast Ranches. Oral presentation abstract In: California Society for Ecological Restoration 2006 Meeting, Shovels to Science: A Full Range of Restoration Practice in California.

CONSIDERATIONS AND RECOMMMEDATIONS

Our study results provide quantitative confirmation that riparian revegetation is resulting in numerous beneficial outcomes at the project site scale in the 40 years following project implementation. This includes biologically significant improvements to instream habitat, including maximum pool depth, and plant community and structure metrics such as woody species density and species diversity. This documentation and confirmation supports the continuation of efforts to restore vegetation along area streams and rivers.

The results of our study are also instructive for the design, implementation, and management of riparian revegetation projects. These include considerations and recommendations for the use of passive and active revegetation methods, factors that drive tree species restoration, and more general direction on understory plant community outcomes. Lastly, our efforts provide important direction on monitoring these riparian revegetation projects and the role monitoring can play in managing project outcomes.

Integrating Site Potential with Restoration Tools

The evolution of riparian restoration methods over the duration of our study period indicates that restoration partnerships have a variety of tools to use in implementing a particular project. For purposes of study and comparison we have used the broad groups of passive and active to group these tools. Our study results have identified important differences and similarities in the outcomes resulting from these two groups (Table 7).

Table 7: Generalized restoration trajectory outcomes resulting from passive and active riparian revegetation methods

Revegetation Method	
Passive	**Active**
Trajectory for majority of aquatic habitat and plant community structure outcomes is similar to those from active revegetation methods 10 to 20 years post project implementation.	Trajectory for many plant community outcomes is accelerated in comparison to passive revegetation methods during the first ten years post project implementation.
Successful for most early seral species at sites with active floodplains, perennial stream flow and relict seed source.	Tree species diversity is consistently greater than that resulting from passive revegetation methods.

Both active and passive revegetation methods are viable tools for the restoration partnership to use. Selection of one over the other should be based upon a balance between site specific goals and objectives and programmatic goals and resource allocation. An accelerated or rapid response may be desired and can be achieved through active methods, but with an associated higher project budget. Alternatively, a program may place a premium on treating the greatest length of stream per restoration dollar spent, which favors the use of passive methods requiring a longer time horizon to achieve project site response. At some locations, active methods are required to address acute bank stability issues or because plant species diversity is a primary goal. Our general recommendation is that project design should be guided by site potential for passive revegetation and active methods should be used to enhance that potential.

Establishing Trees

In general, the core goal of riparian revegetation is the reestablishment of appropriate native tree species. These large flora provide critical structural functions to streams such as canopy, bank stability, woody debris recruitment and pool formation that understory plant species generally do not. Riparian tree species are highly variable in the microhabitat conditions required for propagation and the individual growth patterns of establishment. Our results identified fundamental site-specific physical factors driving the recovery of common tree taxa (Table 8). Consideration of the factors affecting passive restoration potential to establish native trees is valuable for guiding decisions to meet specific site objectives. Understanding which trees will potentially naturally regenerate and where planting would be more successful will increase the efficient use of resources when implementing a project and thus increase project success.

Table 8: Physical factors influencing tree establishment.

Taxa	Bank height[2]	Perennial flow[2]	Relict population[2]	Depositional L.C.[1]	Erosional L.C.[1]	Upper bank L.C.[1]
Shrub Willow	↓	ns	↑	↑	↑	↓
Tree Willow	↓	↑	ns	↑	↑	ns
Cottonwood	ns	↑	ns	~↑	~↓	ns
Alder	↓	↑	↑	↑	↑	↓
Ash	ns	↑	↑	↑	↑	↑
Maple/ Box elder	ns	~↑	ns	↑	↑	↑
Bay	↑	↑	↑	ns	↑	ns
Evergreen oak	↑	↑	ns	↑	↑	↑
Deciduous oak	ns	ns	ns	↑	↑	↑
Buckeye	ns	↑	↑	↑	↑	↑
Douglas-fir	ns	ns	↑	ns	ns	ns

<u>Notes:</u>

↑ = significant positive regression coefficient (p<0.05).

ns = not significant (p>0.10) regression coefficient.

~↑ = nearly significant (p<0.10) regression coefficient.

[12] = model set #1, 2 or both results summarized

In addition, our results indicate which revegetation method contributed to the successful restoration of eleven common riparian tree groups (Table 9). Passive methods alone were successful for seven of the eleven groups investigated and six taxa colonized bioengineering structures specifically. Bank stabilization projects utilize depositional processes to prevent further erosion. We speculate that in trapping flotsam, fine sediment and seeds during floods revegetation is facilitated. Direct planting was successful for establishing all genera, though alder establishment from planting was least effective. Our results show that species-specific objectives towards a diverse riparian forest are obtainable at a project site scale over time by utilizing a combination of restoration methods, with the potential for this response to occur at a landscape scale.

Table 9: Restoration factors affecting tree establishment.

Taxa	Passive[1]	Planting[12]	Bioengineering[12]
Shrub Willow	↑	↑	↑
Tree Willow	↑	↑	↑
Cottonwood	↑	↑	ns
Alder	↑	~↑	↑
Ash	↑	↑	ns
Maple/ Box elder	ns	↑	ns
Bay	ns	↑	ns
Evergreen oak	↑	↑	↑
Deciduous oak	ns	↑	↑
Buckeye	↑	↑	↑
Douglas-fir	ns	↑	ns

Notes:
↑ = significant positive regression coefficient ($p<0.05$).
ns = not significant ($p>0.10$) regression coefficient.
~↑ = nearly significant ($p<0.10$) regression coefficient.
[12] = model set #1, 2 or both results summarized

Understory Responses and Potential Alternatives

Another outcome of the evolution of riparian restoration is the increased attention to the restoration of riparian understory species. Our results provide documentation of the shrub and herbaceous vegetation response following revegetation.

Shrub species increase in density and diversity during the first forty years post project implementation. The composition of the shrub plant community is dominated by native species; however, the most abundant species is Himalayan blackberry (*Rubus discolor)*, an invasive non-native. Discussion of this topic should avoid vilifying non-native species and nostalgic dreams of a pure native landscape. Instead, the restoration partnership should focus on project objectives and desired outcomes and the trade-offs that these species present for achieving those objectives in the long-run. These species often contribute to riparian functions including structure for wildlife habitat during the early years of restoration. However, many of these species have a competitive advantage in their growth pattern relative to other understory species and thus the potential to exclude those species.

Regarding the herbaceous vegetation layer, there is a general transition from annual to perennial grass and forb species during the first forty years following project implementation. The composition of the herbaceous community contains an abundance of non-native and invasive species. There is also a decrease in sedge (*Carex sp.*) and rush (*Juncus sp.*) species over time.

Alternatives to these responses will require that project design and vegetation management focus on the long-term maintenance of native understory species. Design and layout that includes targeted niches within project sites of reduced canopy on the appropriate landform will contribute to understory species growth and diversity. Similarly, removal of invasive species at select times during the first ten years post project implementation will reduce the competitive advantage they demonstrate over other native understory species. This may require an integrative and site-specific approach, including the use of herbivory, mechanical methods, and herbicides.

Baselines and Strategic Intervention: tools for adaptive management

This cross-sectional survey demonstrates the usefulness of monitoring in documenting project success and site response. Because of this and other monitoring projects there should no longer be debate about the importance of documenting restoration efforts. Instead, the discussion needs to focus on determining the type, duration, and frequency of monitoring to be implemented. This discussion needs to realistically consider the cost of monitoring in comparison to the cost of restoration, as well as the funding and contractual structures available to support monitoring.

Qualitative monitoring to document restoration project implementation and effectiveness, usually in the form of photo-point monitoring, is generally required during the three or four year contract period. This approach is effective in its aim, as demonstrated by the series of photographs presented in this report, and should be continued. This is a manageable task to ask the restoration partnership to conduct during the project's contract and provides useful feedback on project site reponse.

There is a need for some level of quantitative monitoring of project effectiveness on a longer-term basis than the typical project contract provides. However, site and project baseline conditions can be documented during the contract timeframe. How realistic it is to ask the restoration partnership to conduct this monitoring will depend upon the level of expertise available to implement suggested methods and the additional funding support needed to conduct repeated monitoring. At a minimum, an additional day and a half staff time per riparian revegetation project should be considered. This includes one day of field time and at least half a day of data compilation and reporting.

We collected data on more than 25 variables and metrics at each project site during our survey. This required two staff days in the field and one staff day for data processing per site. Our recommendation is that fewer metrics be monitored to establish baseline conditions wher the expertise and knowledge exists in the restoration partnership to use the suggested methods. These metrics include:

- Canopy cover
- Width-to-Depth ratio
- Maximum pool depth
- Tree and shrub cover
- Tree and shrub composition

Measuring these parameters prior to project implementation will establish the baseline needed to make comparisons to measurements that in future years.

Subsequent visits to projects sites for quantitative evaluation of site response are tied to the need for strategic intervention and vegetation management. Insuring that exclusionary fencing or irrigation systems are operable during the contract timeframe is one potential phase of intervention. Longer-term, there is a time step at which the resulting plant community at a project site needs to be evaluated if management of non-native and invasive species is an objective. According to our survey results, this evaluation and intervention should be conducted at years five and ten post project implementation depending on site-specific needs. At these time steps, the abundance of species like Himalayan blackberry, harding grass, and poison hemlock can be evaluated and, more importantly, effectively managed according to current ranch and watershed goals. Waiting much longer would increase the probability managers may miss the window for adaptive management, resulting in the need for more costly and difficult intervention. These considerations should play an important role in guiding the adaptive management process of riparian areas in California.

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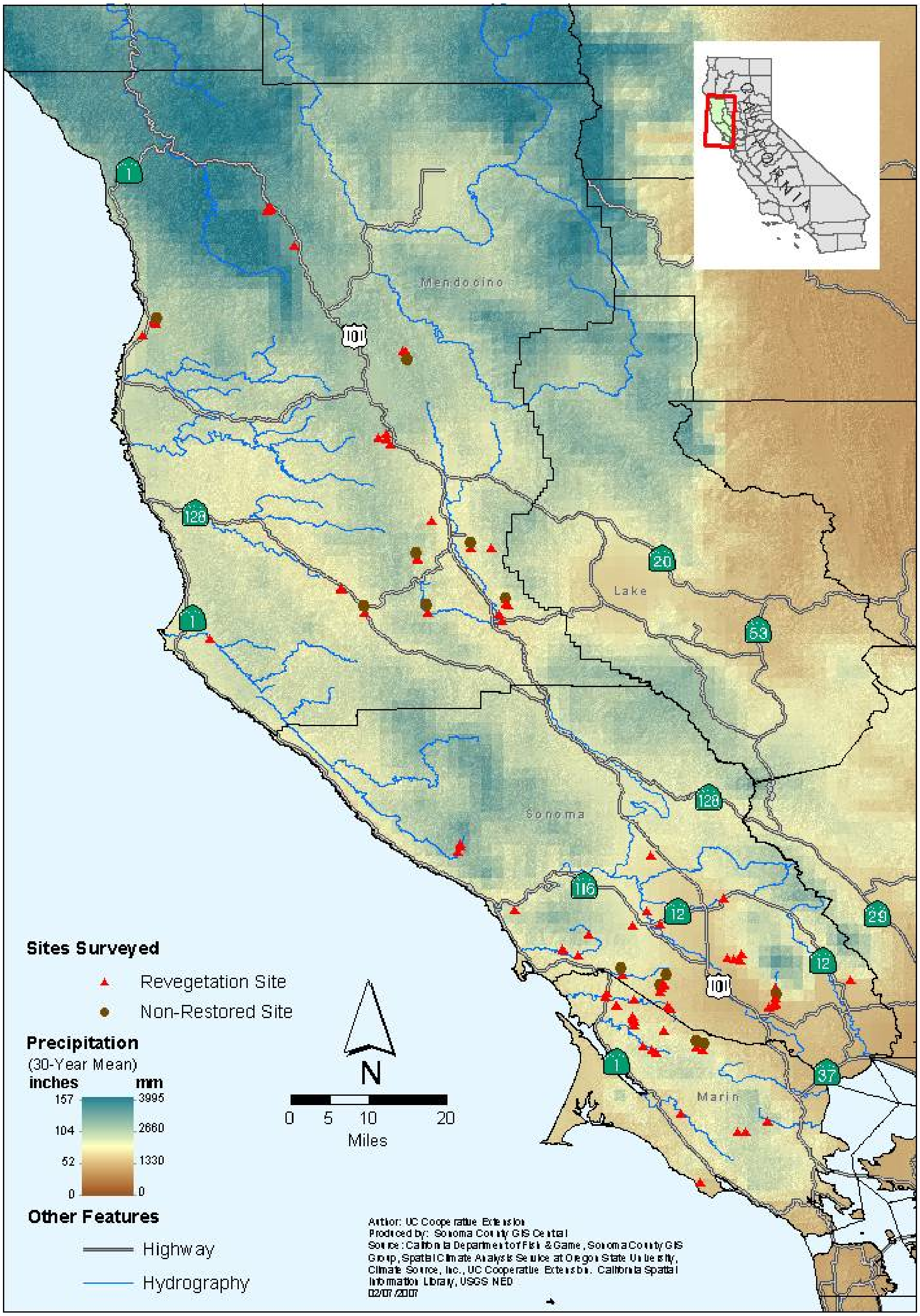
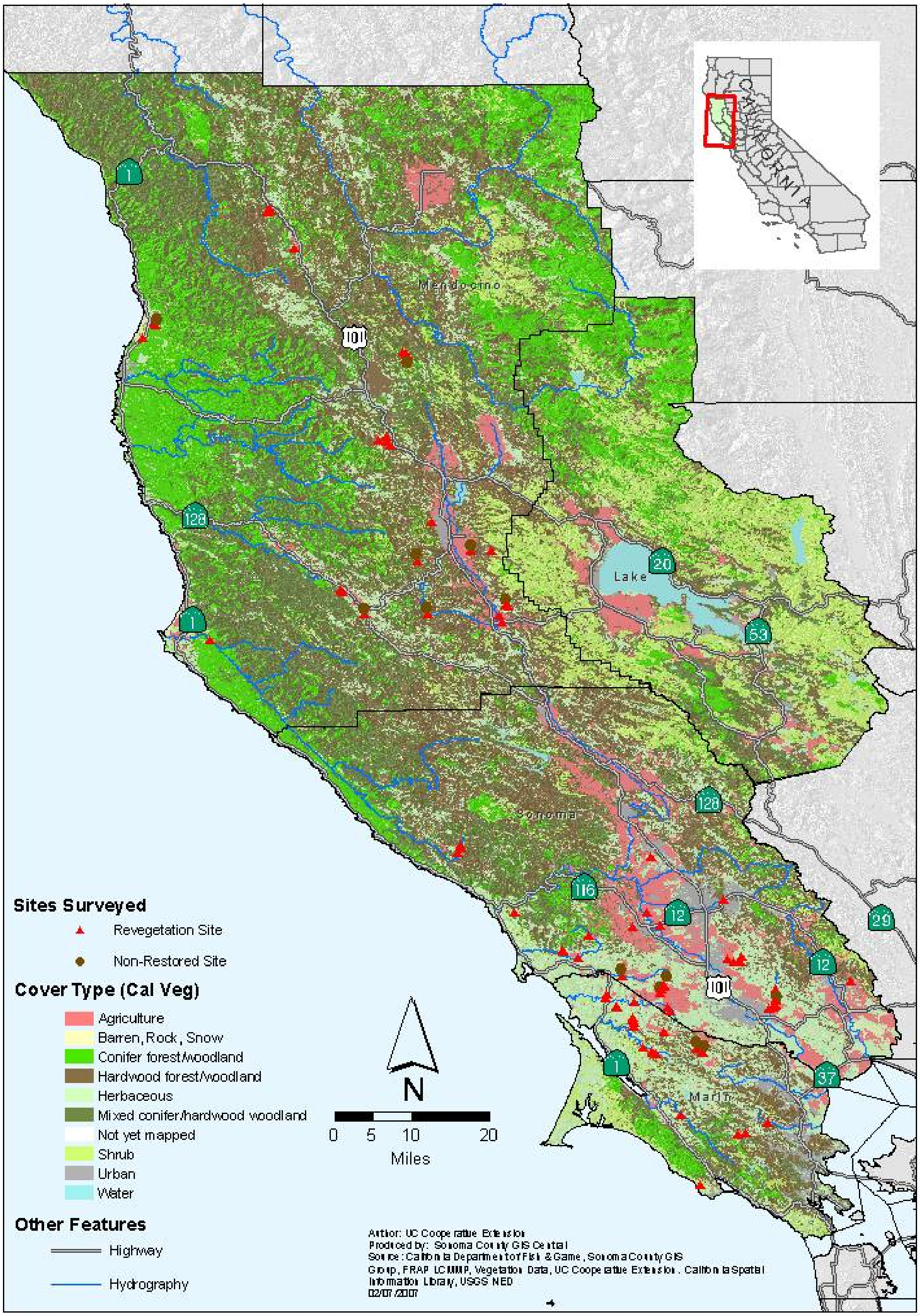
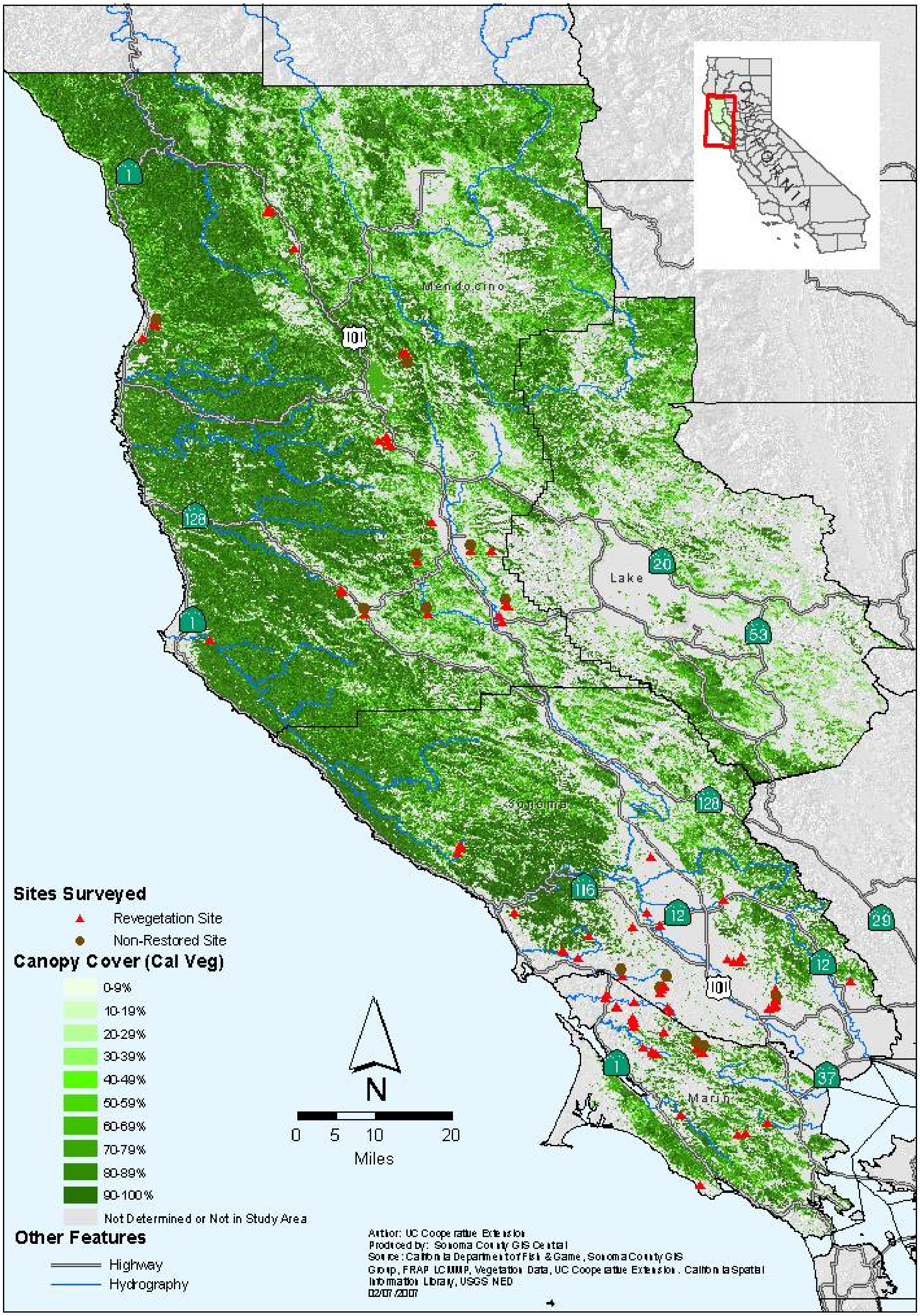
Appendix A: Maps of survey sites.



Mean precipitation (Climate Source 2001) over the study area with restoration sites (red) and non-restored sites (brown).



Cover type of dominant vegetation (CDF 2005) over the study area with restoration sites (red) and non-restored sites (brown).



Canopy cover (CDF 2005) over the study area with restoration sites (red) and non-restored sites (brown).

Appendix B: Frequency of observed woody species.

Species	Frequency (% sites present)	Density (ind./hectare) Mean (Min. - Max.)	Origin/ Form	Genus
arroyo willow	92.0%	150 (2.50 - 587)	native tree	*Salix*
Himalayan blackberry	88.6%	316 (3.10 - 2517)	exotic shrub	*Rubus*
shining willow	58.0%	30.5 (1.80 - 157)	native tree	*Salix*
Ca. blackberry	58.0%	369 (4.80 - 1492)	native shrub	*Rubus*
coyote brush	53.4%	31.4 (1.50 - 229)	native shrub	*Baccharis*
red willow	46.6%	30.0 (1.90 - 119)	native tree	*Salix*
poison oak	46.6%	49.6 (1.40 - 474)	native shrub	*Toxicodendron*
oregon ash	44.3%	22.7 (1.30 - 128)	native tree	*Fraxinus*
coast live oak	42.0%	20.7 (1.60 - 141)	native tree	*Quercus*
bay	39.8%	15.9 (1.30 - 98.0)	native tree	*Umbellularia*
white alder	37.5%	71.2 (2.60 - 381)	native tree	*Alnus*
Ca. rose	31.8%	31.8 (3.40 - 211)	native shrub	*Rosa*
sandbar willow	30.7%	70.4 (2.40 - 315)	native tree	*Salix*
valley oak	28.4%	27.1 (2.60 - 172)	native tree	*Quercus*
snowberry	27.3%	92.2 (3.30 - 482)	native shrub	*Symphocarpus*
black oak	25.0%	11.4 (1.30 - 40.8)	native tree	*Quercus*
red alder	22.7%	113 (4.10 - 295)	native tree	*Alnus*
big leaf maple	20.5%	7.40 (2.10 - 20.9)	native tree	*Acer*
buckeye	20.5%	8.60 (1.40 - 28.8)	native tree	*Aesculus*
Fremont cottonwood	17.0%	23.6 (3.10 - 106)	native tree	*Populus*
Douglas-fir	17.0%	21.4 (2.00 - 126)	native tree	*Pseudotsuga*
honeysuckle	17.0%	18.4 (1.00 - 89.6)	native vine	*Lonicera*
nine bark	15.9%	57.2 (1.20 - 351)	native shrub	*Physocarpus*
coffeeberry	14.8%	18.1 (1.50 - 60.8)	native shrub	*Rhamnus*
twinberry	14.8%	31.0 (1.60 - 181)	native shrub	*Lonicera*
broom species	13.6%	21.1 (2.00 - 73.4)	exotic shrub	multiple genera
madrone	11.4%	3.90 (1.40 - 10.5)	native tree	*Arbutus*
redwood	11.4%	16.2 (2.70 - 48.9)	native tree	*Sequoia*
blue elderberry	10.2%	4.80 (1.70 - 8.10)	native shrub	*Sambucus*
dogwod species	10.2%	43.7 (1.20 - 237)	native shrub	*Cornus*
spice bush	10.2%	48.1 (5.00 - 115)	native shrub	*Calycanthus*
toyon	8.0%	9.90 (1.00 - 45.2)	native shrub	*Heteromeles*
box elder	6.8%	20.9 (3.90 - 65.1)	native tree	*Acer*
hawthorn	6.8%	14.2 (2.90 - 29.1)	native shrub	*Crataegus*
black cottonwood	5.7%	21.2 (1.40 - 94.1)	native tree	*Populus*
English ivy	5.7%	14.1 (1.20 - 28.6)	exotic vine	*Hedera*
exotic plum species	5.7%	6.30 (2.80 - 14.0)	exotic tree	*Prunus*
hazel nut	5.7%	14.3 (3.80 - 34.7)	native shrub	*Corylus*
sticky monkey flower	4.5%	7.20 (2.10 - 15.6)	native shrub	*Mimulus*
acacia species	3.4%	6.70 (1.00 - 10.7)	exotic tree	*Acacia*
gorse	3.4%	10.8 (5.80 - 17.5)	exotic shrub	*Ulex*
birchleaf mahogany	2.3%	15.3 (11.1 - 19.6)	native shrub	*Betuloides*
wax myrtle	2.3%	14.1 (5.80 - 22.4)	native shrub	*Myrica*
eucalyptus	1.1%	35.7 (35.7 - 35.7)	exotic tree	*Eucalyptus*
Monterey pine	1.1%	11.3 (11.3 - 11.3)	exotic tree	*Pinus*

Appendix C: Model set #1 results
(restoration treatments compared to non-restored sites)

Early seral tree taxa:

Predictor Variables	shrub willow		tree willow		cottonwood		alder	
	Coefficient (95% CI)	*P*- value	Coefficient (95% CI)	*P*- value	Coefficient (95% CI)	*P*- value	Coefficient (95% CI)	*P*- value
HM+, P-, B-	1.33 (0.02, 2.65)	0.047	3.01 (1.88, 4.14)	<0.0001	3.53 (-0.17, 7.23)	0.062	1.60 (0.17, 3.03)	0.028
HM+, P+, B-	1.60 (0.36, 2.84)	0.012	3.17 (1.84, 4.50)	<0.0001	9.95 (5.41, 14.5)	<0.0001	1.42 (-0.21, 3.06)	0.089
HM+, P-, B+	1.67 (0.22, 3.12)	0.024	3.10 (1.80, 4.40)	<0.0001	0.04 (-3.33, 4.13)	0.835	2.40 (0.87, 3.93)	0.002
HM+, P+, B+	1.97 (0.73, 3.20)	0.002	3.50 (2.35, 4.65)	<0.0001	5.61 (1.96, 9.25)	0.003	2.41 (0.88, 3.93)	0.002
Project age (years)	0.03 (0.01, 0.06)	0.005		0.404	.	0.210		0.156
Landform, Depos. FP	0.81 (0.45, 1.16)	<0.0001	1.43 (0.95, 1.90)	<0.0001	1.44 (-0.20, 3.08)	0.085	1.80 (1.26, 2.34)	<0.0001
Landform, Eros. FP	0.81 (0.35, 1.27)	0.001	1.02 (0.45, 1.59)	0.011	-1.17 (-2.49, 0.15)	0.082	1.35 (0.76, 1.93)	<0.0001
Landform, Upper Bank	-1.21 (-1.79, -.62)	<0.0001	-0.14 (-1.59, -0.09)	0.189	-0.68 (-1.79, 0.44)	0.234	-1.50 (-2.62, -0.39)	0.009
Clay %	0.04 (-0.001, 0.07)	0.054		0.109		0.205		0.946
Height (bankful #)	-0.23 (-0.31, -0.15)	<0.0001	-0.35 (-0.49, -0.21)	<0.0001		0.505	-0.37 (-0.48, -0.26)	<0.0001
Flow none, pools only	0.06 (-0.49, 0.60)	0.835	0.09 (-0.83, 1.02)	0.844	3.36 (1.24, 5.48)	0.002	1.22 (0.24, 2.21)	0.015
Flow perennial	0.65 (0.14, 1.16)	0.012	0.81 (0.06, 1.55)	0.034	4.16 (2.39, 5.93)	<0.0001	2.40 (1.64, 3.16)	<0.0001
Ambient temp. (C.)	0.09 (0.02, 0.16)	0.008		0.610	0.80 (0.33, 1.26)	0.001		0.881

Late seral tree taxa:

Predictor Variables	ash		maple		bay		live oak	
	Coefficient (95% CI)	*P*- value	Coefficient (95% CI)	*P*- value	Coefficient (95% CI)	*P*- value	Coefficient (95% CI)	*P*- value
HM+, P-, B-	0.98 (-0.35, 2.31)	0.150	-1.71 (-3.49, 0.07	0.060	-0.10 (-1.32, 1.13)	0.874	-1.62 (-3.36, 0.11)	0.066
HM+, P+, B-	3.64 (2.17, 5.11)	<0.0001	1.29 (-0.19, 2.78)	0.088	1.73 (0.41, 3.05)	0.010	2.09 (0.46, 3.73)	0.012
HM+, P-, B+	0.60 (-0.56, 1.77)	0.309	-0.93 (-2.45, 0.58)	0.226	0.65 (-0.58, 1.88)	0.298	-0.01 (-1.60, 1.58)	0.987
HM+, P+, B+	4.07 (2.61, 5.54)	<0.0001	1.88 (0.26, 3.49)	0.023	1.41 (0.28, 2.55)	0.015	2.03 (0.36, 3.69)	0.017
Project age (years)	0.11 (0.07, 0.16)	0.066	0.06 (-0.001, 0.11)	0.032		0.325	0.07 (0.03, 0.12)	0.001
Landform, Depos. FP	3.02 (2.25, 3.78)	<0.0001	2.69 (0.93, 4.45)	0.005	1.23 (-1.02, 3.47)	0.285	15.2 (14.7, 15.7)	<0.0001
Landform, Eros. FP	2.34 (1.64, 3.33)	<0.0001	2.56 (0.87, 4.26)	0.016	2.17 (-0.05, 4.39)	0.055	16.0 (15.2, 16.9)	<0.0001
Landform, Upper Bank	1.76 (0.93, 2.59)	<0.0001	3.03 (1.29, 4.78)	0.002	1.55 (-0.83, 3.93)	0.202	15.6 (14.8, 16.4)	<0.0001
Clay %		0.906		0.927		0.149		0.616
Height (bankful #)		0.111		0.410	0.37 (0.17, 0.58)	<0.0001	0.37 (0.21, 0.54)	<0.0001
Flow none, pools only	1.86 (0.74, 2.99)	0.001	0.14 (-1.25, 1.54)	0.843	-0.19 (-1.44, 1.06)	0.770	0.02 (-0.92, 0.96)	0.969
Flow perennial	2.20 (1.25, 3.15)	<0.0001	0.84 (0.02, 1.67)	0.044	1.90 (0.63, 3.17)	0.003	0.86 (0.16, 1.56)	0.016
Ambient temp. (C.)	0.53 (0.33, 0.74)	<0.0001		0.995		0.115	0.23 (0.06, 0.40)	0.009

Predictor Variables	deciduous oak		buckeye		Douglas-fir	
	Coefficient (95% CI)	*P*- value	Coefficient (95% CI)	*P*- value	Coefficient (95% CI)	*P*- value
HM+, P-, B-	0.16 (-0.98, 1.29)	0.785	15.5 (13.5, 17.4)	<0.0001	-1.37 (-3.36, 0.63)	0.179
HM+, P+, B-	2.18 (0.88, 3.49)	0.001	19.0 (16.5, 21.5)	<0.0001	6.06 (4.15, 7.96)	<0.0001
HM+, P-, B+	0.45 (-0.70, 1.60)	0.442	16.2 (14.4, 18.0)	<0.0001	1.20 (-0.41, 2.81)	0.143
HM+, P+, B+	2.79 (1.46, 4.12)	<0.0001	18.9 (17.3, 20.5)	<0.0001	3.96 (2.13, 5.79)	<0.0001
Project age (years)	0.09 (0.04, 0.13)	<0.0001	0.08 (0.01, 0.15)	0.024		0.109
Landform, Depos. FP	1.44 (0.11, 2.78)	0.034	15.6 (14.7, 16.5)	<0.0001		0.410
Landform, Eros. FP	3.89 (2.33, 5.45)	<0.0001	17.4 (15.9, 18.8)	<0.0001		0.822
Landform, Upper Bank	3.09 (1.74, 4.44)	<0.0001	17.8 (16.7, 18.8)	<0.0001		0.895
Clay %	0.05 (-0.009, 0.11)	0.095	-0.13 (-0.24, -0.01)	0.026	0.15 (0.08, 0.22)	<0.0001
Height (bankful #)		0.187		0.488		0.294
Flow none, pools only		0.936	-1.43 (-2.95, -0.09)	0.066	3.48 (0.83, 6.13)	0.010
Flow perennial		0.227	1.48 (0.40, 2.55)	0.007	1.25 (-0.61, 3.11)	0.186
Ambient temp. (C.)	0.65 (0.38, 0.91)	<0.0001	0.20 (-0.001, 0.41)	0.051		0.983

Notes:
Negative binomial backward regression (Intercooled Stata 7.0) predictors accepted with *P* -value < 0.100 for a single category.
Coefficients quantify the effect of revegetation method compared to non-restored sites (HM-, P-, B-).

Appendix D: Model set #2 results
(restoration treatments compared to passively revegetated sites)

Early seral tree taxa:

Predictor Variables	shrub willow		tree willow		cottonwood		alder	
	Coefficient (95% CI)	*P*- value	Coefficient (95% CI)	*P*- value	Coefficient (95% CI)	*P*- value	Coefficient (95% CI)	*P*- value
HM+, P+, B-	0.29 (-0.01, 0.59)	0.214	0.52 (-0.05, 1.07)	0.295	7.06 (3.77, 10.3)	<0.0001	0.06 (-0.92, 1.04)	0.902
HM+, P-, B+	0.40 (-0.05, 0.85)	0.290	0.21 (-0.32, 0.69)	0.671	-2.66 (-4.01, -1.31)	0.021	0.42 (-0.22, 1.07)	0.199
HM+, P+, B+	0.48 (0.23, 0.72)	0.028	0.55 (0.11, 0.91)	0.155	2.50 (1.46, 3.54)	0.017	0.82 (0.02, 1.62)	0.045
Project age (years)	0.03 (0.02, 0.04)	0.003		0.72		0.222		0.832
Relict population	0.63 (0.38, 0.88)	0.006		0.878		0.542	0.89 (0.21, 1.56)	0.011
Herbivores L-, D+		0.822	1.21 (0.72, 1.71)	0.004	13.9 (12.4, 15.4)	<0.0001		0.724
Herbivores L-, D-		0.914	0.42 (-0.31, 1.14)	0.465	12.9 (10.2, 15.7)	<0.0001		0.139
Landform, Depos. FP	1.09 (0.79, 1.40)	<0.0001	1.43 (0.95, 1.90)	<0.0001		0.103	1.69 1.10, 2.24)	<0.0001
Landform, Eros. FP	1.12 (0.76, 1.48)	<0.0001	1.02 (0.45, 1.59)	0.006		0.121	1.40 (0.77, 2.02)	<0.0001
Landform, Upper Bank	-0.91 (-1.40, -0.42)	<0.0001	-0.14 (-1.59, -0.09)	0.218		0.215	-1.58 (-2.77, -0.40)	0.009
Clay %		0.430		0.195		0.301		0.951
Height (bankful #)	-0.23 (-0.30, -0.17)	<0.0001	-0.35 (-0.46, -0.24)	<0.0001		0.309	-0.38 (-0.49, -0.26)	<0.0001
Flow none, pools only		0.785	0.17 (-0.30, 0.69)	0.670	3.62 (1.52, 5.72)	0.001	0.81 (-0.15, 1.77)	0.097
Flow perennial		0.330	0.85 (0.44, 1.18)	0.033	4.30 (2.56, 6.04)	<0.0001	2.38 (1.61, 3.14)	<0.0001
Ambient temp. (C.)		0.349		0.503	0.76 (0.34, 1.19)	<0.0001		0.200

Late seral tree taxa:

Predictor Variables	ash		maple		bay		live oak	
	Coefficient (95% CI)	*P*- value	Coefficient (95% CI)	*P*- value	Coefficient (95% CI)	*P*- value	Coefficient (95% CI)	*P*- value
HM+, P+, B-	2.99 (1.90, 4.08)	<0.0001	3.21 (1.98, 4.45)	<0.0001	2.23 (0.79, 3.67)	0.002	3.76 (2.70, 4.82)	<0.0001
HM+, P-, B+	-0.09 (-1.12, 0.92)	0.85	0.80 (-0.16, 1.75)	0.181	0.75 (-0.17, 1.66)	0.109	1.61 (0.79, 2.43)	<0.0001
HM+, P+, B+	3.66 (2.46, 4.87)	<0.0001	3.37 (2.02, 4.73)	<0.0001	2.22 (1.12, 3.31)	<0.0001	3.61 (2.55, 4.67)	<0.0001
Project age (years)	0.10 (0.06, 0.15)	<0.0001	0.06 (0.01, 0.1)	0.032		0.422	0.07 (0.03, 0.11)	0.001
Relict population	1.25 (0.32, 2.18)	0.008		0.349	1.59 (0.73, 2.44)	<0.0001		0.335
Herbivores L-, D+		0.113	2.34 (-0.15, 4.85)	0.066		0.912		0.151
Herbivores L-, D-		0.506	2.57 (0.11, 5.02)	0.040		0.137		0.429
Landform, Depos. FP	2.95 (2.16, 3.73)	<0.0001	2.61 (0.38, 4.83)	0.005		0.314	13.9 (13.2, 14.7)	<0.0001
Landform, Eros. FP	2.21 (1.09, 3.32)	<0.0001	2.09 (-0.22, 4.40)	0.016		0.042	14.9 (13.8, 15.9)	<0.0001
Landform, Upper Bank	1.73 (0.84, 2.63)	<0.0001	2.86 (0.63, 5.09)	0.002		0.145	14.3 (13.2, 15.4)	<0.0001
Clay %		0.723		0.809		0.205		0.984
Height (bankful #)		0.113		0.901	0.30 (0.11, 0.48)	0.001	0.52 (0.38, 0.65)	<0.0001
Flow none, pools only	1.86 (0.59, 3.13)	0.004	-0.36 (-2.53, 1.81)	0.746	-0.22 (-1.50, 1.05)	0.729	-0.36 (-1.14, 0.42)	0.43
Flow perennial	1.91 (0.28, 0.61)	0.001	0.73 (-0.11, 1.57)	0.088	1.33 (0.07, 2.60)	0.039	0.86 (0.23, 1.48)	0.026
Ambient temp. (C.)	0.44 (0.19, 0.69)	<0.0001		0.712		0.132	0.25 (0.14, 0.37)	0.007

Predictor Variables	deciduous oak		buckeye		Douglas-fir	
	Coefficient (95% CI)	*P*- value	Coefficient (95% CI)	*P*- value	Coefficient (95% CI)	*P*- value
HM+, P+, B-	1.95 (0.84, 3.06)	<0.0001	5.07 (3.14, 7.00)	<0.0001	6.98 (4.83, 9.13)	<0.0001
HM+, P-, B+	0.40 (-0.69, 1.49)	<0.0001	0.49 (-0.52, 1.51)	0.341	0.47 (-0.78, 1.72)	0.461
HM+, P+, B+	2.36 (1.03, 3.69)	<0.0001	3.30 (1.71, 4.89)	<0.0001	4.54 (2.64, 6.43)	<0.0001
Project age (years)	0.08 (0.04, 0.13)	0.001		0.167		0.187
Relict population		0.205	2.16 (1.01, 3.32)	<0.0001	3.23 (1.92, 4.53)	<0.0001
Herbivores L-, D+	3.10 (0.54, 5.67)	0.018	1.24 (-0.08, 2.56)	0.066	15.6 (14.2, 17.1)	<0.0001
Herbivores L-, D-	2.22 (-0.45, 4.89)	0.103	1.08 (-0.55, 2.71)	0.194	17.8 (16.3, 19.4)	<0.0001
Landform, Depos. FP	1.31 (0.003, 2.61)	0.050	14.8 (14.0, 15.54)	<0.0001		0.286
Landform, Eros. FP	3.79 (2.29, 5.28)	<0.0001	16.2 (15.1, 17.3)	<0.0001		0.759
Landform, Upper Bank	2.95 (1.63, 4.28)	<0.0001	17.0 (15.9, 18.2)	<0.0001		0.667
Clay %	0.07 (0.003, 0.13)	0.039	-0.2 (-0.3, -0.01)	0.030	0.15 (0.08, 0.22)	<0.0001
Height (bankful #)		0.154		0.488		0.322
Flow none, pools only		0.568	-1.63 (-2.86, -0.40)	0.009		0.705
Flow perennial		0.342	1.75 (0.46, 3.05)	0.008		0.553
Ambient temp. (C.)	0.65 (0.38, 0.91)	<0.0001	0.19 (-0.01, 0.40)	0.065		0.183

Notes:
Negative binomial backward regression (Intercooled Stata 7.0) predictors accepted with P-value<0.100 for a single category.
Coefficients quantify the effect of active revegetation techniques compared to passivley revegetated sites (HM+, P-, B-).