The Differential Growth of Native Plant Species in a California Urban Creek Restoration Site

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ABSTRACT

In 2012, the Strawberry Creek Ecological Stabilization Project planted thirteen species of native plants along an 80-foot stretch of Strawberry Creek, a degraded urban stream located in Berkeley, California. This study determined which of those species exhibited the greatest success over a 5-month winter season, using a relative growth rate metric calculated from the change in each plant's volume and leaf counts. The relative growth rates were compared using a boxplot summary, which was supplemented quantitatively with ANOVA and Tukey's HSD post-hoc analyses. In addition, each plant's soil moisture, proximity to the creek, sunlight exposure, willow cover, and creek bank (right vs. left) were analyzed as possible covariates using a multiple regression analysis, first for all plants and then for three guilds (trees, shrubs, and forbs). *Acer macrophylum*, *Rosa californica*, and *Lonicera hispidula* exhibited the highest overall relative growth rates, indicating that they be good species to include in future restoration projects. *Polystichum munitum* and *Lonicera involucrata*, on the other hand, had low relative growth rates and *P. munitum* had a mortality of 60%, indicating that these species may be wise to exclude from future restoration efforts. Proximity to creek showed a significant positive correlation to growth rate and willow cover showed a significant negative correlation. Creek bank was significant only for the shrubs guild, indicating that the Eucalyptus grove on the left bank of the creek exhibits a stronger negative effect on the growth of shrubs than trees or forbs.

KEYWORDS

relative growth rate, riparian vegetation, Strawberry Creek, multiple regression analysis, primary productivity

INTRODUCTION

Over the past century, the majority of streams located in urban areas have suffered degradation due to human activities, a phenomenon so common that it is named the "urban stream syndrome" (Meyer et al. 2005). There are several factors common to urbanization that degrade the environmental quality of urban streams. The first is an increase in impervious surface cover, such as paved roads and buildings, which greatly increases an urban stream's response to rainfall and makes it prone to short, extreme flooding events (Dunne & Leopold 1978, Walsh 2000, Paul & Meyer 2001). A stream that exhibits this phenomenon is considered to have a flashy hydrograph, and is also vulnerable to high levels of erosion as the energy of the water in these flooding events cuts at the stream bank and carries away soil (Walsh et al. 2005). In addition, runoff from impervious surfaces carries a large number of pollutants, such as nutrients, metals, and pesticides, which are often allowed to flow unfiltered into the stream (Walsh et al. 2005). These factors deteriorate the environmental quality of an urban stream by greatly reducing its biodiversity and encouraging the most tolerant species to dominate the ecosystem (Wenger et al. 2009). In addition, recent studies have shown that the land cover changes associated with urbanization cause stream channel loss by burying, diverting, or in some way altering the physical channels through which a stream would naturally flow (Julian et al. 2015). These examples illustrate the many ways that urbanization negatively alters the ecological functioning of streams.

Recently restoration efforts have been growing, representing an attempt to rectify the anthropogenic harms that have been inflicted upon urban creeks. One the most important components of urban creek restoration is fostering native vegetation appropriate to the niches of the riparian system; that is, vegetation that exhibits success which can be quantified by a high growth rate and low mortality. Such riparian vegetation performs a large number of key ecosystem functions essential to maintaining a healthy stream habitat. For instance, the roots of vegetation increase the stability of a streambank, helping reduce the high levels of erosion that an urban stream is normally vulnerable to (Simon & Collison 2002, McMillan et al. 2014). Riparian vegetation also inputs organic matter, such as woody debris and leaf litter, to the soils and channels of a riparian system, which is an essential resource for many populations of aquatic and terrestrial organisms (Dosskey et al. 2010, McMillan et al. 2014). Furthermore, vegetation buffers a stream from non-point sources of pollution, particularly nitrogen, and also improves in-stream processing of pollutants (Sweeney et al. 2004, Connolly et al. 2015). Finally, riparian vegetation increases the overall quantity of available habitat for native wildlife, and contributes to temperature regulation. (Sweeney et al. 2004, McMillan et al. 2014). Thus, native riparian vegetation performs a large number key ecosystem functions which contribute to the overall health of a stream ecosystem, and because of this, reintroduction of native vegetation is an important component of many riparian restoration projects.

The Strawberry Creek Ecological Stabilization Project is such a riparian restoration project, started in August 2014 with the goal of restoring an 80-foot stretch of Strawberry Creek, a California urban stream that has suffered many of the symptoms of the urban creek syndrome. Strawberry Creek is located on the campus of the University of California, Berkeley, and its overall environmental quality began to degrade in the early 1900's due to the urbanization of its drainage basin, alteration of its channel flow, and significant water pollution (Charbonneau and Resh 2006). The deterioration of the creek's environmental quality became throughout the mid-1900's through the marked absence of flora and fauna, poor water quality, and severe erosion (Charbonneau and Resh 2006). Restoration efforts for Strawberry Creek formally began in 1988, when Berkeley's Department of City and Regional Planning implemented a management plan focusing on reducing water pollution and erosion, with the eventual goal of promoting the creek's habitat quality (Charbonneau 1988).

Under the direction of the University's Office of Environmental Health and Safety, further restoration efforts have continued since that initial management plan, and the Strawberry Creek Ecological Stabilization Project represents the most recent step in this 30-year effort to promote Strawberry Creek's habitat quality. The goal of the project was to remove a failed check dam, installed a new step-pool system, and planted thirteen species of native California flora, in order to reduce soil bank erosion and improve habitat quality for native aquatic organisms (Massell 2015). While the project leaders chose the species of native plants based on the recommendations of a private contractor, there is no publicly available research as to which species are best suited to the unique microhabitats of Strawberry Creek, and many of the native plants used in previous restoration projects have not survived (D. Chapple, personal communication).

The goal of this study was to determine which plant species in the Strawberry Creek Ecological Stabilization Project exhibit the greatest success, quantified using a relative growth rate metric. In addition, I also studied the effects of soil moisture, proximity to the creek, sunlight exposure, creek bank, and amount of cover from neighboring willows on the growth of the different species of plants, in order to determine which variables were most important in predicting the success of a plant. Knowing which species of plants exhibit the greatest success along Strawberry Creek and the factors that affect their growth rates would allow for more informed decisions about which plants to include in future restoration projects, allowing the creek to maximize the ecosystem benefits provided by riparian vegetation.

METHODS

Study site

My study site was the restoration site of the Strawberry Creek Confluence Ecological Stabilization Project, located at the west end of U.C. Berkeley's campus adjacent to the Eucalyptus Grove. The project was initiated in 2014 by Berkeley's Office of Environmental Health and Safety, with the goal of improving habitat for native aquatic species and reducing bank erosion. The restoration site extends from the confluence of the north and south forks of Strawberry Creek to 80 feet up the creek's north fork, and its drainage area upstream of the confluence is approximately 1,147 acres (Massell 2015). The restoration site covers both the left and right banks of the creek, with the vegetation on the left bank dominated by a large grove of blue gum Eucalyptus trees (*Eucalyptus globulus*). My study subjects consisted of 12 of the 13 species of native California flora that were planted along the two banks of the site (Table 1). I chose to exclude the red willow (*Salix laevigata*) from my study because their large size would have made it very difficult to conduct height, width, and leaf count measurements, and it was evident that they were thriving from simple observation. Of the 12 remaining species, I took measurements for 66 individuals on the left bank and 95 on the right bank, comprising 161 plants in total.

Table 1. Study subjects. Twelve of the thirteen species (excluding *S. laevigata*) of native riparian vegetation planted in the original restoration project, which were the subjects of this study. Also shown is the total, right bank, and left bank abundance of surviving individuals.

Species	Total abundance	Right bank abundance	Left Bank Abundance
Alum Root (*Heuchera maximus)*	17	9	8
Big Leaf Maple (*Acer macrophylum*)	2	1	1
Black Twinberry (*Lonicera involucrata*)	5	0	5
California Honeysuckle (*Lonicer hispidula*)	18	9	9
California Rose (*Rosa californica*)	14	7	7
Common Rush (*Juncus effisus*)	36	12	24
California Bay (*Umbellularia californica*)	2	2	0
Western Sword Fern (*Polystichum munitum*)	16	16	0
Western Wild Ginger (*Asarum caudatum*)	6	6	0
White Alder (*Almus rhombifolia*)	4	3	1
Wild Strawberry (*Fragaria californica*)	7	2	5
Douglas Iris (*Iris douglasiana*)	35	28	7

Data collection

To assess the relative growth rate of each plant, I first took measurements of the height, width, and leaf counts of all the living plants. To take height measurements, I used a tape measure to measure each plant its base to the top of its crown. For width measurements, I measured each plant horizontally along its widest axis. For the leaf counts, I counted the total number of living leaves on each plant, considering any leaf that was more than 25% green to be alive, and excluding any young leaves that had not fully emerged from their buds. I took the first round of measurements over the course 1.5 months, from November to mid-December 2015. I then took the second round of measurements in a much shorter time, over the course of one weekend in mid-March 2016.

To track the locations of the plants on the right bank, I used the vegetation map listed as Figure 6 in the attachments of the Summary of As-Built Conditions for the Strawberry Creek Confluence Ecological Stabilization Project (Massell 2015). The vegetation of the left bank, however, was not mapped in the original restoration project because the left bank was not subject to permit monitoring requirements due to the presence of the Eucalyptus grove. Therefore, I mapped the locations of the vegetation of the left bank by numbering 51 wooden stakes inserted in various locations throughout the site during the original restoration project, and then recording each plant's relation to the creek, the numbered wooden stakes, and the other plants in order to track its location.

In addition to height, width, and leaf counts, I analyzed each plant's soil moisture, proximity to the creek, sunlight exposure, willow cover, and creek bank (right vs. left) as possible covariates. To measure soil moisture, I used an Extech Instruments soil moisture meter to take measurements at a soil depth of approximately 4 inches. I took three measurements for each plant at a 6-inch radius from plant's base, and then took the average of those three values. I measured each plant's proximity to the creek using a tape measure, measuring the distance from the base of the plant's stem to the edge of the boulders which mark the end of the soil bank. To measure sunlight exposure, I used a LI-COR LI-250A light meter to measure the solar radiation over each plant. I took measurements at three times (9am, 12pm, 3pm) over the course of a clear, sunny day, and then averaged those three values to get an estimate of each plant's average sunlight exposure throughout the day. Finally, for willow cover, I ranked each plant on a scale from 0 to 5 (Table 2). All the covariate measurements were taken in February and March 2016.

Table 2. Defining willow cover. The scale I used for ranking the amount of willow cover experienced by each plant.

Willow Cover	Definition
5	Dense cover, within 2m of the base of closest willow
4	Dense cover, within 4m of the base of closest willow
3	Medium cover and shading, but not in close proximity of neighboring willow trunks
2	Minor cover and partial shading at certain times of day
1	Minimal cover and shading, or no shading but presence of willow leaves nearby
0	No willow cover

Analysis

Comparison of relative growth rates

From those measurements, I first subtracted each plant's height, width, and leaf count in Fall 2015 from the values measured in Spring 2016 in order to determine the change in height, width, and leaf count for each plant. I then multiplied the change in height and width to calculate an approximate change in volume for each plant. I then divided each plant's change in volume from the sum of its initial and final volumes, to obtain a relative growth rate metric for volume. I divided the change in volume by the sum of the initial and final volumes in order to obtain a relativized metric, so that the plant's increase in volume is proportional to the plant's overall size. I then used the same equation to obtain a leaf count relative growth rate metric; I divided each plant's change in leaf count by the sum of its initial and final leaf counts. I then generated a boxplot summary using R studio for each of the two relative growth rate metrics across the twelve species (Figure 1, Figure 2). All statistical analyses in this study were conducted using R studio (R Core Team 2015).

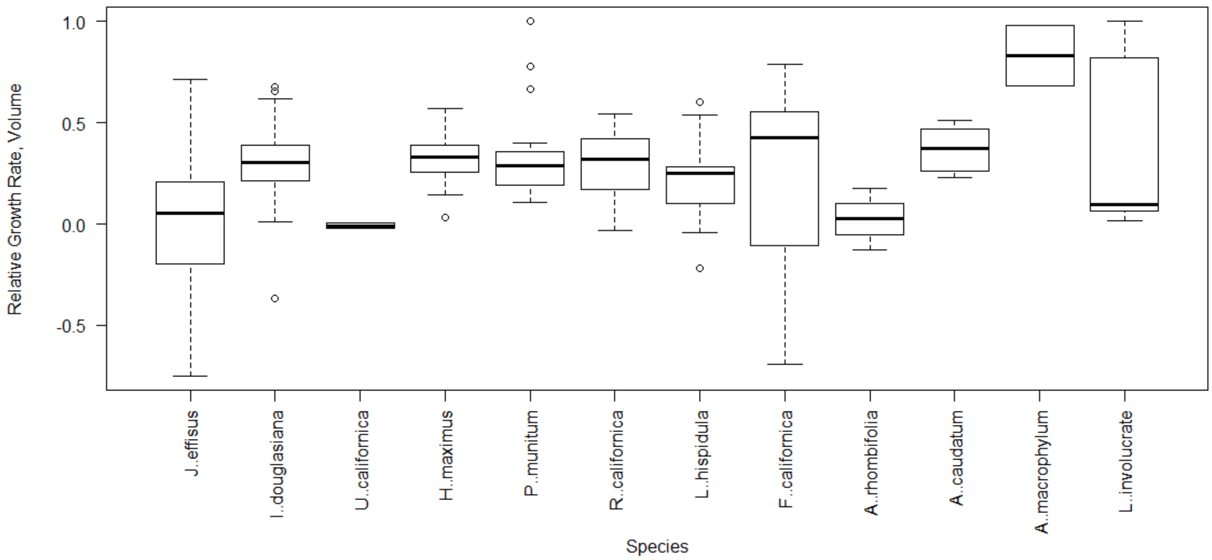

Figure 1. Volume relative growth rates. A boxplot summary of the volume relative growth rates across the twelve plant species.

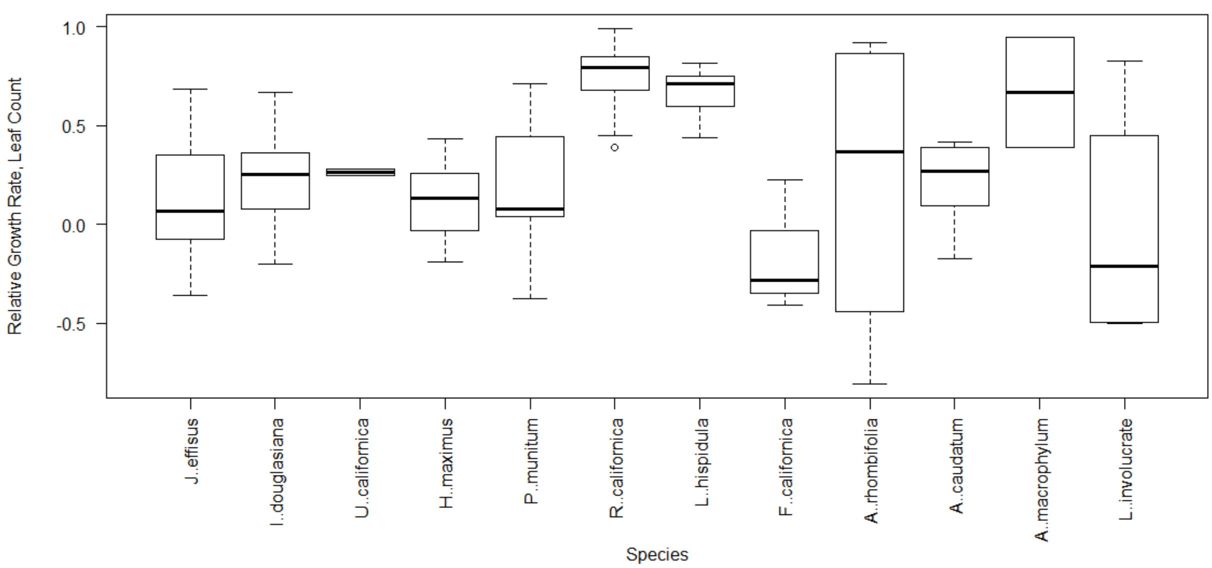

Figure 2. Leaf count relative growth rates. A boxplot summary of the leaf count relative growth rates across the twelve plant species.

I then added each plant's volume and leaf count relative growth rates together to obtain my final relative growth rate metric. The volume metric estimates the amount of physical space each plant occupies in the restoration site, while the leaf count metric represents the amount of new biomass that each plant adds, and I wanted to include both those factors in my final relative growth rate metric. I generated a third boxplot summary for that final growth rate metric (Figure 3).

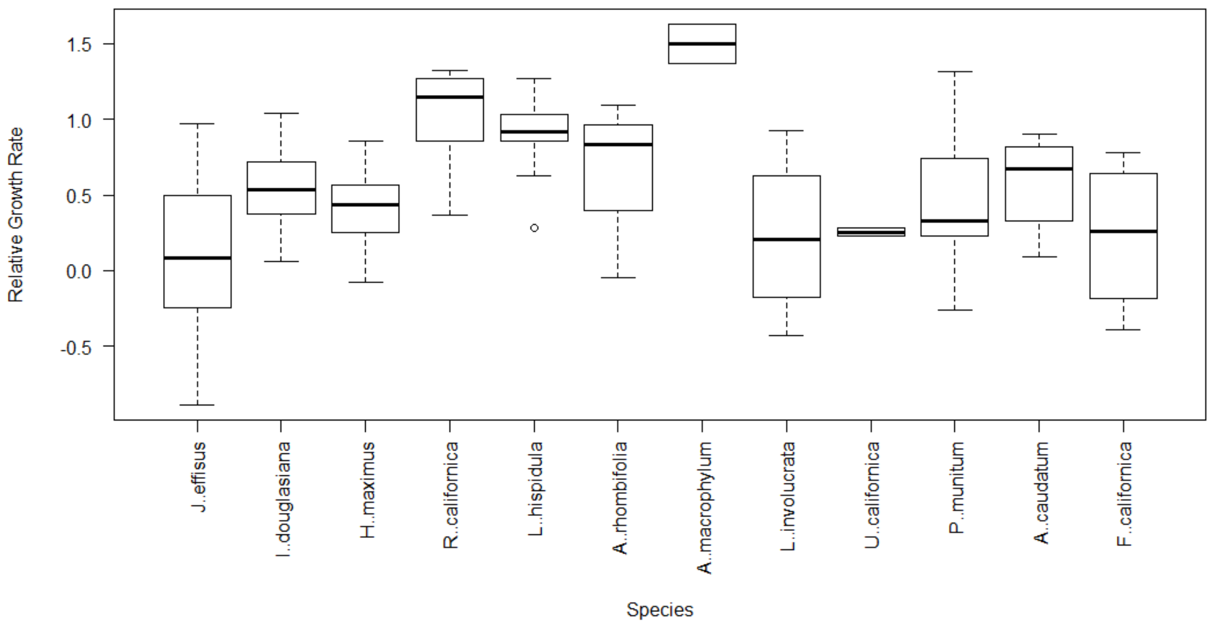

Figure 3. Final relative growth rates. A boxplot summary of the final relative growth rate metric, a summation of the leaf count and volume relative growth rates, across the twelve plant species.

I then generated a linear model for all the plants in R, using relative growth rate as the response variable and species as the predictor variable. From that linear model I ran an Analysis of Variance (ANOVA) test, which generated a p-value of $6.679 * 10^{-10}$. I then ran Tukey's honest significant difference test (Tukey's HSD) as a post-hoc analysis, which compared the average relative growth rates for all possible pairs of species. Because this generated a very large number of p-values and only allowed for comparisons between two individual species, I compared relative growth rates primarily using the boxplot summary, and used Tukey's HSD as a quantitative check for my conclusions.

Testing correlation between predictor variables and growth rate

To analyze the effects of the five covariates (soil moisture, proximity to creek, sunlight exposure, willow cover, and creek bank) on relative growth rate, I used a backwards stepwise multiple regression analysis. I chose to exclude *J. effisus* from this analysis, because all the individuals of this species were planted directly along the edge of the creek. Thus, there was likely to be little variation in many of the covariates, particularly soil moisture and proximity to creek, which would not have made this analysis worthwhile. Therefore, I first conducted the backwards stepwise multiple regression analysis for all plants except *J. effisus*; I used a linear model in R, and excluded one by one the covariate with the highest p-value (least significance) until I was left with only significant variables. I then conducted this same analysis only for plants with more than 10 replicates in the study site (excluding *J. effisus*), as the average growth rate of those species is likely to have a higher accuracy. For all plants, the linear model had an R^2 value of 0.087, and proximity to the creek and willow cover with the only two significant variables (Table 3). For plants with more than 10 replicates, the R^2 value was 0.118, and the same two covariates were significant. Proximity to the creek had a positive slope, indicating that plants farther away from the creek tended to exhibit higher growth rates, while willow cover had a negative slope, meaning plants with greater willow cover tended to have lower growth rates. I then divided the plants into three guilds consisting of trees, shrubs, and forbs, and conducted the same multiple regression analysis for each guild. Trees, shrubs, and forbs had R^2 values of 0.612, 0.217, and 0.041 respectively. Proximity to creek was the only significant predictor of growth rate for trees, creek bank was the only significant variable for shrubs, and forbs did not have any significant variables.

Table 3. Multiple regression results. R^2 values and significant variables for multiple regression analyses of all plants, plants with greater than 10 replicates, and the three guilds.

Model Group	R^2 value	Significant variables (slope, p-value)
All Plants (excluding *J. effisus*)	0.087	Proximity to creek (0.002, 0.005) Willow cover (-0.060, 0.011)
>10 replicates (excluding (*J. effisus*)	0.118	Proximity to creek (0.002, 0.003) Willow cover (-0.074, 0.004)
Trees	0.612	Proximity to creek (0.016, 0.049)
Shrubs	0.217	Bank (0.446, 0.006)
Forbs	0.041	None

P. munitum mortality

The sword fern (*P. munitum*) had an especially high mortality rate, which is not represented in the earlier relative growth rate analyses since I only calculated relative growth rates for living plants. Every sword fern planted on the left bank of creek died, which is the creek bank adjacent to a large grove of blue gum Eucalyptus (*Eucalyptus globulus*). On the right bank of the creek, *P. munitum* had a mortality rate of 43%, and its overall mortality in the restoration site was 60%.

DISCUSSION

The successful growth of riparian vegetation has been shown to provide numerous benefits to riparian ecosystems, particularly in degraded urban streams (Sweeney et al. 2004, Dosskey et al. 2010, McMillan et al. 2014). Of the twelve species of native plants planted in the Strawberry Creek Confluence Ecological Stabilization Project, I found that *A. macrophylum*, *R. hispidula*, and *A. rhombifolia* exhibited the highest overall relative growth rates, and thus I recommend their increased use in future restoration projects. *L. involucrata* and *P. munitum*, on the other hand, exhibited the lowest relative growth rates, and therefore I recommend limiting their inclusion in future projects. *P. munitum* in particular should be excluded, particularly in areas with highly competitive vegetation, as it showed an overall mortality rate of 60%, and a

100% mortality rate on the Eucalyptus-dominated left bank. Among the five covariates, proximity to the creek and willow cover had a significant correlation to relative growth rate for all species, and were therefore the most important predictors of a species' success. For the shrubs guild, creek bank was a significant covariate, with individuals on the left bank exhibiting lower growth rates than those on the right bank. This indicates that the grove of *E. globulus* negatively affect the growth of shrubs, but not trees or forbs. Therefore, I recommend excluding shrubs in addition to *P. munitum* from future sites with highly competitive vegetation like *E. globulus*. These results can be reasonably generalized to future restoration projects in Strawberry Creek and similar urban creeks, however their application to general riparian restoration is more limited.

Comparing relative growth rates

Of the twelve species of plants studied, *A. macrophylum*, *R. californica*, *L. hispidula*, and *A. rhombifolia* exhibited the highest overall relative growth rates (Figure 3). In a Tukey's HSD post-hoc analysis, *A. macrophylum* showed a significantly higher growth rate when compared to five of the other eleven species, which was the greatest number of significant differences among all the species. However, the low level of replication reduces the accuracy of *A. macrophylum*'s findings, as there were only two individuals planted in the restoration site (Table 1). This finding, however, is in alignment with that of Landis & Leopold, which found that native riparian trees were most successful in an urban New York stream (2014). *R. californica* and *L. hispidula*, on the other hand, both had a large number of replicates in addition to high growth rates; 14 and 18, respectively, which indicates that their results are more likely to be accurate. In this study, *R. californica* exhibited greater success than it did for Aplert et al.'s in the Sacramento River Project, where its growth was roughly average among all measured plants (2002). The high growth rates calculated for *A. rhombifolia* are unreliable, due to the timing of the first round of leaf count measurements. When the first round of leaf counts was taken in mid-November, many of the individuals had already begun to shed their leaves, which artificially inflated the change in leaf counts and thus the relative growth rate calculations. Because of this, I withhold from recommending *A. rhombifolia* for future restoration efforts, since their high growth rates in this study may not be entirely accurate.

The calculated growth rates of *J. effisus* and *F. californica* are also unreliable, but for different reasons. For *J. effisus*, all individuals were planted along the edge of the stream, and over the winter season a large amount of plant debris was washed on top of many of the individuals, weighing down their leaves. Therefore, many of the individuals had lower volumes during the second round of measurements due to debris weighing them down, rather than a lack of growth. The growth rates of *F. californica* are also unreliable, because the nature of the plant is that it is very low to the ground and spread out, such that it was often difficult to determine what was one individual as opposed to several smaller plants spread along an area. Therefore, in the second round of measurements it is likely that I failed to measure the exact same individuals as the first round, and thus the analysis for *F. californica* is likely to contain some degree of error.

L. involucrata and *P. munitum* exhibited the lowest relative growth rates among all the species with reliable measurements, indicating that they would not be good species to include in future restoration projects. In addition, *P. munitum* had an overall mortality rate of 60%, and every individual that was planted on the left bank of the creek died. I learned from personal communication that *P. munitum* has been largely unsuccessful in past restoration projects, and this study further confirms that it may be a wise species to exclude from future projects (T. Pine and D. Chapple, personal communication). A possible explanation for *P. munitum*'s high mortality and low growth rate is that in Berkeley it does not benefit from the fog drip that it would in its native redwood forest ecosystem (Limm and Dawson 2010, Limm et al. 2012).

Relative growth rate against the five covariates

Among the five covariates, proximity to the creek and willow cover were the only two that showed a significant correlation to relative growth rate for all species, indicating that they are the most important predictors of a plant's success in a Strawberry Creek restoration site (Table 3). Proximity to creek showed a positive correlation; plants farther from the stream tended to have higher growth rates than those closer to stream's edge. Willow cover, on the other hand, had a negative correlation to growth rate, indicating that plants under dense willow cover tended to have lower growth rates than those with no cover. The R^2 value for this model was 0.087, indicating that 8.7% of the variation in the plants' growth rate was explained by proximity to the creek and willow cover. For species with greater than 10 replicates, the multiple regression analysis showed the same results, with a slightly high R^2 value of 0.118 and slightly lower p-values for the two significant variables (Table 3). This provides a further confirmation of these results, as the accuracy of this analysis increases with a greater number of replicates.

The multiple regression analysis of the trees guild revealed a high R^2 value of 0.612 and proximity to creek as the only predictor. The shrubs had an R^2 value of 0.217, and creek bank was the only significant variable. The growth of the shrubs had a positive correlation to the right bank, indicating that the Eucalyptus grove on the left bank of the creek has a strong negative effect on the growth of shrubs. This has been well documented in previous literature; Eucalyptus suppress the growth of understory vegetation by producing allelopathic chemicals, as well as out-competing for soil moisture and overstory coverage (Moral et al. 1978, May and Ash 1990, Wang et al. 2014, Chu et al. 2014). A multiple regression analysis of the forbs guild produced no significant variables, and a low p-value of 0.041.

I initially hypothesized that soil moisture would be the most significant predictor of a plant's success, but this turned out not to be the case, as it was not a significant predictor in any of the five multiple regression analyses. A possible explanation for this is that the study was conducted during an El Niño winter with greater than average rainfall. Because of this, plants in the drier areas of the restoration site still likely received high amounts of water, and in addition to this many of the species are drought tolerant.

Limitations and Future Directions

One major limitation of my study design is that the first round of measurements was taken over the course of approximately 1.5 months (from November to mid-December of 2015). This may be a source of confounding in my study method, as some differences in relative growth rate may be attributed to the fact that initial measurements were not taken at the same time, and some growth may have occurred over that month and a half. Luckily, however, new growth is often limited in the early winter season, which reduces the confounding effect of that limitation. The overall time span of my study, however, was another significant constraint. Five months is a relatively short amount of time to observe plant growth, and the accuracy of representing a species' ability to succeed in a restoration site by its growth over a 5-month winter season is far more limited than, say, five years. Furthermore, human influences also likely had a confounding effect on the growth of the different species. For instance, while collecting data I witnessed several times dogs rushing through the restoration site and disturbing the plants, as well as people walking and stepping on them. These factors likely negatively affect the relative growth rates of the plants in a way that is not represented by the covariates or the species' intrinsic ability to grow in that niche.

Further analysis is needed in order to assess the effects of the five covariates on each individual species; for instance, the relationship between proximity to the creek and relative growth rate in the California Rose. This would allow insight into the relative successes of the individual plant species in the different microhabitats of a riparian area, allowing for better planning of the spatial distribution of plant species within a future restoration site. In addition, measuring plant growth over a larger time scale would provide more accurate findings, allowing one to choose the optimal species for future restoration projects with greater confidence. Furthermore, a scale for the amount of ecosystem benefit provided by a species would be useful for determining the optimal species for future restoration efforts, in addition to the success of the individual plants. This is because different plants provide different benefits in different quantities; for instance, *F. californica*, a small forb, is unlikely to stabilize a stream bank as much as the large roots of *U. californica*, a large tree. Knowing which ecosystem functions each plant provides, and the extent to which they provide them, would allow for wiser planning to maximize the restoration benefits provided by riparian vegetation.

Conclusions

Based on the results of this study, I recommend an increased use of *A. macrophylum*, *R. californica*, and *L. hispidula* in future restoration projects due to their high average relative growth rates. *L. involucrata* and *P. munitum* on the other hand, showed consistently low relative growth rates, and thus it may be wise to limit their use in the future. *P. munitum* also showed a very high mortality rate, indicating that this species in particular would be best to exclude from future projects. Proximity to the creek and willow cover were the two variables with a significant correlation to relative growth rate for all species, thus they are the most important predictors of a plant's success in a Strawberry Creek restoration site. The left creek bank had a significant negative correlation to relative growth rate for the shrubs, indicating that the Eucalyptus grove particularly inhibits the growth of shrubs, rather than trees or forbs. Thus, I would recommend emphasizing the use of trees and forbs in restoration sites exposed to highly competitive vegetation.

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