The Effect of Canopy Cover and Soil Conditions on Growth Rate of *Mimulus aurantiacus* and *Rhamnus californica* in San Francisco

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Abstract Although habitat restoration projects are becoming increasingly common, many of them do not include pilot studies which could potentially guide future restoration efforts. Local, native plants are currently being planted under a Monterey Cypress forest as part of a restoration project at Lands End, San Francisco, California. This is the first year of planting and the findings of this paper are meant to help guide plantings in future phases of the restoration project. The effect of canopy cover and soil type on the rate of plant growth of two of the native species, sticky monkey flower (*Mimulus aurantiacus*) and coffee berry (*Rhamnus californica*), was determined through planting seedlings in three plots under three levels of canopy cover (30%, 50%, and 80%), and varying soil types. Significant differences ($p<0.05$) were found between different plots depending on the species. Both species had the highest growth rate in the plot with 80% canopy cover and with the highest pH (6.75), but neither followed a pattern where growth rate increased with increasing canopy cover or soil pH. Based on my results I offer suggestions for future plantings and also for follow up experiments that could help determine which factors have the greatest effect on rate of growth.

Introduction

In recent years, habitat restoration has become an increasingly common subject in the environmental sciences, with the term "restoration" encompassing many different meanings and goals depending on the particular project or ecosystem. A general textbook definition of restoration is to get ecosystems as close to a "natural" or undisturbed ecosystem as is feasible (Botkin and Keller 2005). In many cases, especially in urban settings, this goal might not even be applicable; buildings, roads, or human presence could prevent an ecosystem from being restored to its "natural state". This leads to other more broad definitions such as the one by Society for Ecological Restoration International Science & Policy Working Group which states that "ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed" (2004). Under this definition, goals might include simply removing some toxic chemical or invasive species, recovering local biodiversity, improving aesthetics, or teaching purposes (Clewell et. al. 2006; Burton et. al. 2006; Burger et. al. 2006). Usually restoration projects begin with plant restoration since they often make up the majority of the ecosystem, or at least the basis of it (Young et. al. 2005). With plant restoration it is hoped that the animals associated with the native flora will come back, recovering the ecosystem to a more natural state (Young et. al. 2005).

Although restoration efforts are widely performed, they are often not monitored for success or effectiveness (Holl et. al. 2003). Without monitoring, the success of a restoration project cannot be assessed which could lead to wasted resources and time (Harrington 1999). Monitoring programs can vary greatly from restoration project to restoration project based on goals, funding, and feasibility; a variety of indicators can be used as signs of success, for example, plant survival or the return of associated wildlife (Harker et. al. 2000).

Currently at Lands End in San Francisco, California, a restoration project is underway. Lands End has a rich ecological and cultural history part of which included the planting of thousands of Monterey cypress trees in the 1920's and 1930's (McBride et. al. 2006). The Monterey Cypress which is native to California, but not to this area, were planted with the intention of beautifying the area, which naturally consisted of low growing coastal scrub (Lands End Lookout 2006). The restoration project at Lands End revolves around this cypress forest, with goals to increase the health of the forest through thinning the trees to a more natural density, improve aesthetics, and to increase natural diversity through the planting of an understory of native plants (The Lands

End Lookout 2006). The cypress trees were planted at a high density (in some cases up to 500 trees/acre) which is causing competition between the trees for water and nutrients, so one of the first goals of the project was to prune and thin the existing grove at Lands End with the ultimate goal of creating a density of 200 trees/acre to minimize competition (McBride et. al. 2006). Pruning and thinning was completed in the fall, which opened up parts of the canopy, creating more variation in the canopy cover. Since a cypress forest would not naturally be at Lands End, and because the plants chosen for native restoration need to be local, (so not necessarily the same ones that would be a part of a natural Monterey cypress understory), it is uncertain which plants will be most successful, but plants were chosen that are found in other local understories. (conversation with Asha Setty).

Monitoring the success of these native species under the cypress canopy would be helpful to the project since this winter they received about 3,000 plants, but next year they are able to order about 20,000 plants and need to know which they should request (conversation with Asha Setty). There is evidence that level of canopy cover and canopy gaps have an effect of survival of many different understory plants (Van Der Meer et. al. 1999; Sanford et. al. 2003; Reader 1992). In addition to simply survival, evidence shows that different species of plants react differently to canopy cover in speed of growth and leaf density (Sanford et. al. 2003; Kim et. al. 2004).

Of the approximately 20 different species of plants that are to be planted in the cypress understory, I suspect that some will do better than others and that others might fail all together. Due to time constraints I chose two species of understory plants to compare, California coffeeberry (*Rhamnus californica*) and sticky monkey flower (*Mimulus aurantiacus*) to see if there is a significant difference in the rate of growth under varying levels of canopy cover, with the hope that this monitoring can contribute to the decision making process for which plants should be ordered for the following year and where they should be planted.

Methods

Study Area The study site where I collected my data is at Lands End, San Francisco, California (37.465N 122.304W), which is part of the Golden Gate National Recreation Area. The study was performed in the understory of the Monterey Cypress forest that currently grows there. The portion of the forest that I concentrated on is the part that is just north of the Merrie Way parking lot, shown in the figure below (Fig 1). Within this area, I set up three plots based on the

level of canopy cover, one with limited canopy cover (35%), one with nearly total canopy cover (80%), and one that had an intermediate canopy cover (50%).

Figure 1. Aerial map showing the study site in San Francisco.

Measurement of Canopy Cover Canopy cover was assessed using a handheld canopy densimeter made from a convex mirror with a series of marks made with ink in a circular shape. By counting the number of dots that reflect sky while holding the mirror parallel to the ground in a single spot, while facing north, west, south, and east, the approximate percent canopy cover can be assessed. For example, if a total of 25 dots appear on the mirror where the sky is reflected, then the canopy cover is 75%.

Plot Design Under the three levels of canopy cover described above, plots (10.5 feet by 10.5 feet) were set up. Within each plot I planted 48 plants regularly spaced (1.5 feet between each), 24 of sticky monkey flower (Mimulus aurantiacus) and 24 California coffeeberry (Rhamus californica) in a pattern such that every other plant was the same species as shown in the figure below (Fig 2). I weeded one extra foot on each side of the plot and continually weeded throughout the rest of the experiment to control for competition with the weedy species that have grown in under they canopy. I used the same planting method used by the volunteers in the restoration project to make sure that my findings are applicable to future management.

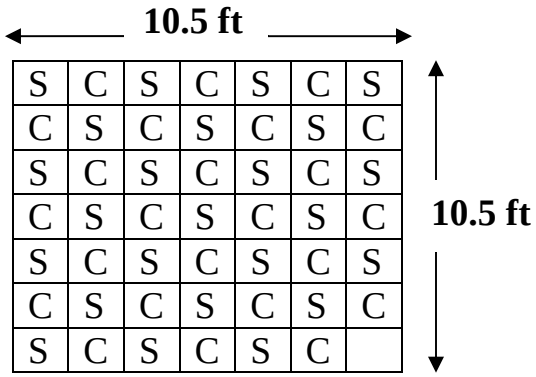

Figure 2. Plot design where S refers to sticky monkey flower and C refers to coffee berry.

Soil Measurements In addition to canopy cover I made measurements to quantify variation in soil characteristics in each plot. Soil pH was measured using a Hellige-Truog Soil Reaction (pH) Tester. Within each plot I tested three soil samples, one taken from the center and two from opposite corners to check for uniformity across the plot.

Soil texture was determined by using the methods described by the USDA Soil Texturing Field Flow Chart. This involved taking a small sample of soil in the hand, adding water, and following the instructions of a flow chart. Based on whether the soil can be formed into a ball, and then a ribbon, and then assessing the amount of sand in the soil, a description can be applied to the soil type such as sandy loam, or silt loam for example. Again, three samples were used from each plot, one from the center, and two from opposite perimeters.

Soil moisture was measured by taking three samples from each plot and placing them in soil cans. These samples were then weighed to the nearest tenth of a gram, dried in a drying oven at 105 degrees Celsius for 24 hours, and then weighed again. The difference in weight is accounted for by the amount of water in these samples. From these weight measurements the percent moisture can be determined.

Measurement of Plant Growth Once every two to three weeks I took measurements to the nearest millimeter of the plant height, measuring from the base of the plant to the highest point. Sticks with marks on them, showing the level of the soil at the base of the plants were placed next to each plant to assure that the base measurement was from the same point. Given the time, I took a total of four measurements for each plant between the months of February and April 2007. In addition to this I recorded any mortality that occurred.

Statistical Analysis Using the data collected I compared average rates of growth of the two species under the varying canopy and soil conditions using an ANOVA and an all pairs Tukey test to see if there were any significant differences between the plots in JMP IN Version 5.1.2.

Results

Two species of plants, sticky monkey flower and California coffee berry, were planted in varying soil and canopy cover conditions in February 2007. A total of four height measurements were taken between February and April 2007, but due to problems with soil shifting and therefore inaccurate measuring before the implementation of the sticks that marked the base measurement point, only the last two measurements were used in analysis.

The soil pH, soil moisture and average rate of growth for each of the species was calculated (Table 1).

Table 1. Average growth for plant species under varying canopy and soil conditions.

% Canopy Cover	Soil pH	Soil Moisture (by weight)	Growth ± SE (mm/week)	Growth ± SE (mm/week)
			Sticky monkey flower	Coffee berry
35	5.5	2.3%	2.6 ± 0.30 (n=20)	1.02 ± 0.21 (n=22)
50	6.5	4.5%	1.77 ± 0.26 (n=24)	0.68 ± 0.20 (n=21)
80	6.75	10.6%	3.73 ± 0.49 (n=24)	3.08 ± 0.27 (n=24)

Soil texture was found to be the same for the soil in all three plots and is classified as sandy loam. The three separate soil samples tested for each plot all had the same pH, so did not need to be averaged, suggesting that the plot size was small enough to have uniform pH throughout. After drying the samples used for soil moisture, I calculated the average soil moisture percentage by weight from the three samples for each plot.

Using an ANOVA and an all pairs Tukey test, I tested to see if there was a significant difference in growth between the three plots for each of the species. For the coffee berry there was a significant difference ($p<0.05$) between the 35 and 80 percent canopy cover, as well as the 50 and 80 percent, but not the 35 and 50. For the sticky monkey flower there was a significant difference ($p<0.05$) between 50 and 80 percent, but not the 35 and 50, or the 35 and 80 percent canopy cover as can be seen in the following two figures.

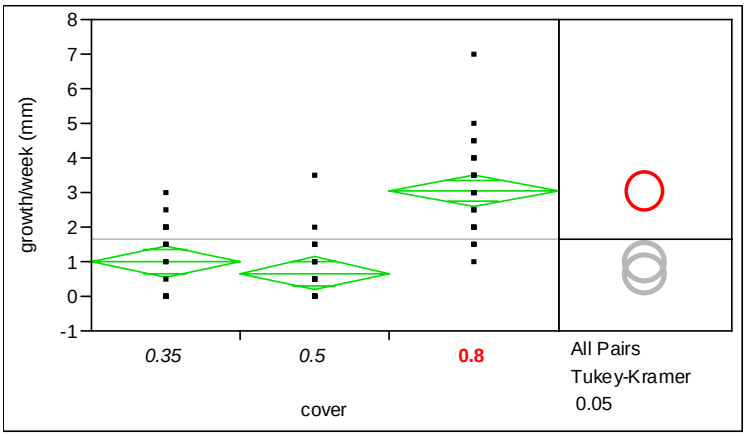

Figure 3. ANOVA and Tukey test results for coffee berry.

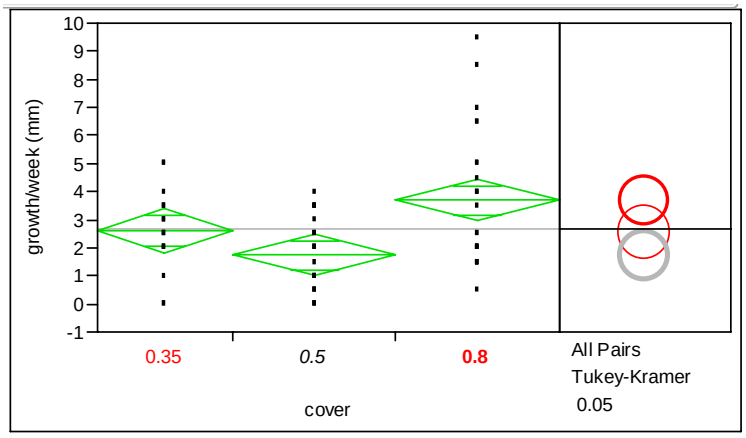

Figure 4. ANOVA and Tukey test results for sticky monkey flower.

In addition to growth I recorded mortality. At the end of the experiment in April, two of the coffee berry plants had died in each of the 35 and 50 percent canopy cover plots, and five of the sticky monkey flower plants died in the 35 percent plot. I found that mortality was significant in the three plots using a chi-square test ($p<0.01$).

Discussion

The restoration project at Lands End is different from most restoration projects that are studied since the goals are not to create an ecosystem that resembles the one that was at the site before human presence. Instead its goals include supporting the history of the site by keeping the Monterey Cypress forest as well native values by removing invasive species and replacing them with native local species. With the increased amount of urban environment, this type of

restoration project will probably become more common as a way to make a compromise between human needs and activities as well as the needs of native plant and wildlife. The results found from this experiment can be used for future phases of this particular restoration project and maybe can be used as a comparison for other restoration projects that are a part of a similar situation in which human and native values compete.

The results found from this experiment suggest that variation in canopy cover and soil conditions have a significant effect on both the California coffee berry and sticky monkey flower. Both plants had the highest rate of growth under the 80% canopy cover, followed by the 35%, and then 50%. In addition to having higher rate of growth under the 80% canopy cover, the plants overall appeared healthier, with more new growth and fuller bodies. Very few of the plants appeared wilted or sickly as they did in the other plots. Where one might expect the plants under the denser canopy cover would have more outward growth as they try to reach areas with more sunlight, this did not seem to be the case in this study, as the plants grew the tallest in this plot. I was not able to quantify the fullness of the body, and it would be an interesting follow up study to see if the plants in the 80% canopy cover had the greatest vertical growth as well as horizontal, or if the plants in the other plots had greater horizontal growth. From just a visual inspection, the plants in the 80% cover appeared to have grown the most in both directions. Since the results did not show that the plants grew at an increasing rate as the canopy cover increased (i.e. 35%<50%<80%), they suggest that it was more than just the amount of light reaching the plants through the canopy that affected their growth.

Looking at soil pH values, the plant growths, as with the level of canopy cover, do not increase with increasing pH. It might be that the low pH in the 35% canopy cover plot was a contributing factor in the higher number of mortalities, with the sticky monkey flower being affected more (5 plants died, as opposed to the 2 coffee berry). These results also suggest that there are more factors than just pH and canopy cover that have an effect on the plant growth rates of the sticky monkey flower and coffee berry.

Another possibility is that the level of soil moisture was the main cause in the difference in growth rates. The 80% canopy cover plot also had the highest soil moisture, which I suspect might have had a large effect on the growth rate since this was a fairly dry year. But as with canopy cover and pH, the growth rate does not increase with increasing soil moisture, with the 35% and 50% canopy cover plants being in reverse order.

This reverse order seen in each of the variables: canopy cover, soil pH, and soil moisture might have had something to do with the high number of mortalities in the 35% cover plot since it reduced the number of samples to be averaged. Perhaps if more of the plants had lived, the growth rate would have shown lower than the 50% canopy cover. Other possibilities might be that there are over factors that affected the growth like soil nutrient levels or the level of protection from wind.

Given the data, it is impossible to know which one factor, if any, had the greatest effect on plant growth. A major factor that cannot be satisfactorily assessed in terms of this experiment is time. Although there were significant differences between some of the plots in plant growth, these differences might change or disappear as time goes on. For example, if soil moisture has had the greatest effect on plant growth so far, the summer months when the weather is drier, might produce different results. For instance, given that all the soil will be drier, the amount of light coming through the canopy might have a larger affect on growth, and the plot with the most open canopy might be exposed to too much sun causing stunted growth or mortality.

Assuming that the main interest in terms of the plants in the Lands End restoration project is survival, my results show that all the conditions produced positive growth and low rates of mortality. The sticky monkey flower seemed to be less hardy given that it had higher mortality numbers and so perhaps if choosing sites, the ones with a fuller canopy cover and higher soil pH and moisture should be given to it over the coffee berry. But just in terms of survival all plots faired well, at least in the timeframe of my project.

I would have expected the plot with the highest mortality to also be the plot with the lowest growth rate, but in this experiment, the results did not show that. The lack of continuity between growth rate and canopy cover or soil pH might suggest that no one factor has the largest effect on growth rate and survival at all times, and that different combinations of factors could produce very different results.

Two interesting follow up experiments could be to test the soil conditions at other locations at the Lands End site to see if soil pH and moisture are always equated with certain levels of canopy cover or if it varies. It would also be interesting to separate the different factors—canopy cover, soil pH, and soil moisture in a lab setting to see if one of the factors outweighs the others in terms of effect on growth.

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