

**A Reference for Restoration: Applying the Reference Site Model to Riparian Restoration Sites in the California Coastal Sage Scrub, Chaparral, and Oak Woodlands Ecoregion**

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**ABSTRACT**

Riparian ecosystems have been heavily affected by anthropogenic land use and urbanization, and as a result, they have become high priority restoration targets. One widely accepted model for restoring these degraded riparian systems is the use of reference ecosystems to establish restoration goals, but until recently, the comprehensive data necessary to accurately apply the model to the California Coastal Sage Scrub, Chaparral and Oak-Woodlands ecoregion has not existed. In this study, I compared restoration projects in the East San Francisco Bay area to reference sites within the California Coastal Sage Scrub, Chaparral, and Oak Woodlands ecoregion to assess how well restoration projects have been able to restore woody plant diversity and return degraded urban creeks to positive ecological trajectories. I measured woody plant diversity at five restored urban creek sites, and compared them to a database of reference site information using the metrics of species richness, relative abundance, Shannon Diversity Index, and tree size class. Restoration sites exhibited species richness and Shannon Diversity Index values that were similar to those at reference sites, whereas tree size class was significantly smaller at restoration sites. Relative abundance of species was also mismatched at restoration and reference sites, showing different patterns of dominance within each site type. I concluded that the levels of woody plant diversity present at restoration sites are indicative of positive ecological trajectories, but restoration sites may function at alternative stable states along the trajectory toward a mature reference state.

**KEYWORDS**

Ecological restoration, restoration trajectory, woody plant diversity, urban creeks, species richness

## INTRODUCTION

Ecological restoration is, “an intentional activity that initiates or accelerates an ecological pathway—or trajectory through time—towards a reference state” (SER Primer 2004). Specifically, the purpose of restoration is to emulate the structure, function, diversity, and dynamics of a specific target ecosystem and return disturbed ecosystems to a healthy state (Hobbs and Norton 1996; SER Primer 2004; Harris et al. 2006). Ecosystems can be restored by recreating the historic plant communities and habitat characteristics or rehabilitated by repairing damaged or obstructed ecosystem functions (Aronson 1993). In some cases rehabilitation can lead to alternative stable states, or novel ecosystems, that are functional and productive but do not have a present or historic analog to which they can be compared (Suding 2004; Hobbs et al. 2009). Restoration aims to strike a balance between rebuilding past systems and attempting to build resilient ecosystems that can provide ecosystem function and survive disturbance events (Harris et al 2006). However, it is difficult and rarely possible to determine what historic ecosystems looked like and how they behaved, which leads to ambiguity and discontinuity in restoration goals across the spectrum of restoration projects (Cairns 1991; Bernhardt et al. 2007; Zedler 2007).

One framework for setting restoration goals is the use of reference sites as model ecosystems that represent the desired, pre-disturbance ecosystem state. Generally, reference sites can provide guidance to restoration projects for plant community design and habitat characteristics that match the pre-disturbed state (Aronson 1995; Palmer et al. 2005). However, selection of reference sites is difficult because nature is variable in time and space (White and Walker 1997) and ecosystems are dynamic, or in a constant “flux of nature,” making the use of reference sites contingent on each site’s unique ecological history and leading to multiple reference states to choose from (Pickett and Parker 1994; Hobbs and Harris 2001). For these reasons, it is impractical to set a universally applicable restoration endpoint, and reference sites must be chosen on a site-specific basis, with consideration given to historic and contemporary habitat characteristics such as community complexity, exotic invasion, geomorphology, hydrology, and plant-species similarity to the restoration site (White and Walker 1997; Harris 1999; Palmer et al. 2005). A reference ecosystem is necessary to establish restoration goals and evaluate the progress toward those goals (Aronson 1991, 1995), but until recently there has been

no existing protocol for the use of reference-based restoration (Cairns 1991; Palmer et al. 2005); therefore, reference-based restoration efforts have led to a wide spectrum of restoration trajectories, especially in urban stream ecosystems (Beechie et al. 2010).

Urban streams represent some of the most degraded ecosystems in the San Francisco bay area, and many of the restoration efforts in the region focus on mitigating the effects of urbanization on local streams and creeks. Urban stream restoration has dual objectives: (1) restore and enhance ecological function of urban streams as a habitat for riparian and aquatic flora and fauna, and (2) provide ecosystem services, such as flood control and recreation, for the urban areas surrounding the stream (Goodman et al. 2006; Ludy and Podolak 2007). Unfortunately, these goals can run contrary to each other, and urban restoration projects viewed as restoration success stories cannot always be considered ecologically successful (Palmer et al. 2005). One way to reconcile urban stream restoration goals is through riparian planting designs based on reference sites that recreate specific healthy, diverse, and historically relevant communities (Harris et al. 2006). However, there are few guidelines for restoration practitioners choosing which reference sites to emulate. Along with limited species diversity data from reference sites, the lack of resources has led to subjective choices for restoration goals and planting designs, and a wide variety of “restored” urban streams that do not necessarily match their reference ecosystems. In the San Francisco Bay area, restoration projects have yet to be assessed to determine if they have succeeded in restoring urban creek sites to the level of woody plant species diversity present at reference sites, or if they attempted to restore degraded riparian systems based on established reference communities.

This study assesses the state of riparian restoration projects in the San Francisco bay area by comparing the species diversity of woody plant species at local restoration sites to woody plant species diversity at applicable reference sites. It is widely accepted that restoring biodiversity is beneficial to ecological function and ecosystem resilience (Naeem et al 1994; Tilman 1996); therefore it is important to determine the number of species and their relative abundances that are characteristic of healthy, functioning ecosystems (Palmer et al 1997). In this study I have two objectives: (1) to identify the woody plant species that exist at restored riparian sites in urban areas of the Eastern San Francisco bay region, and (2) determine if the woody plant species observed at the restoration sites match the expected species richness, abundance, and community structure based on reference sites. By comparing restoration sites to reference sites,

we can then determine to what extent restoration efforts have accelerated degraded urban riparian sites along ecological trajectories toward a reference state. Based on the current limitations in setting goals for urban creek restoration, I predicted there would be lower woody plant species diversity in the restoration sites than the reference sites.

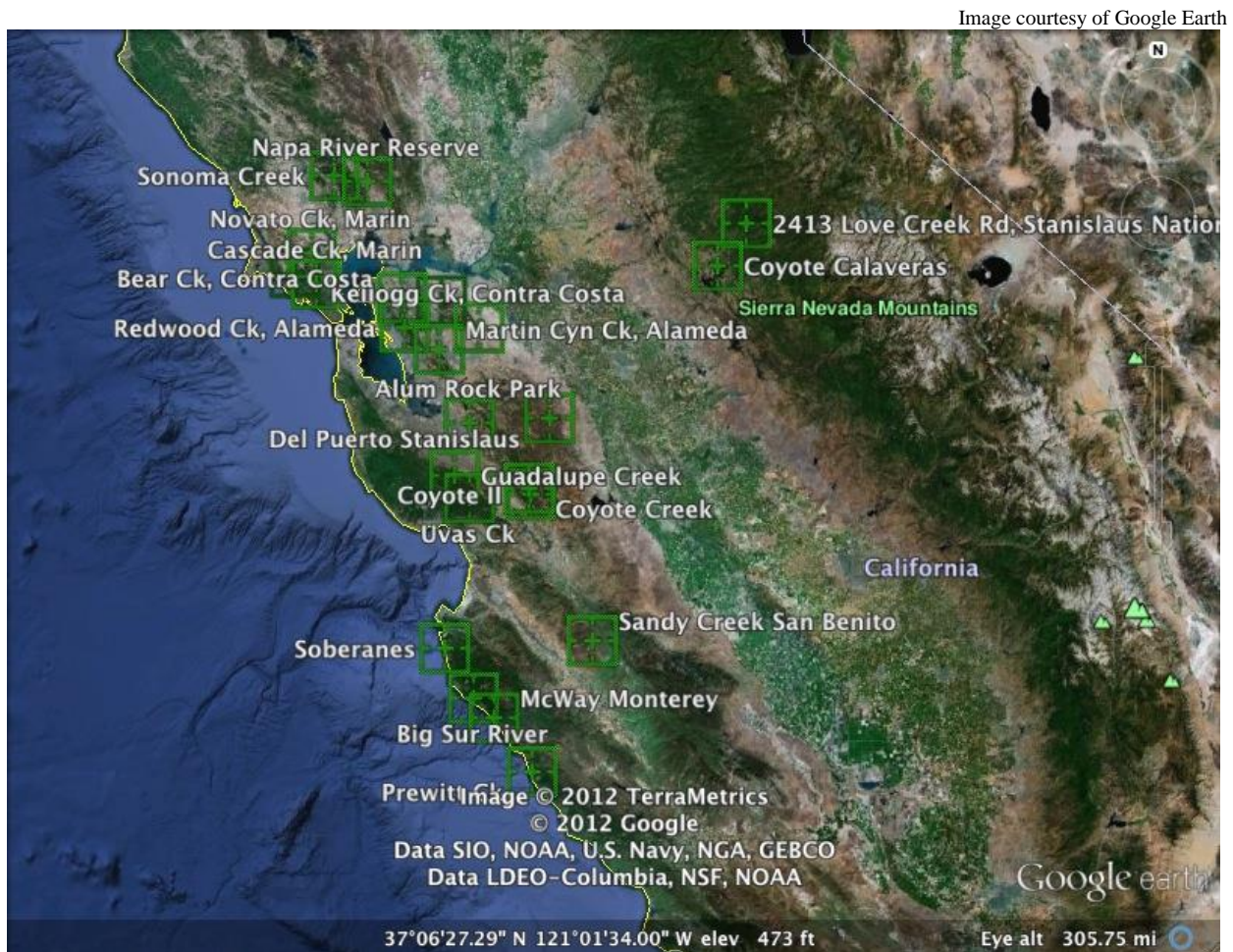
## METHODS

### Reference Site Model

The Society of Ecological Restoration (SER) produced a Primer that outlines nine ecosystem attributes that can be used to measure the success of any ecological restoration project. The first of those attributes states that a restored ecosystem should show “similar diversity and community structure in comparison with reference sites” (SER 2004). In a review of 68 articles in the journal *Restoration Ecology*, diversity and community structure were the most commonly assessed factors in restoration-based studies (Ruiz-Jaen and Aide 2005). Combining these two factors, restoration projects can be measured on how the factors of diversity and community structure compare to those at reference sites. An inherent drawback to this model is the dynamic nature of ecosystems, which makes it difficult to get an accurate physical and temporal assessment of diversity and community structure for any given type of system (Pickett and Parker 1994; Hobbs and Harris 2001). Generating reference data for a restoration project requires the synthesis of many sites to provide an accurate restoration goal, and this can be time consuming and costly (Palmer et al. 2005).

In a recent unpublished study, Kristen Van Dam collected woody plant diversity (WPD) data from 21 riparian reference sites throughout the California Coastal Sage Scrub, Chaparral, and Oak Woodlands ecoregion (Figure 1). By synthesizing data from sites across the ecoregion, van Dam’s reference data provides a comprehensive snapshot of richness, abundance, and structure of riparian reference systems, which can be used by restoration practitioners to plan and set goals for urban creek restoration projects. The California Surface Water Ambient Monitoring Program (SWAMP) used several biological assessment techniques such as benthic macroinvertebrate indices to assess stream habitat quality and designated these sites as reference habitats for streams in the eco-region. We assumed that streams with good stream habitat quality

also represent healthy riparian habitats with natural and undisturbed vegetation patterns. The WPD data collected at these sites determined the expected number of woody plant species present in natural stream ecosystems. A species-area curve synthesized from WPD data at reference sites showed that the occurrence of new woody plant species leveled off after about 400ft of habitat was surveyed. This indicated that the species present within a distance of 400ft were representative of the community as a whole. This relationship provided the survey length control for comparing WPD between riparian reference and restoration sites.



**Figure 1. Reference Sites across California Coastal Sage Scrub, Chaparral, and Oak Woodlands ecoregion**

### **Restoration Test Sites**

I chose five stream restoration sites in the San Francisco Bay Area to assess WPD as it compared to reference sites. The sites were chosen because they reside within the California

Foothills ecoregion, are located less than an hour from Berkeley, CA, and accessible by public transportation. Each site is located in a highly urban area, and each has been restored within the last ten years. The restoration projects took several different approaches to restoring the streams and riparian corridors, but I focused my study on the reestablishment of the vegetation in the riparian zone. The five restoration sites I chose were located on Tassajara Creek, Baxter Creek, Codornices Creek, Lower Wildcat Creek, and Strawberry Creek (Table 1).

**Table 1. Restoration Test Sites**

Site	Location	GPS	Restoration Date	Restoration Goal
Tassajara Creek	Dublin, CA	37°42'21.69" N 121°52'42.52" W	2000	Stop incision, revegetation
Baxter Creek	Richmond, CA	37°55'11.18" N 122°19'33.85" W	2000	Increased sinuosity, revegetation Steelhead
Codornices Creek	Albany, CA	37°52'56.24" N 122°18'13.01" W	2004	reintroduction, revegetation
Lower Wildcat Creek	North Richmond, CA	37°57'45.92" N 122°20'52.90" W	2000	Flood control, revegetation
Strawberry Creek	Berkeley, CA	37°52'05.218" N 122.17'11.27" W	1982	Daylighting

### Survey of Woody Plant Diversity

Kristen Van Dam designed the protocol for surveying woody plants, and the same protocol was used to collect data at reference sites. To measure WPD at riparian restoration test sites, I censused living woody plants along a 121m long x 30m wide transect. To survey WPD, I walked along the transect and recorded the distance along the transect, species, and size class by estimating diameter at breast height (DBH) of each native tree or shrub within the transect dimensions. I included woody plants with trunks outside 30m if the canopy was overhanging the streambed and could contribute allochthonous input to the stream because these plants were considered as contributing to the stream nutrient cycle. I did not assign a size class to native shrubs because they have stems rather than larger trunks, but I noted the transect distance and

species of individual plants for their contribution to WPD. I visually identified species and estimated distance measurements on site.

## **Paired Comparisons: Restoration vs. Reference sites**

### *Species richness*

Species richness was calculated by counting the total amount of species present at each site. Sites with more species are considered more specie rich. I calculated the mean species richness for reference and restoration sites, and used a Students one-sample t-test to compare the means for statistical significance. A p-value of  $p < 0.05$  indicates a significant difference in means.

### *Shannon Diversity Index*

The Shannon Diversity index is a measure of the species richness and evenness of a community. It is calculated with the following equation:

$$H = \sum_{i=1}^s - (P_i * \ln P_i)$$

where  $H$  is the Shannon Diversity value for the community.  $P_i$  is the proportion of the total population represented by species  $i$ . A higher value of  $H$  indicates communities with greater species richness and evenness. I calculated the Shannon Diversity value for all restoration sites and reference sites and compared  $H$  values to determine which sites were more diverse.

### *Size class*

To compare reference and restoration sites through size class, I estimated the diameter at breast height (DBH) of all tree individuals. I calculated the mean size class for reference and restoration sites, and used a Student's one-sample t-test to compare the means for statistical significance. A p-value of  $p < 0.05$  indicates a significant difference in means.

### *Non-Metric Multidimensional Scaling Analysis*

To assess whether sites were characterized by unique plant communities, I used nonmetric multidimensional scaling analysis (NMS) on the  $\log_{10}(n+1)$  species abundances of both reference and restoration sites. I used the PC-ORD 5.10 software to obtain a 2-Dimensional solution based on Sørensen distance (McCune and Mefford 1999). I examined clustering among sites in ordination space in relation to the continuous variables species richness and abundance. I ran the NMS with 4 axes, 1000 runs with real data using a stability criterion of 0.00001, 15 iterations to evaluate stability, and a maximum number of iterations of 250.

## **RESULTS**

### **Survey of Woody Plants**

#### *Reference sites*

Each survey of woody plants represented a unique community of woody plants from the California Coastal Sage Scrub, Chaparral, Oak Woodlands ecoregion. Reference sites were generally more species rich and supported a wide variety of woody plants and shrubs, exhibiting a mean species richness of 15.3 species. Richness by individual reference site ranged from the most species at Site 2 on Coyote Creek in Calaveras County, CA (25 species) to the lowest at McWay Creek in Monterey County, CA (5 species) (Table 2). All plants included in the surveys were native woody plants or shrubs (Appendix A). I did not observe any overwhelming dominance by one species or another at reference sites, but *Umbellularia californica* showed the



highest relative abundance (22.7%) (Figure 2). Woody trees and shrubs at reference sites varied widely in size class and communities were qualitatively representative of mature habitats. There was little to no contamination by garbage or other waste material, largely due to the more remote nature of reference sites.

### *Restoration Sites*

I observed an average of 11 species at 5 restoration sites in the eastern San Francisco Bay area. The median species richness for restoration sites was 9 species. Plant communities at restoration sites were generally less species rich and tended to be dominated by one or two woody plant species. Among the 23 plant species found at restoration sites (Appendix A), *Salix lasiolepis*, the common arroyo willow, was by far the most abundant woody plant at restoration sites (710 individuals; 70% relative abundance of woody plants and shrubs), and was present at all surveyed restoration sites in the eastern San Francisco Bay area. Species richness at restoration sites ranged from the greatest at Tassajara Creek in Alameda County, CA (18 species) to the least at Codornices Creek in Alameda County, CA (8 species) (Table 2). Many of the sites were visibly contaminated with garbage, and in some cases dead animals.

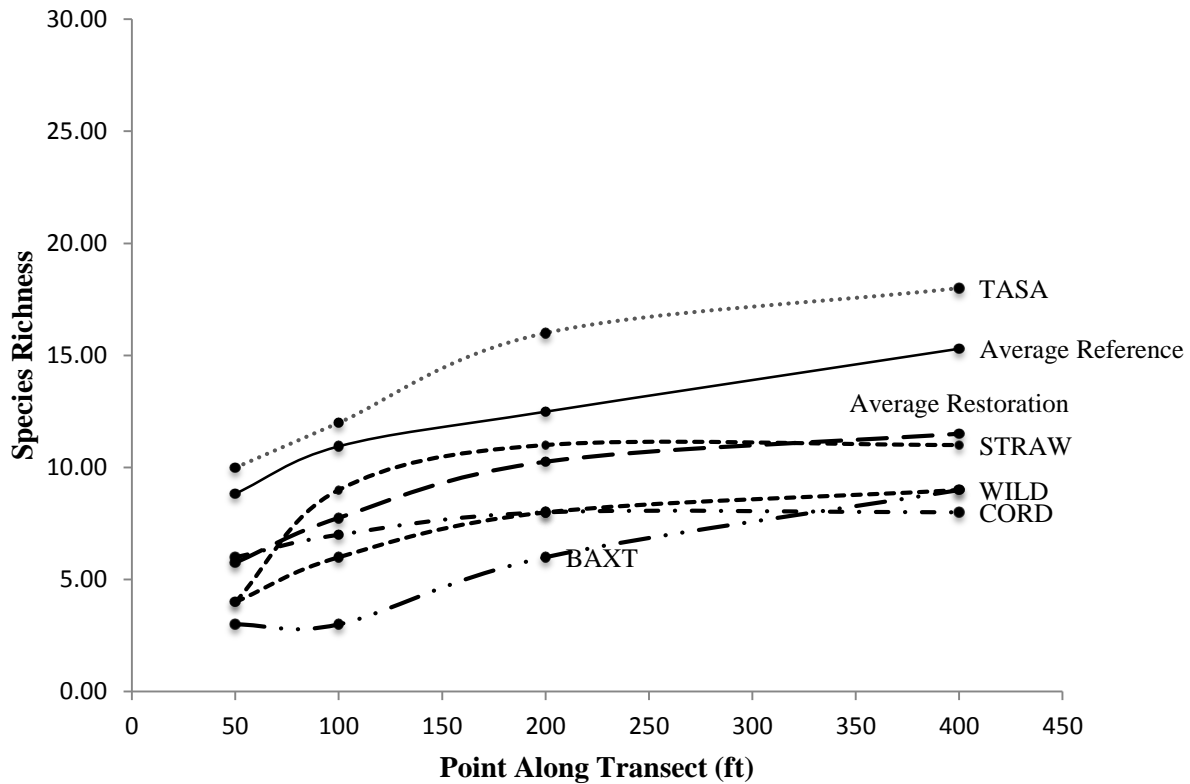
## **Paired Comparisons**

### *Species Richness*

On average, I found restoration sites to be less species rich than reference sites. Restoration sites ( $11 \pm 4$  species,  $n=5$ ) averaged 4 less species of woody plants and shrubs than reference sites ( $15 \pm 4.5$  species,  $n=21$ ), but the difference did not prove to be statistically significant (one-sample t-test  $t=-2.3671$ , 4 d.f.,  $p = 0.07707$ ). There were 57 species found at reference sites, and only 25 species found at restoration sites. Of the 25 restoration species, all but three species were also found at reference sites. Species accumulation tended to level off after 121m, which was consistent with reference communities (Figure 2). Tassajara Creek was the only restoration site with species richness greater than the reference-site average.

**Table 2. Species Richness at Reference and Restoration Sites.**

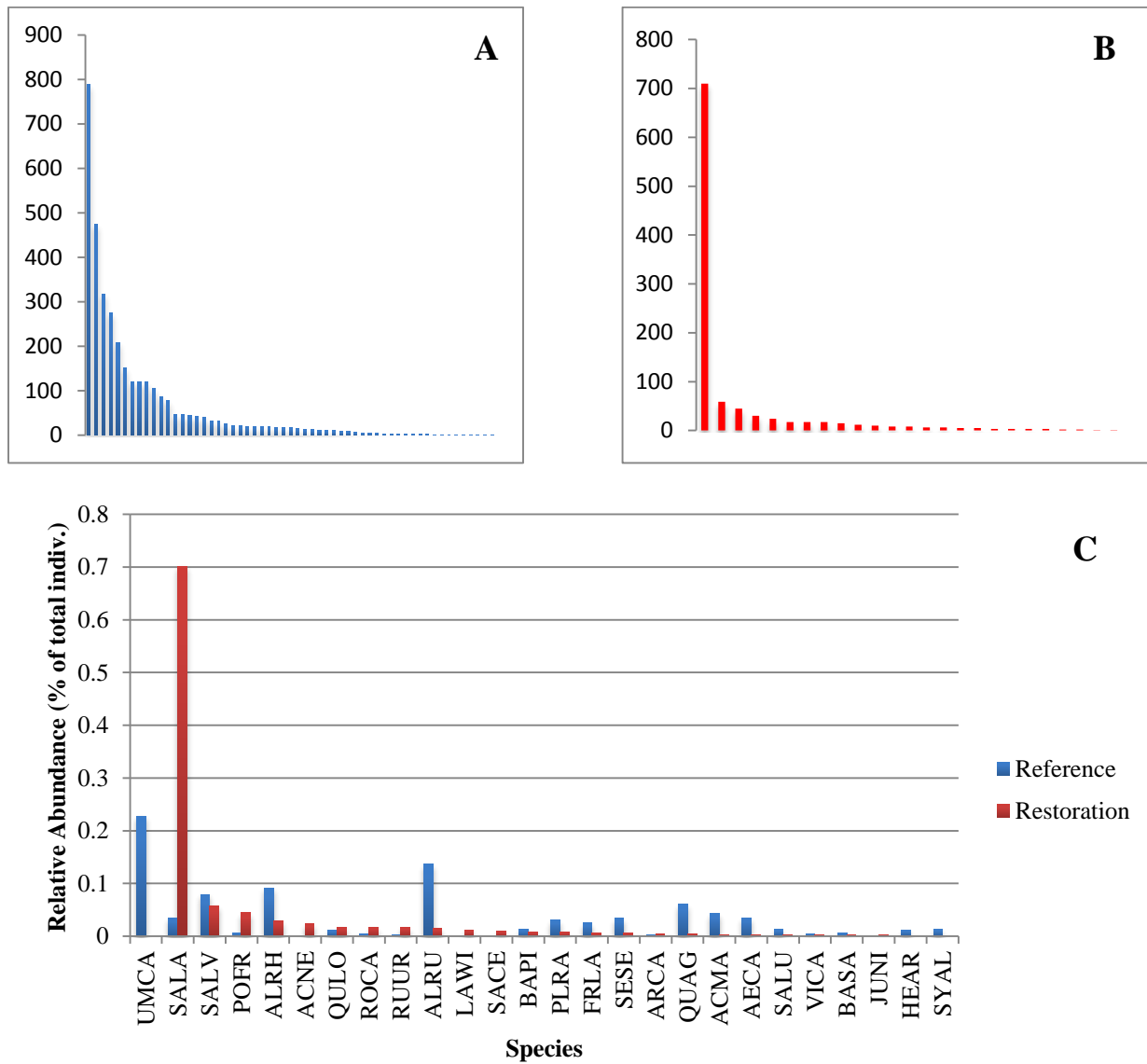
<b>Code</b>	<b>Name</b>	<b>Total Tree Species</b>	<b>Total Shrub Species</b>	<b>Total Species</b>
<b>Reference Sites</b>				
COSCI	Coyote Creek I	9	3	12
GUSC	Guadalupe Creek	6	5	11
SCSO	Sonoma Creek	10	9	19
CAMA	Cascade Creek	7	6	13
MCAL	Martin Canyon Creek	6	8	14
BECO	South Fork Bear Creek	5	6	11
REAL	Redwood Creek	8	6	14
NRNA	Napa River	11	3	14
REMA	Redwood Creek	3	5	8
LAMA	Lagunitas Creek	7	2	9
PESC	Penitencia Creek	10	9	19
DPST	Del Puerto Canyon Creek	4	3	7
COCA	Coyote Creek Calaveras	9	11	20
PCMO	Prewitt Creek	5	5	10
MWMO	McWay Creek	3	2	5
BSMO	Big Sur River	8	2	10
SOMO	Soberanes Creek	2	10	12
SCSB	Sandy Creek	8	1	9
UVSC	Uvas Creek	8	4	12
COSCII	Coyote Creek Site II	7	13	20
LASC	Llagas Creek	6	6	12
<b>Restoration Sites</b>				
TASA	Tassajara Creek	6	12	18
BAXT	Baxter Creek	2	7	9
STRAW	Strawberry Creek	2	9	11
CORD	Codornices Creek	3	5	8
WILD	Wildcat Creek	1	8	9



**Figure 2. Measured Species-Area Curves for Restoration Sites and Averages Across All Sites.** A majority of restoration sites showed lower species richness at 121m (400ft) than the average reference site. TASA was uncharacteristically species rich compared to reference and restoration sites.

### Relative Abundance

Reference and restoration sites showed asynchronous patterns of relative abundance. The distribution of reference sites shows several dominant species that comprised the majority of individuals surveyed, followed by many minor species with lower relative abundances. The three most dominant species were *Umbelullaria californica* (22.7% of all individuals), followed by *Alnus rubra* (13.7%) and *Alnus rhombifolia* (9.1%). The remaining 54 species exhibited lower than 8% abundance and were considered minor species. *Umbelullaria californica* was conspicuously absent from restoration sites, which were dominated by *Salix lasiolepis* (70.1% of all individuals). The next most abundant species at restoration sites was *Salix laevigata* (5.8%).



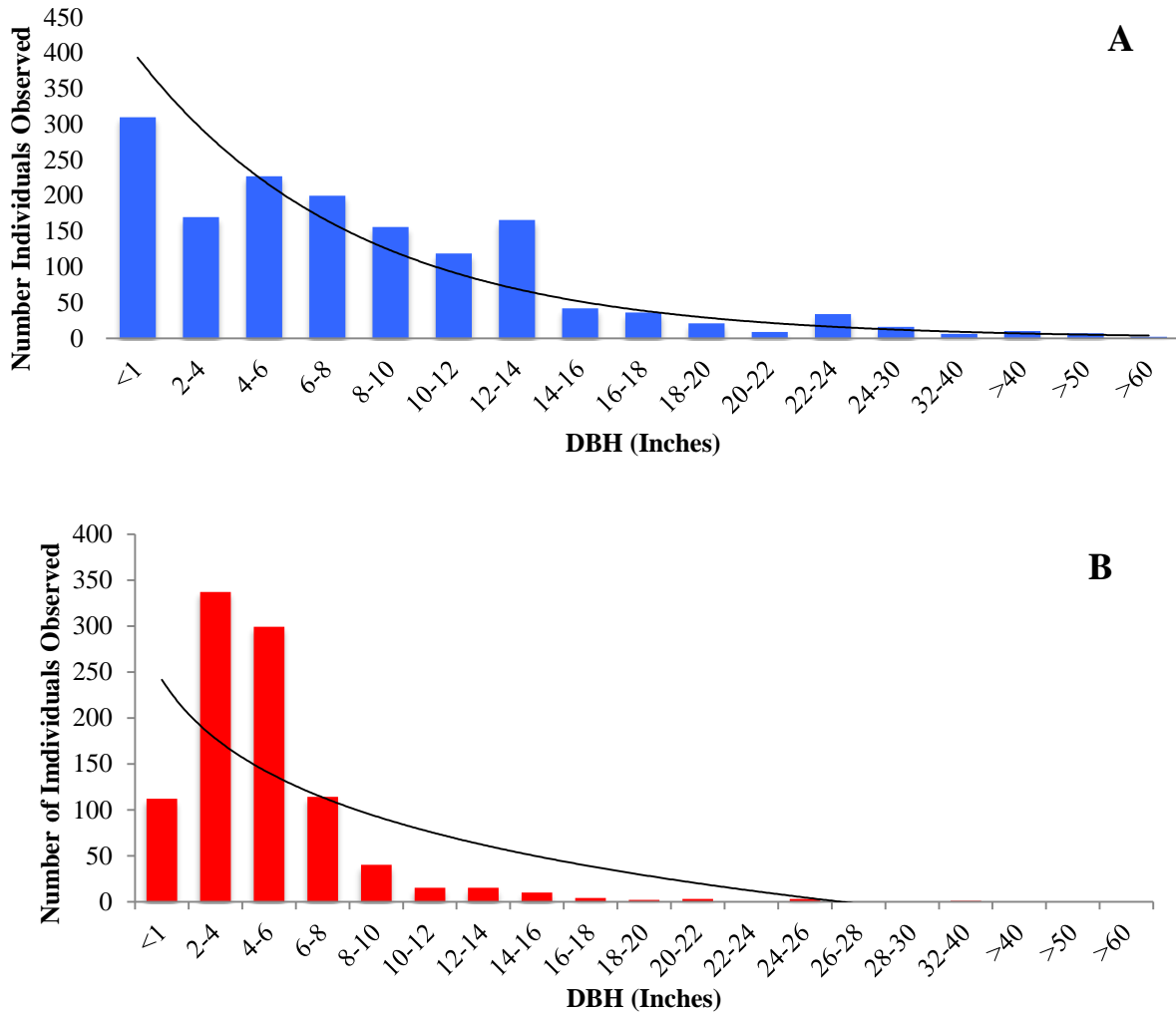
**Figure 2. Comparison of Relative Abundance of Species.** A) Abundance distribution at reference sites and B) abundance distribution at restoration sites. Reference sites show multiple dominant species whereas restoration sites show one hyper-dominant species. C) Compared relative abundance at reference and restoration sites. All species found at restoration sites are included, and UMCA is present because it was the most abundant species at reference sites. Abundance patterns at restoration sites do not match those at reference sites. The most abundant species at reference sites, *Umbellularia californica*, was not present at restoration sites. Restoration sites were dominated by *Salix lasiolepis*, whereas reference sites showed a much more even distribution of abundance.

### *Shannon Diversity Index*

Diversity indices showed restoration sites to have lower WPD than reference sites (Table 3). The mean Shannon Diversity Index for restoration sites ( $H = 1.099 \pm 0.29$ ) was slightly lower than the mean Shannon Diversity index for reference sites ( $H = 1.3450 \pm 0.22$ ), but a one-sample t-test of means indicated no significant difference between the two (one-sample t-test,  $t = -1.2114$ , 4 d.f.,  $p = 0.2924$ ).

### *Size Class*

Trees at reference sites had larger diameters at breast height than restoration sites (Table 3). Reference sites showed an mean size class of  $7.77 \pm 8.3$  inches, compared to a mean size class of  $4.99 \pm 2.15$  inches at restoration sites. Students one-sample t-test indicates a significant difference in size class between reference and restoration sites ( $t = -2.8848$ , 4 d.f.,  $p = 0.0448$ ). Size class distributions for restoration and reference sites highlighted different patterns in community structure (Figure 3). Reference sites decreased gradually in a descending curve from many individuals in small classes to fewer large diameter individuals. Restoration sites showed few individuals in the “< 1” category, and a majority of individuals in the 2-4, 4-6 diameter range. The distribution did not follow a descending curve, and there were fewer larger plants at restoration sites.



**Figure 3. Size Class Distributions.** A) Reference sites showed gradual decrease in individuals from low to high DBH, whereas B) restoration sites show a concentration of individuals from 2-4 inches, with much fewer smaller and larger individuals.

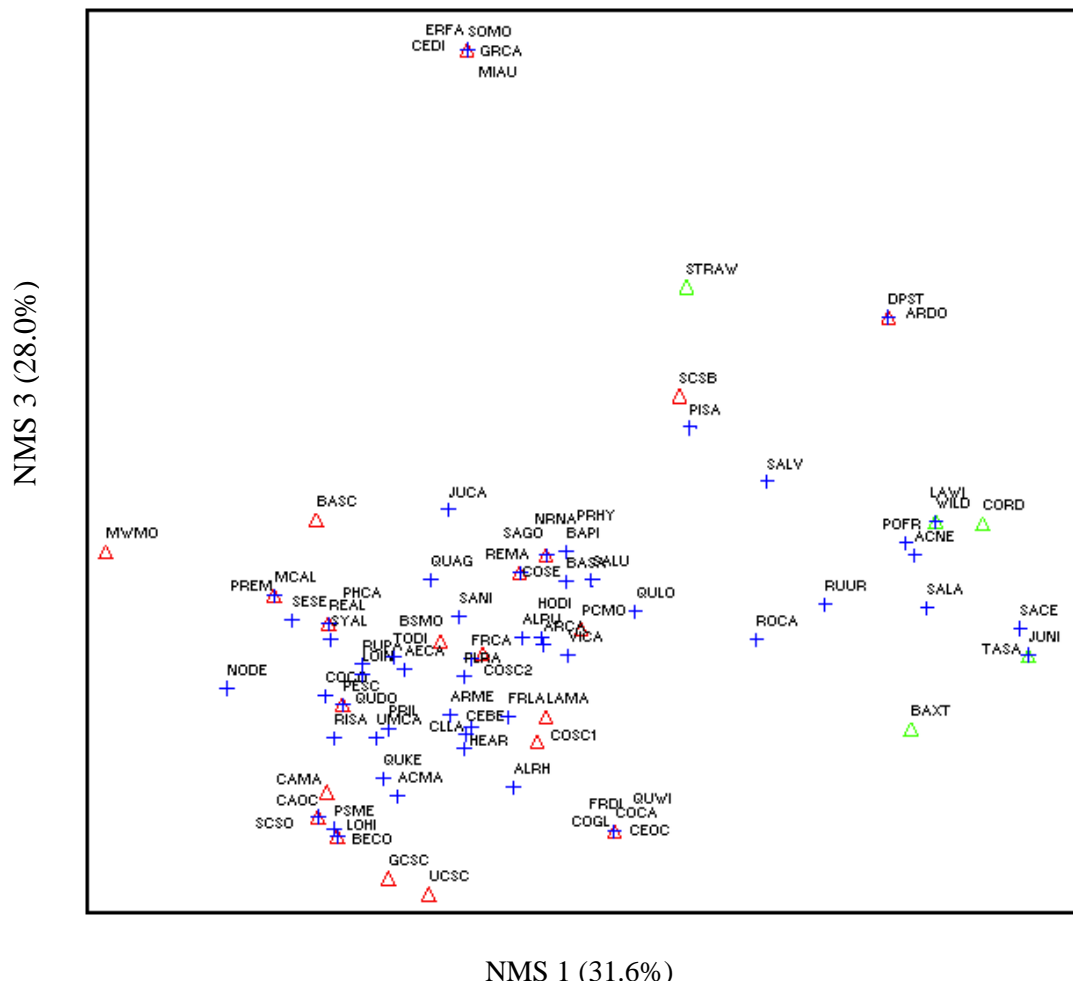
**Table 3. Summary of Paired Comparisons.** Mean values for compared metrics with p-values.

	Reference	Restoration	p-value
Species Richness	15.3	11.0	0.0770
Shannon Diversity	1.346	1.043	0.2924
Size Class	7.77	4.99	0.0448*

\* indicates statistical significance

### Multivariate Analysis

The first and third NMS axes explained a cumulative total of 59.6% of the variability in the species abundances observed, with 31.6% explained by the first axis and 28.0% by the third axis (Figure 4). Restoration sites separated out from reference sites in ordination space along Axis 1, but were slightly more dispersed along Axis 3, indicating that restoration sites are characterized by different plant assemblages than reference sites.



**Figure 4. Non-metric Multidimensional Scaling Analysis.** The horizontal axis was the strongest, describing 31.6% of variation among sites based on species abundance ( $r^2 = 0.316$ ). Restoration sites (green triangles) are generally separated out from reference sites (red triangles) based on unique assemblages of plant species (blue crosshairs).

## DISCUSSION

Restoration sites exhibited similar species richness and Shannon Diversity Index values as reference sites but differed in their distribution of size classes within the plant communities. This suggests that restoration efforts at test sites followed the reference site model of restoration when building plant communities, but these systems may be at functioning at some alternative state along their ecological trajectory toward a reference state.

### Species Richness and Ecological Resilience

Restoration sites exhibited levels of species richness similar to those at reference sites. This ran contrary to our prediction that they would show significantly lower richness levels than reference sites, and it indicates that restoration practitioners are planting communities that follow the reference site model's expected levels of species richness. One site, Tassajara Creek, showed increased species richness levels compared to the original restored plant community (Trinh and Percelay 2008), which is indicative of the return of plant successional processes at this site (Corenblit et al. 2009). Of the 23 plant species recorded across all surveyed restoration sites, only two native species were not found at reference sites, *Juglans nigra* and *Sambucus cerulea*, which verifies that restoration practitioners are generally using reference communities as a template for restoration (Aronson 1995; Palmer et al. 2005).

With species richness levels similar to reference communities, restoration sites have the potential to be as ecologically resilient to disturbances as reference communities (Knops et al. 2002). Resilience is dependent on the occupation of functional niches within the plant community (Funk et al. 2008), so consequently increased native species richness enhances ecological resilience by allowing natives to occupy functional niches that would otherwise be colonized by invasive exotic plants (Fischer et al. 2006; White and Stromberg 2011). Since all the restoration test sites in this study were located in highly urban areas with increased threat of exotic invasion, functional diversity becomes all the more important at these sites.

Plant communities at restoration sites showed the expected species richness, but were not always characterized by the same species assemblages. Species such as *Salix spp.* and *Populus fremontii* were consistently found at all restoration sites, and they are popular restoration plants



because of their ability to colonize quickly and withstand high levels of disturbance (Kuzovkina and Quigley 2005). In contrast, these species were not found as frequently at less-disturbed reference sites, which exhibited many more minor species than restored test sites (Van Dam 2013). Recent studies have illustrated the importance of both dominant and minor species in resisting invasion (Lyons and Schwartz 2001), so the lack of minor species suggests restored test sites may be less functional diverse and ecologically resilient than reference communities. My results suggest that restoration efforts have met levels of species richness, but restoration plans should include richness considerations for both dominant and minor species based on the levels found at reference sites so as to rebuild ecological resilience at degraded riparian sites.

### **Relative Abundance, Alternative States, and Extended Ecological Trajectories**

Relative abundance is an essential tool for characterizing vegetative communities, and therefore needs to be considered when applying the reference model for restoration. Restoration and reference sites exhibited drastically different abundance patterns. *Salix lasiolepis* dominated restoration sites by accounting for 70% of the total plants surveyed, whereas *Umbellularia c.* was the most abundant species at reference sites with 22% abundance but did not appear at any restoration test sites. Abundance levels of both reference and restoration sites conformed to the inherent rarity principle of community conservation, exhibiting fewer dominant and many infrequent or rare species (Maina and Howe 2000), however the distribution of species at restoration sites was skewed much farther toward one species. Ecosystem processes have been directly correlated to abundance of both dominant and minor species in a plant community (Grime 1998; Knops et al. 1999; Lyons and Schwartz 2001), so differences in abundance patterns between restoration sites and reference sites may suggest different levels of ecosystem function.

Many recent studies have shown that restoration efforts do not always lead to a fully restored pre-disturbance state (Zedler and Callaway 1999; Hobbs and Harris 2001; Hobbs et al 2009), but rather result in alternative stable states that are a product of biotic feedbacks with the physical environment (Suding 2004; Jones and Schmitz 2009). Riparian plant communities in semi-arid Mediterranean climates are expected to be naturally resilient systems because they exist in highly variable environments and disturbance regimes (White and Stromberg 2011), but

restored riparian communities in urban areas are subject to many environmental pressures that reference communities are not, such as altered hydrology, heavier nutrient loads, and loss of native propagule pools (Suding 2004; Klausmeyer and Shaw 2009). If not addressed by restoration efforts, these added disturbance factors have the potential to alter the ecological trajectory of restoration projects toward alternative states rather than a reference state. Abundance patterns at restoration sites may be indicative of ecosystems that are functioning at alternative states. In some cases, hyper abundance of *Salix lasiolepis* can be attributed to original planting design (Kier Associates 2003), but it may be reinforced by the harsher abiotic conditions and limitations of urban creek sites. *Salix spp.*, along with other plants in the Salicaceae family, have been found to facilitate recruitment of other woody species as “ecosystem engineers” (Corenblit et al. 2009), but many minor species may be too sensitive for the harsher abiotic conditions and disturbance regimes associated with degraded systems (Gómez-Aparicio et al. 2004). Without the native propagule pools that are present in less-disturbed reference conditions, restoration sites become dominated by one or two species instead of reaching pre-disturbance abundance levels.

Although restoration sites may be deviating from their ecological trajectories toward reference states, lengthening the time scale of monitoring may show that restoration sites eventually return to their desired trajectories. Strawberry Creek was restored about a decade earlier than all other restoration sites included in this study, and this site exhibited the greatest similarity to reference conditions. This site showed less extreme abundance patterns, greater average size class, and the highest Shannon Diversity Index value among restoration sites, suggesting that ecological trajectories of restored sites may need to be assessed over longer periods of time. Similarly, monitoring studies have found that many restoration or mitigation projects had not met their desired goals of functional rehabilitation within 10 years after establishment (Zedler and Callaway 1999). If it requires several decades for ecosystem processes and function to return to a pre-disturbance state, then it may suggest that restoration trajectories are much longer than expected, and restoration sites at alternative states still have the potential to reach pre-disturbance conditions. Long-term monitoring is needed to fully explore this possibility.

## **Size Class Distribution and Recruitment Processes**

Riparian restoration assumes that restored communities, although fabricated, follow natural trajectories and are characterized by natural recruitment patterns once they have been established (Zedler 1999). In contrast, significant differences in size class distributions between restoration and reference communities are an indication that restored plant communities are not following natural patterns of recruitment. A lack of newly recruited plant material at restoration sites poses a threat to the longevity of the plant community, and the concentration of most individuals within the 2-6 inch size class range shows reduced diversity in size class at restoration sites. Current restoration planning rarely incorporates considerations for successional processes or recruitment patterns largely because all projects are assumed to be capable of producing new size classes. Recent literature corroborates my findings, suggesting that the restoration projects may not be following expected successional patterns (Bernhardt et al. 2007; Jones and Schmitz 2009), which can also lead to alternate states of ecosystem function. Restoration plans should include adaptive management strategies such as multi-year plantings to mitigate for the loss of these processes, and ensure that restoration projects maintain their ecological trajectories toward a reference state.

## **Limitations and Future Research**

Implied in the concept of an ecological restoration trajectory is the idea of progress of a system through time. Ecological restoration is a relatively new field, growing out of the contemporary increase in environmental awareness, which means there is very little long term data pertaining to restored ecosystems. To accurately assess the trajectory of an ecosystem, we would ideally need decades of information that currently doesn't exist. This study provides a comparative snapshot of diversity at riparian restoration sites to diversity at contemporary analogs, which is useful for future restoration considerations, but it acts similarly to one frame in film, giving no indication of whether the film is being played forward or backward. Without long term monitoring data, we cannot definitively tell what type of trajectory restored systems are following.

Monitoring data for diversity can be flawed in itself due to variation in the species present at a site. For example, *Salix spp.* grow in large stands of many small stalks and trunks that are difficult to count, and *Alnus rubra* and *Alnus rhombifolia* are notoriously difficult to differentiate in the field. These factors can affect richness values and inflate or deflate abundance levels when data is aggregated across an ecoregion. For this reason, it may be useful to further associate restoration sites and restoration sites beyond the ecoregion scale to vegetation alliances. Vegetation alliances are assigned based on richness and abundance levels of dominant plant species and are characterized by unique communities of plants. Some vegetation alliances are inherently more or less diverse, so pairing restoration sites to a specific reference alliance may reduce the amount of variation caused by aggregating data across an ecoregion.

## Conclusion

As ecological restoration and restoration science continue to develop, practitioners and researchers must confront the challenge of measuring restoration “success.” The dynamic nature of ecosystems has made it very difficult to quantify how well restoration projects have managed to rebuild degraded systems, and liberal use of the term success in restoration ecology has led to a muddled perception of restoration goals. Negative effects of urbanization increasingly threaten urban creeks in the East San Francisco Bay area, and restoration of the riparian zones surrounding them is a step in the right direction toward conserving these important ecosystems. A framework for evaluating restoration projects must be developed if we are to gain scientific knowledge from the practice of restoration, and comparative studies such as this one, along with long term monitoring, are valuable tools in gauging the ecological trajectories of restoration projects. After comparing woody plant diversity between riparian restoration test sites and their contemporary analog reference sites, I conclude that restoration sites have the potential to become ecologically resilient ecosystems that function similar to reference sites, but it may require more long-term management strategies to ensure these systems follow ecological trajectories toward reference states.

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**APPENDIX A: Complete Species List****Table A1. All species found at both restoration and reference sites.**

<b>Species</b>	<b>Species Code</b>	<b>Species</b>	<b>Species Code</b>
Acer macrophyllum	ACMA	Notholithocarpus densiflorus	NODE
Acer negundo	ACNE	Physocarpus capitatus	PHCA
Aesculus californica	AECA	Pinus sabiniana	PISA
Alnus rhombifolia	ALRH	Platanus racemosa	PLRA
Alnus rubra	ALRU	Populus fremontii	POFR
Artemisia californica	ARCA	Prunus emarginata	PREM
Artemisia douglasiana	ARDO	Platanus hybrid	PRHY
Arbutus menziesii	ARME	Prunus ilicifolia	PRIL
Baccharis pilularis	BAPI	Pseudotsuga menziesii	PSME
Baccharis salicifolia	BASA	Quercus agrifolia	QUAG
Calycanthus occidentalis	CAOC	Quercus douglasii	QUDO
Cercocarpus betuloides	CEBE	Quercus kelloggii	QUKE
Ceanothus diganthus	CEDI	Quercus lobata	QULO
Cercis occidentalis	CEOC	Quercus wislizeni	QUWI
Clematis lasiantha	CLLA	Ribes sanguineum	RISA
Corylus cornuta	COCO	Rosa californica	ROCA
Cornus glabrata	COGL	Rubus parviflorus	RUPA
Cornus sericea	COSE	Rubus ursinus	RUUR
Eriogonum fasciculatum	ERFA	Sambucus cerulea	SACE
Frangula californica	FRCA	Salix gooddingii	SAGO
Fraxinus dipetala	FRDI	Salix lasiolepis	SALA
Fraxinus latifolia	FRLA	Salix lucida	SALU
Grindelia camporum	GRCA	Salix laevigata	SALV
Heteromeles arbutifolia	HEAR	Sambucus nigra	SANI
Holodiscus discolor	HODI	Sequoia sempervirens	SESE
Juglans californica	JUCA	Symphoricarpos albus	SYAL
Juglans nigra	JUNI	Toxicodendron diversilobum	TODI
Lonicera hispidula	LOHI	Umbellularia californica	UMCA
Lonicera involucrata	LOIN	Vitis californica	VICA
Mimulus aurantiacus	MIAU		