Effect of Soil Moisture on Reintroduced Native Seedlings' Growth: Riparian Restoration on Strawberry Creek, Berkeley, California

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ABSTRACT

Invasion of plant species causes a threat to the urban and ecological environment in the modern society. Restoration work on plant community are challenging when multiple factors contribute to the final restoration outcome. Soil moisture level is crucial for the long term sustainability of vegetation restoration. This research will study soil moisture that affect the restoration of Strawberry Creek riparian zone. The following hypothesis will be tested: (1) The effect of Algerian or English Ivy (*Hedera* spp) on soil moisture of Strawberry creek's riparian zone. (2) The effect of soil moisture level, slope and photosynthesically active radiation(PAR) on growth of native seedlings. 9 experimental plots are chosen along the Strawberry Creek's riparian zone to reintroduce 6 native plants. I alternate between watering the plants and measuring soil moisture on a weekly basis to monitor moisture change over time. Slope contributes more than ivy and PAR to determine moisture level. Plots with steep slope and ivy have lower mean soil moisture value than those with gentle slopes and no ivy. PAR has no significant contribution to soil moisture level. The mean number of leaves increased by [insert percentage] and the mean height increased by [insert percentage]. Growth rate is highest in flat plots without ivy. Lower mean growth rate of seedlings on sloped plots than gentle plots indicates that restoration has a higher potential of success on flat terrain with ivy removed.

KEYWORDS

urban creek riparian zone, restoration management, invasive species, native plant community, physical habitat

INTRODUCTION

Invasion of plant species causes a threat to the urban and ecological environment in the modern society. With the advancement of transportation, people can travel across continents more easily. Physical barriers for plants such as oceans, which used to confine organisms, are broken when people bring their seeds to a new habitat. In the San Francisco Bay area, the rate of invasion increases from one invasion per year, between 1851 to1960, to more than three invasions per year, between 1961 to 1995 (Mooney, H.A. and E.E. Cleland 2001). Most invasive plants carry out their intended purpose and benefit humans in many ways. However, some exotic species escape from cultivation and become pests (Reichard, S.H. and P. White 2001). In here, we define the problem of invasive plant species as those that are likely to spread into native habitat and become dominant or disruptive to others (Reichard, S.H. and P. White 2001). One of these examples is Ivy (*Hedera helix* or *Hedera canariensis*), which is introduced in and after 20^{th} century, as a landscaping material. It causes safety issues in urban environment as it climbs up buildings and provides dark hiding places. For the ecological impact, Ivy spreads extensively and becomes the primary ground cover (Berkeley daily planet). It forms dense population that inhibits the regeneration of native vegetation (Weber 2003). The vines of Ivy cannot provide useful habitat for wildlife (Weber 2003). In response to the worsening scenarios in urban and native environment, people attempt to restore vegetation cover to previous situation.

Restoration work on plant community are challenging when multiple factors contribute to the final restoration outcome. Major factors such as availability of sunlight, nitrogen and moisture in soil all affect the growth of plants. People in the past used mechanical measures such as cutting the vines, pulling them from trees and burning with blow torches to remove Ivy. These methods are proved to be partially successful as exotic species reinvade back quickly (Weber 2003). Exotic species reinvade quickly. They change natural abiotic conditions that become not suitable for long-term growth of native species. Then, researchers investigate the impact of invasive species on the abiotic factors such as sunlight, nitrogen cycling, and hydrology on the invaded site. Invasive species, such as Ivy, have high-light suppression ability that decreases light transition to soil surface (Young 2011). Research on nitrogen cycle shows evidence of invasive species altering nitrogen availability for plant community (Levine et.al 2003). Ivy has a much lower Nitrogen 15 root and leaf uptake rate than native species (Bickart 2013). However, for hydrologic pattern, few studies investigate the impacts of invasive species on native species (Levine et.al 2003). Hydrologic patterns, such as soil moisture level play a crucial part of the growth of seedlings. These heavily altered abiotic problems must be addressed for a comprehensive restoration plan.

Soil moisture level is crucial for the long term sustainability of vegetation restoration. It represents the volume of water in a given volume of soil. Water stressed plants experience photoinhibition. Photoinhibition is the light dependent and slowly reversible retardation of photosynthesis (Long et al.1994). It reduces maximum CO_2 uptake and decreases rate of light saturated photosynthesis. Photoinhibition can possibility damage photosystem II (PSII) (Demmig-Adams 1992), which stops breaking water molecules into H^+ ion and oxygen atom in light dependent stage of photosynthesis. Even if water level restores to the plant's favorable level in the later growth stage, chances of recovery is very low (Bjorkman and Powles 1984). Plants in photoinhibition can threaten the photosynthetic system, and thus, the sustainability of native species restoration. However, the study site for this research is in Berkeley, California. California is experiencing a serious drought. It can expect 6-14 fewer precipitation days per year in the coming years (Polade et.al 2014). On the other hand, Ivy will also take away part of the moisture for its growth. Therefore, restoration ecologists have to take the change in soil moisture pattern into account for a successful restoration plan.

This research will study soil moisture that affect the restoration of Strawberry Creek riparian zone. The following hypothesis will be tested: (1) The contribution of slope, Algerian or English Ivy (*Hedera* spp) and Photosynthetically Active Radiation (PAR) to soil moisture on Strawberry Creek's riparian zone. (2) The effect of soil moisture level on growth of as *Asarum cadatum*, *Polystichum munitum*, *Mimulus aurantiacus*, *Aster chilensis*, *Ribes sanguineum*, *Ceanothus thyrsiflorus*. The first hypothesis aims to find out the soil moisture pattern which can inform further restoration plans. The second hypothesis aims to measure the level of success of revegetation of strawberry creek's riparian zone.

METHODS

Study system

Historical background of Strawberry Creek

Strawberry Creek (37°52'N; 122°15'W) is an urban creek located in the city of Berkeley, California. It starts at Strawberry Canyon in the Berkeley Hills and flows Westward across the UC Berkeley campus and city of Berkeley. The creek drains into the Berkeley Marina in central San Francisco Bay (Fig. 1) (OMCA 2010). It initially was the major water supply to the campus community in the early days of development (Charbonneau 2002). In order to meet the campus's increasing demand for water, earlier campus developers built of dams in Strawberry Canyon to gather more water (Charbonneau 2002).

Invasive species on Strawberry Creek

After the damage by urbanization of Strawberry Creek, native plants could not survive. Algerian ivy (*Hedera canariensis*) and English Ivy (*Hedera helix*) took this opportunity to dominate the habitat. Ivy is an evergreen climber that originates from Europe or Canary Islands in Atlantic Oceans. Ivy's native habitat includes forest floors, rocky and shady places. It has simple, shiny and dark green leaves that form in dense populations. Its roots and woody vines are capable of climbing on tree trunks or buildings up to 30 m in height (Weber 2003). Due to its characteristics of evergreen and shade tolerant, they are easy to grow and require minimal manage in the urban environment. Landscapers in the 20th century introduced Ivy to America as a gardening ornament. Ivy was used for landscape decoration, but it grew out of captivity and expanded into native habitats. Since Ivy can absorb particulate matter and pollutants (Sternburg et.al. 2010), when native organisms became regionally extinct in the riparian zone of Strawberry Creek due to extensive pollution and human disturbance, Algerian and English Ivy (*Hedera* spp) spread and dominated the habitat.

Unique soil moisture pattern on Strawberry Creek's riparian zone

Soil moisture pattern was significantly altered due to non-sustainable restoration practices done in the past. Campus officials built concrete culverts and 28 check dams to divert water and slow flow rate respectively (Poskanzer 2001).These structures protected the bank, but also prevented soil from obtaining moisture from creek. The increase in concrete pavements caused more rainwater to runoff into the creek instead of draining through soil (Pollock 2008). This increased creek flow after storms (EH&S, 2008) which, in turn, brought more erosive power to each storm. Soil erosion sideways and downward on creek bed, also known as downcutting, increased (EH&S, 2008). The vicious cycle of downcutting and reinforcment with concrete structure heavily altered the natural soil moisture pattern on Strawberry Creek's riparian zone. The non-sustainable engineering methods prevented the erosion to building foundations at the expense of worsening the creek's soil moisture pattern.

Setup of experimental plots and subplots

To determine the effects of Ivy on soil moisture, I set up 9 plots along the Strawberry Creek's riparian zone to be the experimental site. These sites were chosen because of domination by Ivy. They were parallel to the water flow in the creek. Each plot was divided in half for randomly assigned "Ivy" and "No Ivy" subplots. In the "no Ivy" subplot, Ivy was removed by hand to create a space free of invasive species. There are a total of 18 subplots across campus. Figure 1 shows the geographic location of the 9 plots, or 18 subplots, throughout campus.

In each subplot, I setup 4 rows of plants in parallel. Each row was given a number with 4 being closest to the creek and 1 being furthest away from the creek. There were 3 native plants equally spaced out in diagonal in each row. A total of 12 plants were planted in each subplot. The design layout is in Figure 2.

Plant Selection

To restore the habitat that is closer to its native beauty, I chose 6 native plants for this experiment. They are wild ginger (*Asarum caudatum*), California aster (*Aster chilensis*), western sword fern

(*Polystichum munitum*), blue-blossom ceanothus (*Ceanothus thyrsiflorus*), sticky monkeyflower (*Mimulus aurantiacus*), and pink-flowering currant (*Ribes sanguineum*). All of these species were native to Strawberry Creek and can still be found in Strawberry Canyon, the origin of Strawberry Creek. They were purchased from Watershed Nursery in the city Richmond, Oaktown Native Plant Nursery in the city of Berkeley, and Mostly Natives Nursery in the city of Tomales. The individual plants in each species group were similar in age and were sourced from the same nursery, except for the western sword fern individuals which were purchased from both The Watershed Nursery and Mostly Natives Nursery.

Data collection methods

Gradient of plots

Before planting native seedlings to the plots, I visually assessed the slope of plots that is perpendicular to flow of Strawberry Creek. I only took the perpendicular slope into account since it represents the major path of surface runoff. The slope of plot that is parallel to the flow of Strawberry Creek varies insignificantly when compared to the perpendicular slope.

Watering Methods

After assigning the native seedlings to the plots, I alternated between watering by hand and measuring soil moisture to all 9 plots on a weekly basis. I used water from Strawberry Creek and applied it to the seedlings with a watering can. Each seedling was given roughly the same amount of water every other week. In here, I measured the amount of water using verbal cue “Mississippi”. Each seedling received the amount of water equal to saying 3 “Mississippis”. Throughout the watering process, I said the word “One Mississippi” for the first prescription, “Two Mississippi” for the second prescription and “Three Mississippi” for the third prescription.

Soil moisture measurement

Sampling. Soil moisture was collected by a hand held soil moisture meter on a biweekly basis. I took a total of 2 measurements in a month to see how soil moisture changed after a week. During each measurement, I chose a row of native plants in each subplot by random to generate data for later statistical analysis. As mentioned above, each row of native plants was given a fixed number from 1 to 4 and each row has 3 plants. In order to randomly determine which row to measure in the subplot, I used a random number generator from Microsoft Excel to assign measurements randomly. I chose one row of plants for measurement from all 9 plots, or 18 subplots. A total of 54 samples were generated from each measurement. This was done to satisfy the random sampling requirement in the later statistical analysis.

Procedure. I used a soil moisture meter, made by Extech Instruments (Serial number: MO750), to measure the percent of soil moisture content. It was fully calibrated in the factory with 0.1% resolution. I inserted the probe of the soil moisture meter into the soil beside the seedlings for measurement. Result of soil moisture was displayed as % soil moisture on the moisture meter and was recorded.

Plant Growth

I performed leaf count at the end of April 2015 to identify the overall growth rate of the seedlings over the past year. I compared the number of leaves from April 2014 to April 2015 with the following equation:

$$Growth = \frac{Number\ of\ leaves\ in\ 2015 - Number\ of\ leaves\ in\ 2014}{Number\ of\ leaves\ in\ 2014}$$

Photosynthetically active radiation (PAR)

To determine the light available for plants to carry out photosynthesis, I collected Photosynthetically active radiation (PAR) for each plot on March 19, 2015 at 8:30 am, 1:00 pm and 3:00 pm with a hand-held light meter. It measured the number of photons that was available to activate photosynthesis over a 1 m^2 area each second, with μ mol/m^2 s as unit. First, I took a reference reading around the plot without shade. This data showed the highest amount of light available for plants to carry out photosynthesis. Then, I took 3 readings on top of the introduced seedlings in the no ivy subplots and 3 readings on top of the ivy subplot to obtain the average amount of light available for plant in plots.

Data analysis methods

To consider the change in soil moisture pattern over time, I assessed the difference in mean soil moisture between Ivy and no Ivy plots. After data collection, I imported the randomly measured soil moisture data into statistical software, R, to perform a Shapiro-wilk normality test and Bartlett's test of homogeneity of variances. If the data are normally distributed, then, I can determine which statistical method to use for further analysis.

RESULTS

Study system result

Maintenance

To keep the physical condition consistent at my experimental sites, over the past five months, I carried out three maintenance visits. The 3 visits were on 1st week of September2014, 1st week of October 2014, and 2nd week of January 2015. After setting up the experimental plots, invasive species such as Acacia, Himalayan blackberry and grasses sprouted and needed to be removed on 1st week of September and 1st week of October. I pulled away grasses by hand. For Himalayan blackberries and Acacia with deep root systems, I only cut away the stem above soil with a bypass lopper while keeping the cover soil undisturbed.

I restored two plots in 2nd week of January 2015 in order to repair damage caused by storm. A rain storm in mid-December was the first rain after a long period of drought which damaged Plot 2 and 3 severely. Asarum caudatum in plot 2 were flushed away. Plot 3 faced soil erosion which exposed the roots of native seedlings. I cleared the trash washed onto plot 2 and added some soil to plot 3 to stabilize the seedlings. On April 14, 2015, 2 students accidentally removed 2 *Asarum caudatum* and 2 *Aster chilensis* and all the ivy from ivy subplot in plot 7. Some of the data were lost due to human and natural disturbance. Therefore, in the following statistical analysis, I only used data from the remaining undamaged native seedlings in plot.

Data collection results

Gradient of plots

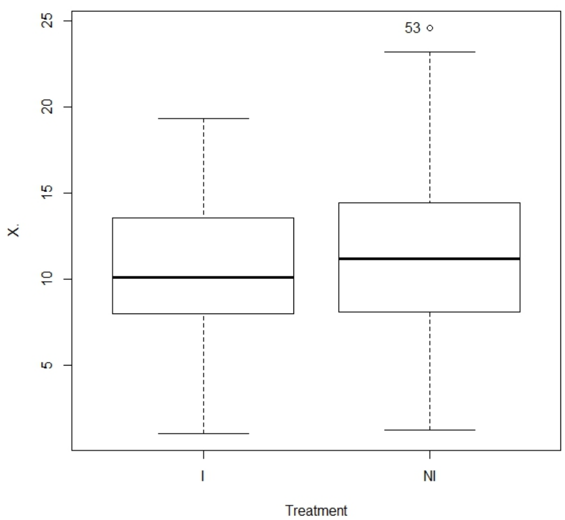
The slope of plots ranged from gentle, steeper and steepest. I categorized the 9 plots into 3 slope groups, gentle sloped plots, steeper sloped plots, and steepest slopped plots. Plots 5, 6, 7 were assigned into gentle sloped plots (Figure 3). Plots 1, 2, 4 were assigned into steeper sloped plots (Figure 4). Plots 3, 8, 9 were assigned into steepest sloped plots (Figure 3).

Soil moisture measurement

Shapiro-wilk normality test. I found that soil moisture data in gentle sloped plots (p-value = 0.02678) and steeper sloped plots (p-value = 0.01226) did not follow normal distribution while the steepest slopped plots (p-value = 0.14) followed normal distribution under Shapiro-wilk normality test. Data in both gently sloped and steeper subplots have p-value < 0.05, which rejected the null hypothesis. Data in steepest sloped plots has a p-value > 0.05, which accepted the null hypothesis. Soil moisture data in steep sloped plots were normally distributed while the one for gentle sloped plots was not normally distributed in Shapiro-Wilk normality test.

Bartlett's test of homogeneity of variances. I also found that soil moisture data in all 3 sloped groups showed no difference in variance between ivy and no ivy subplots under Bartlett's test of homogeneity of variances. Gentle sloped plots had a p-value = 0.5531, steeper sloped plots had a p-value=0.3292, and steepest sloped plots had a p-value=0.56652. Since all the p-values were above the 0.05 threshold, all groups had the same variance between ivy and no ivy subplots. Soil moisture data in steep sloped plots were normally distributed while the data for gentle sloped plots were not normally distributed in Shapiro-Wilk normality test.

Wilcoxon test. Based on the results from Shapiro-wilk normality test and Bartlett's test of homogeneity of variances, I used non-parametric analysis, Wilcoxon test, to compare the difference in mean soil moisture between ivy and no ivy subplot for gentle sloped plots (Figure 6.) and steeper sloped plots (Figure 7.). I used a t-test to compare the difference in mean soil moisture between ivy and no ivy subplot for steepest slopped plot (Figure 8.).



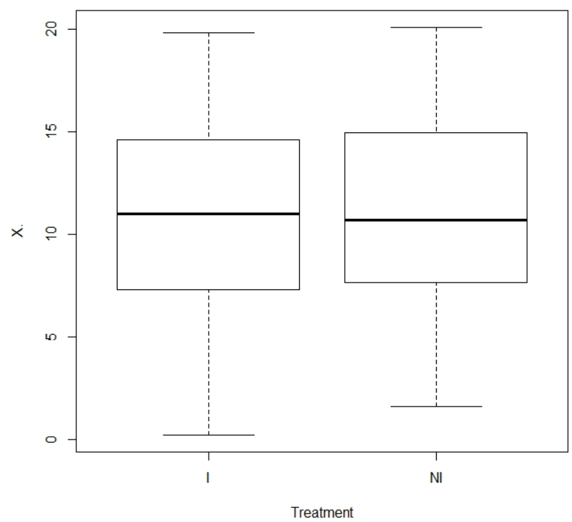


Figure 6. Difference in soil moisture between ivy (I) and no ivy (NI) subplot in gentle sloped plots. I and NI had different mean soil moisture in Wilcoxon test (p-value < 2.2e-16)

Figure 7. Difference in soil moisture between ivy (I) and no ivy (NI) subplot in steeper sloped plots. I and NI had different mean soil moisture in Wilcoxon test (p-value < 2.2e-16)

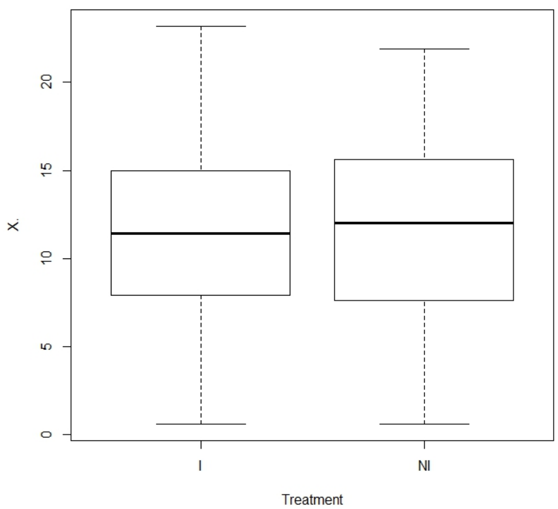


Figure 8. Difference in soil moisture between ivy (I) and no ivy (NI) subplot in steepest sloped plots. I and NI had different mean soil moisture in t- test (p-value < 2.2e-16)

Changes in soil moisture in each plot over time

I plotted soil moisture against time to show the changes of each plot over time. All plots had highest soil moisture on week 9 due to the rainstorm that brought 4.41 inches of rain over 2 days (NOAA 2015). They had lowest soil moisture in week 3 due to the severe drought.

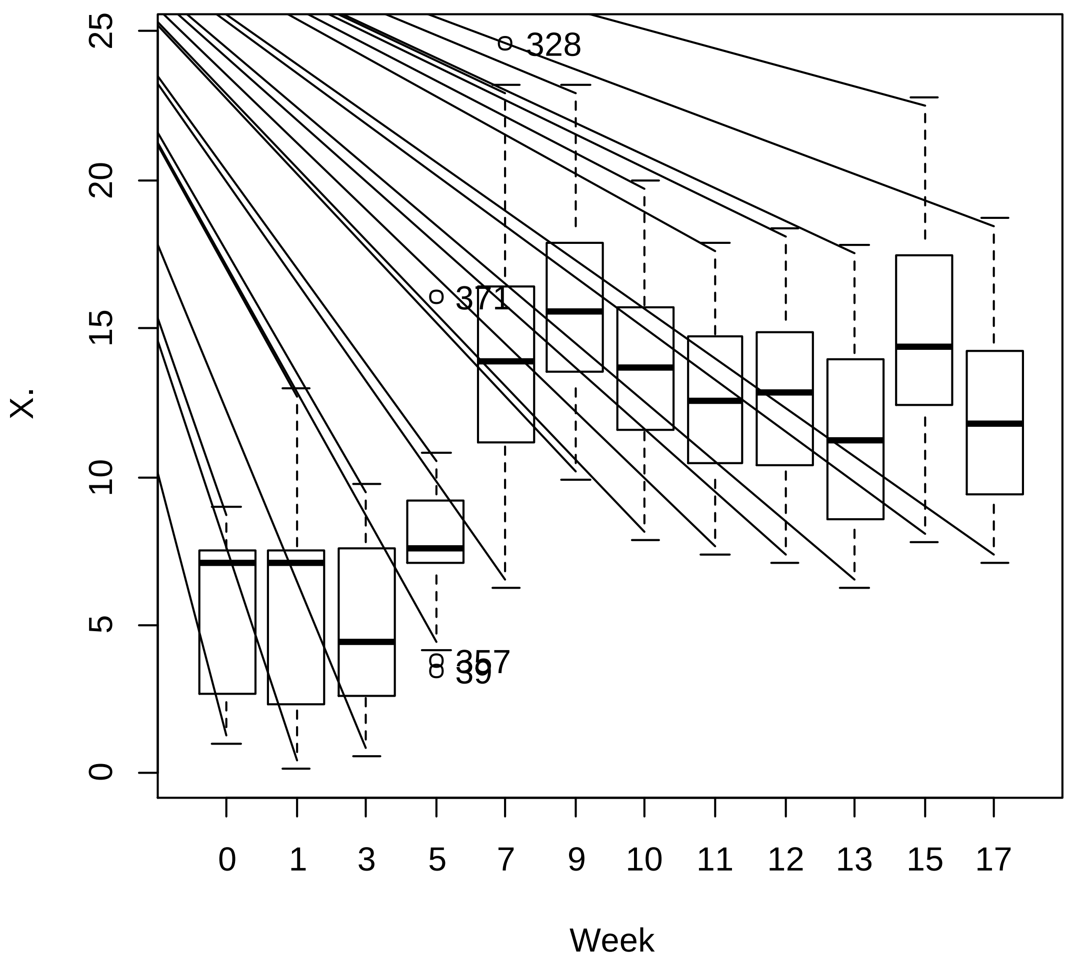


Figure 9. Variation of soil moisture over time.

Plant Growth

I performed a leaf count and height measurement to compare the growth rate of plants. I found that the change in mean number of leaves for each species, respectively, was -41.06% for *Asarum caudatum*, -49.12% for *Aster chilensis*, -58.36% for *Polystichum munitum*, -20.41% for *Ceanothus* *thyrsiflorus*, 540.41% for *Mimulus aurantiacus* and 108.54% for *Ribes sanguineum*. Plants that possess similar biological trait with ivy shows lower growth rate while those with different biological traits than ivy shows significantly higher growth rate.

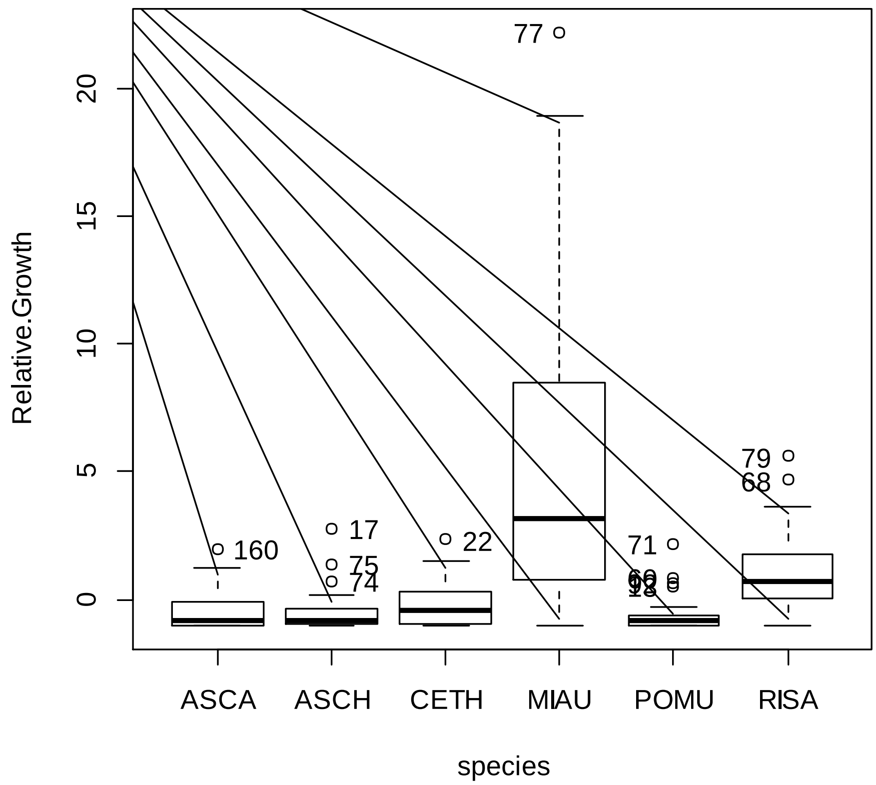
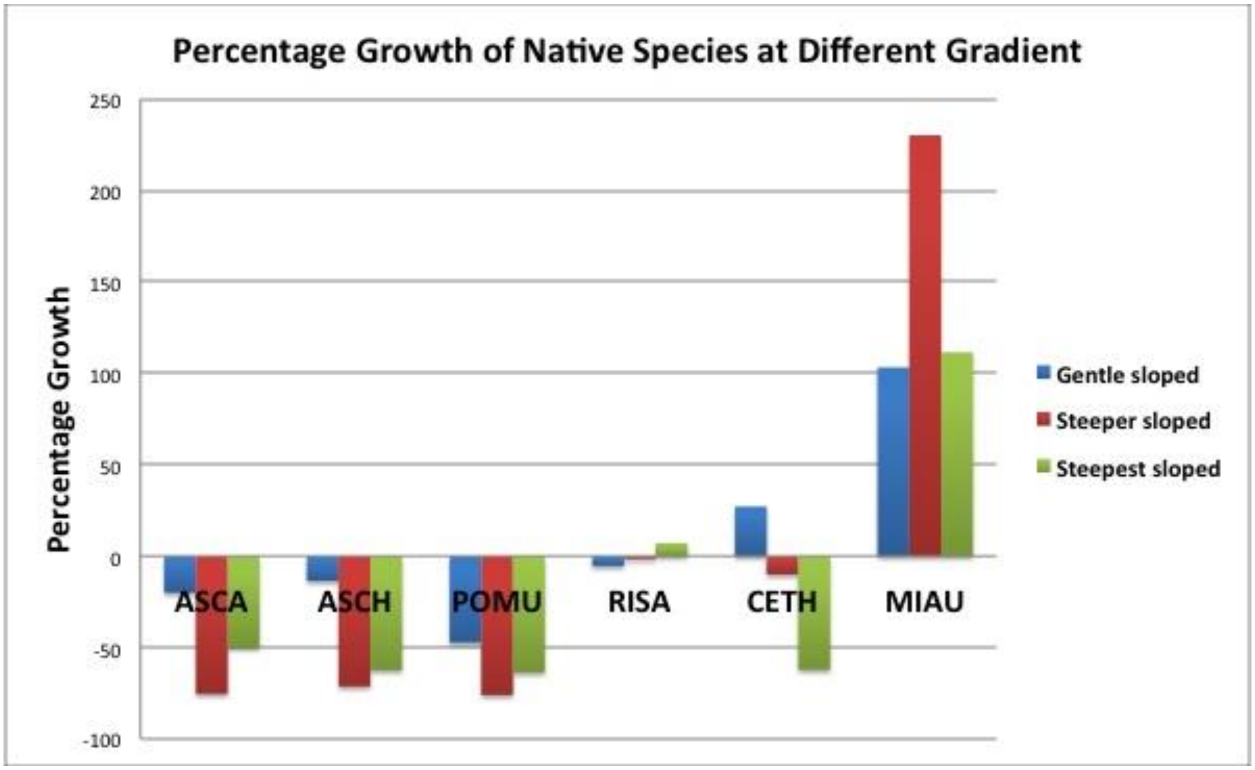


Figure 10. Growth of 6 native seedlings over one year. *Mimulus aurantiacus* (MIAU) and *Ribes sanguineum* (RISA) that possessed different biological traits with ivy had the highest growth. *Asarum caudatum* (ASCA), *Polystichum munitum* (POMU) possessed similar biological traits with ivy had lower growth rate.

Even though different native seedling has different growth rate based on its biological trait, plants in the steepest plots were lower than steeper plots and gentle plots (Graph 1).



Graph 1. Growth of 6 native seedlings at different sloped plots.

Photosynthetically active radiation (PAR)

I took 3 photosynthetically active radiation (PAR) readings on March 19, 2015 at 8:30 am, 1:00 pm and 3:00 pm to compare the difference in solar radiation in different seasons. Plot 7 received the highest mean PAR while plot 1 received the lowest.

For the summer measurement, the photosynthetically active radiation (PAR) from both ivy and no ivy plot did not follow normal distribution. I performed shapiro-wilk normality test in order to determine which statistical to use. PAR in ivy had a p-value = 1.004e-08 while the plot with no ivy had a p-value= 7.254e-09. Since both p-values < 0.05, they did not follow a normal distribution. I would use non-parametric statistical analysis to compare mean.

I found no difference in mean photosynthetically active radiation (PAR) between ivy and no ivy plot from Wilcoxon signed rank test, p-value = 0.427. Since $p>0.05$, the distribution showed no difference in mean PAR between ivy and no ivy plot.

DISCUSSION

This research aimed to evaluate how soil moisture affect the restoration of Strawberry Creek riparian zone. I sought to inform future restoration plans with hydrologic pattern after human degradation and invasion of exotic species of Strawberry Creek's riparian zone. The effect of slope, Algerian or English Ivy (*Hedera* spp) and PAR on soil moisture were not investigated on Strawberry Creek. I hypothesized that steeper sloped plots have less soil moisture, ivy lowered soil moisture from plots and a high PAR caused lower soil moisture. My results suggested that stepper slopes had less moisture, ivy decreases soil moisture level on plots and PAR had no significant effect on moisture level.

Gradient of plots on plant growth

Lower mean growth rate of seedlings on sloped plots than gentle plots indicates that restoration has a higher potential of success on flat terrain. Native seedlings on sloped plots have a lower height and less number of leaves regardless of the presence of ivy.

Soil moisture measurement on plant growth

Difference in mean soil moisture between ivy and no ivy subplots suggests that ivy takes away water from native seedlings. Seedlings in ivy plot have fewer leaves than the same species in no ivy plot regardless of slope of plot. My findings agrees with several studies which suggest the mechanism of lowering soil moisture (Hamilton et al. 1999, Levine et al. 2003). Both studies suggested that competition for water by non-native annual plants was an important factor causing low biomass of seedlings. Non-invasive plants have different rates and timing of evapotranspiration than native species, which in turn changed the soil moisture regime. Even though Hamilton further suggested that adding water to plot could cancel the negative effects of invasive species, watering the plots by hand can only provide enough water for plants to survive through the summer drought.

Photosynthetically active radiation (PAR) on plant growth

No difference in photosynthetically active radiation (PAR) between plots suggest that solar radiation plays a less important role in growth of native seedlings. All the plots are partly shaded by tree canopy cover. Native seedlings in different plots receive similar amount of solar radiation throughout the day, yet, they have different growth rate. In this case, PAR does not play an important role in plant growth. My result disagrees with study by (Monteith and Moss 1977) which showed a strong correlation between total productions of dry matter with the amount of radiation by leaves during growth.

Limitations

My project attempts to draw connections of various abiotic factors with growth of plants such as slope gradient, soil moisture and PAR. However, due to time constraints of research, seasonal changes, growth duration and flowering of plants are not addressed when measuring growth. On the other hand, the soil moisture data do not follow normal distribution, which is opposite to patterns suggested by other paper. It is suggested that, with more plots and a longer measuring period, soil moisture data should follow normal distribution pattern.

Broader Implications

This research finding can be applied to other urban creeks with a history of extensive human degradation and exotic species invasion. However, the soil moisture at each specific site depends on the difference in evapotranspiration rate between invasive species and native species.

Regarding the long term restoration effort, this project builds the basis for a self-sustainable native plant community. As suggested by (Nienhuis et al. 2002), the pre-requisite for rehabilitation of native vegetation is the presence of viable seed bank. Some of the seedlings, such as *Mimulus aurantiacus* (MIAU) are able to mature and produce flowers. Given that the plants can survive without much watering by hand, more species are expected to produce seeds and establish a stable seed bank in near future.

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APPENDIX

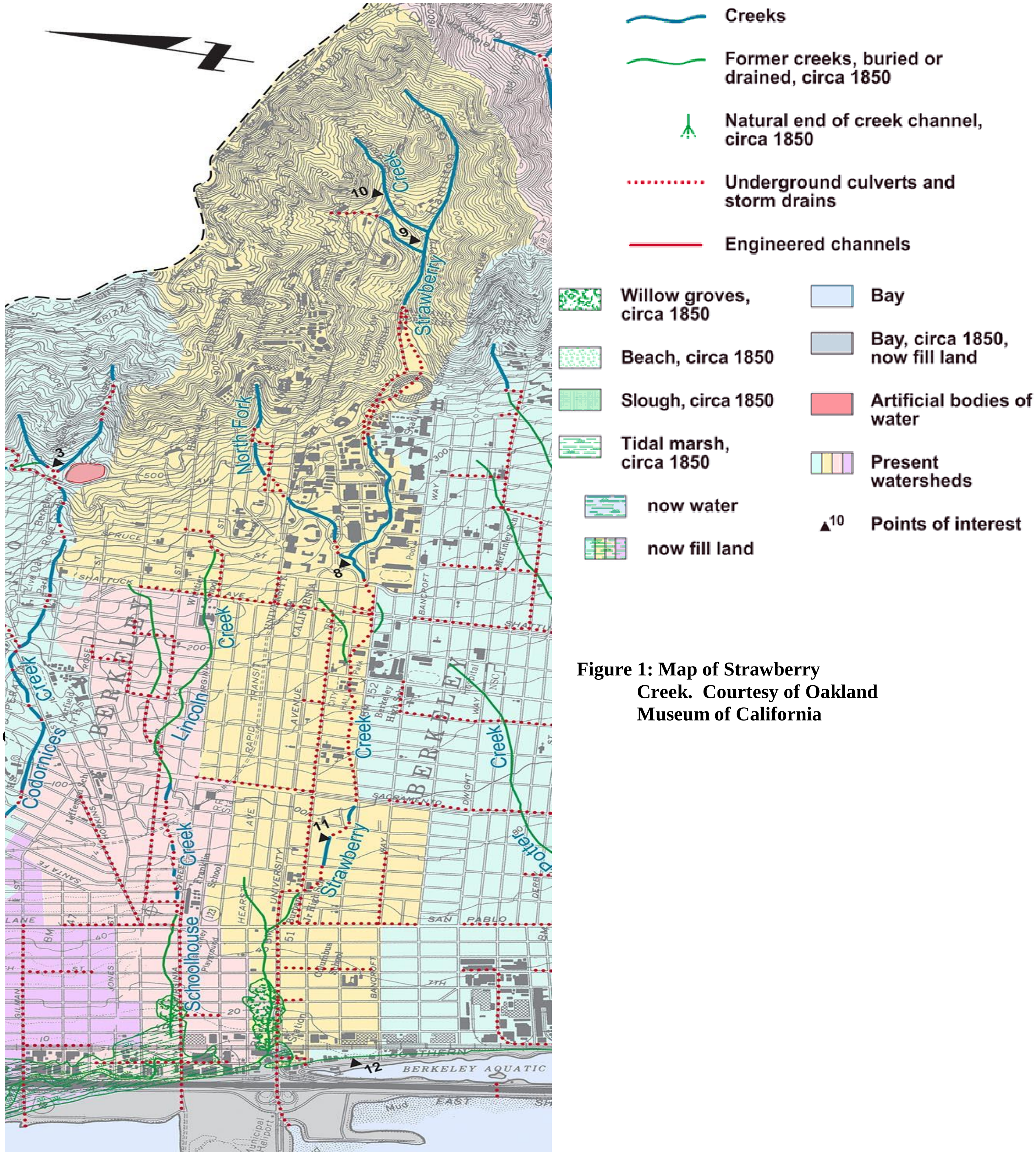

Figure 1: Map of Strawberry Creek. Courtesy of Oakland Museum of California

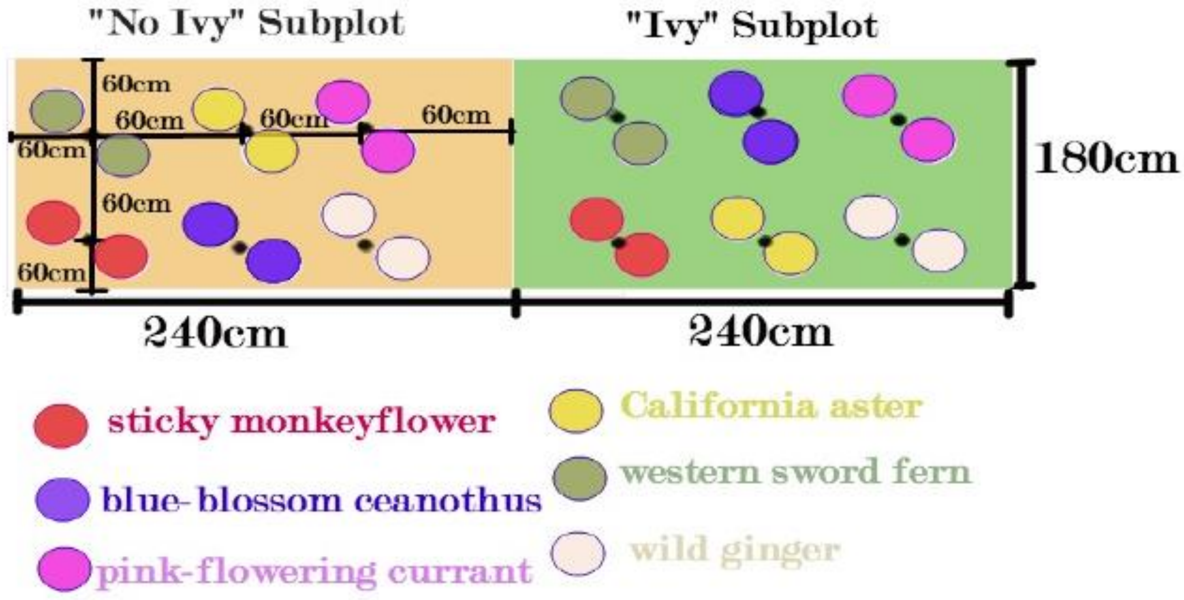

Figure 2: Setup of Plots, Subplots and Plant Arrangement

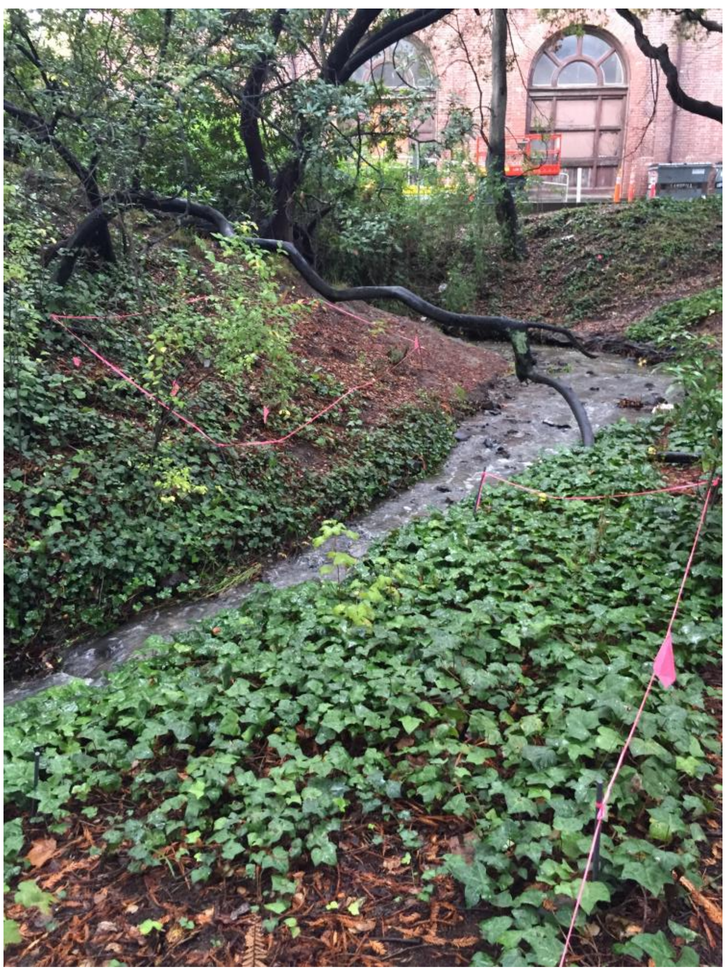

Figure 3: The lower pink ribbon marks the boundary of the gentle sloped plot. The upper pink rectangle marks the boundary of the steepest sloped plot.