Relative growth of *Ribes sanguineum* (pink-flowering currant) in context of novel ecosystem and habitat restoration at restoration sites in Mount Sutro, San Francisco

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ABSTRACT

Novel ecosystems are areas where ecological processes have been substantially altered by global human activity. This includes transport of species to areas where it never existed before, making them exotic. In many areas, invasive exotic species created competition with the native species that could disturb the ecosystem function and biodiversity it supports. As a respond to this degrading change, humans thus play an important role in regulating the types and rates of ecosystem change through restoration ecology. Restoring an ecosystem to its historical composition of native species is thought to be the most effective method to reverse the change. Restoring novel ecosystems, however, requires careful consideration of how conditions have changed ecologically and the socio-economic constraints that limit planning and priorities. To bridge the novelty and efforts in restoration ecology, this study aims to address questions related to ecological effect of restoration efforts on growth of a native shrub species pink-flowering currant (*Ribes sanguineum var. glutinosum*) at restoration sites in an urban forest. I determined relative growth rates of existing *R. sanguineum* plants in Mount Sutro, San Francisco, and assessed the rates in correlation to canopy density, litter accumulation, and proximity to the nearest trail. I found that canopy density is correlated to the growth of *R. sanguineum* across different restoration sites, while litter accumulation and nearby trails had no significant effect on the growth rates. These results suggest that restoration priorities need to consider canopy cover treatment or relocating sites to improve restoration outcomes and maximize native plants' growth potential.

KEYWORDS

biodiversity conservation, invasive species, urban forest, ecological impact, native vegetation

INTRODUCTION

In urban forests across the globe, trees and vegetation play an important role in storing carbon, enhancing biodiversity, and providing numerous ecosystem services that support the wellbeing of urban dwellers (Pesola et al. 2017). Maintaining natural regeneration dynamics is crucial for the purposes of education, research, biodiversity, and recreational value in urban environments (Lehvävirta et al. 2014). Urban environments are characterized by continuous and repeated anthropogenic impacts which may affect the regeneration of native species in urban forests (Tonnesen and Ebersole 1997), yet the potential costs and benefits associated with ecological management of both vegetation and ecosystem properties in urban forests are highly case-specific and not always well understood.

The implications of the spread of non-native species via invasion are growing in importance globally (Mascaro et al. 2012). With the increasing human activity and transport, species from different parts of the world are dominating areas where they never existed before. As result, novel ecosystems such as urban forests are emerging, where ecological processes have been substantially altered by humans. Invasion of introduced species in urban forests, amplified by residential use and climate change, has caused significant decline of ecosystem structural complexity (Perring et al. 2013), specifically at ground level, where most native shrubs and understory species that support biodiversity dwell. Compared to native plant species, invasive plants tend toward greater carbon acquisition and faster growth rates which are associated with greater rates of nutrient uptake and larger aboveground biomass (Ehrenfeld 2003). Invasive species negatively affect richness, density, growth, and fecundity of native species. Consequently, a better understanding of the consequences of biological invasions and the removal of exotics is further needed.

Among the most widely distributed invasive species in forest ecosystems are Tasmanian blue-gum eucalyptus (*Eucalyptus globulus* Labill) and acacia (*Acacia melanoxylon* L.) (Arán et al. 2013). Indigenous to Australia, both eucalyptus and acacia were initially propagated in Northern California urban areas to meet the needs of firewood, timber, and medicinal crops (Babu and Kandasamy 1997). Over time, continuous planting of invasive tree species affect population dynamics which results in soil degradation due to deleterious secondary compound produced by the litter and loss of overall productivity (Zhang and Fu 2009). Dense urban forests also resulted in over shading in natural communities which could potentially limit understory plant performance (Valladares and Niinemets 2008). Understanding impacts of invasive trees is further needed to assess broader impacts for changes in ecosystem functioning and restoration planning, particularly in Northern California urban forest setting where eucalyptus and acacia are valued highly.

Recognizing the limitations on restoration due to ecological change, scarce resources, and socio-economic constraints is important for planning and setting priorities (Perring et al. 2013). In the past, conserving and restoring ecosystems were focused on returning degraded sites to pre-disturbance condition by planting native plants (Murcia et al. 2014). However, retaining strict fidelity to historical species composition as the basis for restoration goals in a time of environmental flux overlooks the possibility that novel ecosystems may provide opportunities for biodiversity conservation and ecosystem service provision (Hobbs et al. 2009). In this era of novelty, it seems important to consider carefully the framework of ecological restoration and contribution to biodiversity conservation in an era of global change, and the role Northern California urban forest plays in questioning where and when to implement these opportunities.

To assess restoration efforts made in novel ecosystem such as urban forests, this study aims to address two questions related to native species succession in response to the exotic species ecology of urban forests in Northern California. How does native shrub species pink-flowering currant (*Ribes sanguineum var. glutinosum*) relative growth rates compare at restoration sites in an urban forest? How do existing native species growth properties (height and leaf count) compare with various invasive trees' density and proximity to hiking trail? To answer these questions, I quantified the impacts of tree litter and canopy density of a temperate urban forest 5 months following the initial observations on *R. sanguineum* sample. I hypothesized that the dynamics of leaf litter mixed in the soil, shade cover, and anthropogenic factors would lower the rate of growth of *R. sanguineum* through observations of leaf count and height. To test this hypothesis, I compared the quantity and quality of *R. sanguineum* leaf count and height between restoration sites with various eucalyptus and acacia density and trails in close proximity.

METHODS

Study site

This study is focused on restoration sites across Mount Sutro Open Space Reserve, which is part of San Francisco's fog belt (37°45′33.19″N 122°27′26.03″W) near the geographical center of San Francisco, California. There are 20 restoration sites managed by Sutro Stewards, a volunteer-based non-governmental organization (NGO) that focuses on habitat restoration in Mount Sutro (Figure 1). The 61-acre reserve is surrounded by University of California, San Francisco Medical Center to the north/northwest and by urban residential neighborhoods to the south, east, and west with over 5.5 miles of multi-use trail built and cared predominantly by volunteers (UCSF Campus Planning). The reserve is dominated (82%) by Tasmanian blue gum eucalyptus and other tree species including blackwood acacia, Monterey pine, Monterey cypress, and coast redwood, while the understory is thick with Himalayan blackberry, English and cape ivy, and other non-native and native shrubs and vines (UCSF Campus Planning).

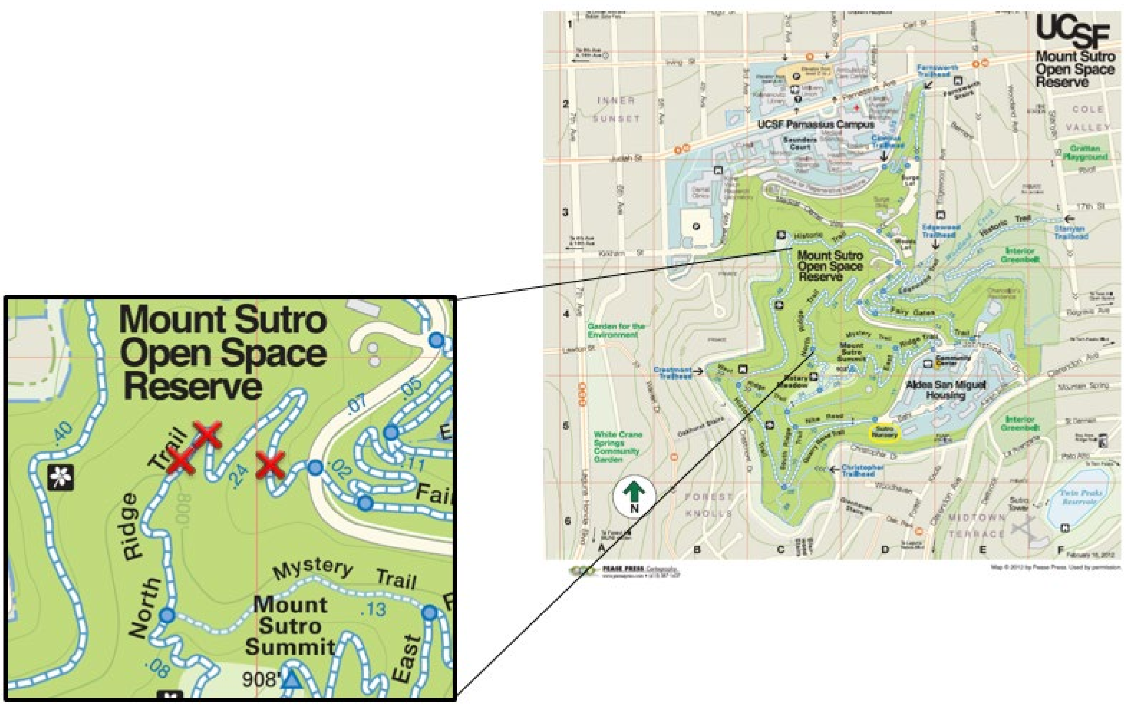

Figure 1. Mount Sutro Trail Map developed by Sutro Stewards. With a 900-foot elevation gain, Mount Sutro's multi-trails cater year-round to hikers, trail runners, dogs on leash and cyclists. UCSF is committed to maintaining the Reserve as a safe and accessible resource that residents and visitors can enjoy (Source: https://www.sutrostewards.org/trail-map).

I selected three major restoration sites located at the North Ridge Trail (NRT), namely Above Realignment, Realignment Switchback, and Realignment "Wet" Area. Restoration was initiated at these sites in 2015 and have no historically existing *R. sanguineum.* The plants on these sites were about the same age and size and were easily quantified compared to other sites with naturally growing *R. sanguineum*. The Above Realignment is located near the summit of Mount Sutro with approximate diameter of 11 meter. 8 native plant species (wood strawberry, Douglas iris, sword fern, bee plant, fringe cup) were planted by Sutro Stewards as part of their restoration project beginning in early 2015. Acacia is the most dominant invasive tree species in the Above Realignment area, with only one eucalyptus stand that grows to the northwest of the site. The existing *R. sanguineum* were planted on the northern edges of the site next to hiking trail. This 60-inch wide hiking trail separates Above Realignment with Realignment Switchback, which has the greatest slope out of the three restoration sites. Aside from 6 eucalyptus stands and 4 acacias that grow on the site, there are 7 different native plant species (yerba buena, Douglas iris, California polypody, sword fern, bee plant, fringe cup) that were planted by Sutro Stewards.

Lastly, Realignment "Wet" Area is located at lower elevation in NRT compared to the two other sites, with approximate diameter of 4 meter and is half-circle shaped. This site is separated from hiking trail with logs and rocks and has small waterways that runs through the southern inner corner of the site. Realignment "Wet" Area has the most abundant restored native plants, totaling of 13 different species (Nootka reed grass, wood strawberry, Douglas iris, blue rush, seep monkey flower, osoberry, water parsley, California polypody, sword fern, red elderberry bee plant, wood mint, fringe cup). Around 7 eucalyptus stands grow at the edges of the restoration site and next to adjacent hiking trail, with no existing acacia tree in proximity to the site.

Data Collection

I took samples of native shrub *R. sanguineum* that were estimated to be about 1-year-old based on Sutro Steward's inventory (Table 1). *R. sanguineum* lives on foothills, riparian, open space, and sloped, and is shade tolerant which is suitable for Mount Sutro habitat. The plant typically blooms from early in January to March, and houses various wildlife such as native bees, hummingbirds, and butterflies *Lycaena arota*, *Polygonia gracilis*, and *Polygonia oreas*. In

Mount Sutro, *R. sanguineum* grows naturally in different parts of the area and is part of Sutro Stewards' main restoration project for its capability to thrive in Mount Sutro's terrain and climate, and the ecological benefit it provides for important wildlife.

Table 1. *R. sanguineum* Sutro Planting at North Ridge Trail. The plants were planted over the course of winter in 2015-2016 from seedlings propagated in Sutro Nursery on 4 inch-sized pots. These sites have no historically existing *R. sanguineum* prior to being planted by Sutro Stewards.

Location	**Date Planted**	**Total Abundance 4"**
North Ridge Trail: Above Realignment	9/16/2015	12
North Ridge Trail: Realignment Switchback	12/9/2015	3
	1/27/2015	5
	1/16/2016	4
North Ridge Trail: Realignment "Wet" Area	12/5/2015	6

To assess the relative growth rates of each *R. sanguineum*, I took measurements for leaf count and height of the existing individuals at the restoration sites. To count the leaves, I considered any leaf that had fully emerged from their buds a mature leaf shape (palmately 3–5-lobed) and I excluded any leaf that have lost more than 50% of its shape and was more than 50% browning. I measured the height of each plant from its base to the top crown using tape measure. The length between the initial data collection and the last round is 5 months, starting in November 2016 and finishing March 2017.

I assessed the correlation between *R. sanguineum* relative growth rates and three ecological factors; shading, the accumulation of litter from surrounding invasive trees, and proximity to trail. I measured the canopy density above each plant at the NRT restoration sites. Considering that restoration sites in this study are located in an evergreen eucalyptus plantation, the percentage of canopy cover will be roughly similar throughout this study. I took the canopy density measurement using a densiometer in February 2017. I first assumed equi-spaced dots in each square of the grid area on the densiometer (Figure 2), such that each square is sub-divided mentally into 4 smaller squares (1/8" × 1/8"). Each dot is assumed to represent one percent of canopy density (Lemmon 1956). I calculated the exact percentage canopy cover value by multiplying the dot counts equivalent to canopy cover by 1.04 ($1.04 \times 96 \approx 100$). I recorded four readings – facing North, East, South, and West over each plant and averaged the percentages.

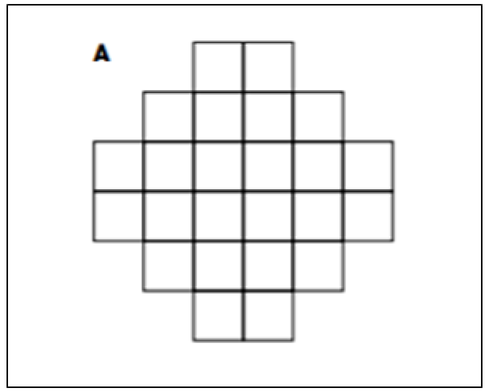

Figure 2. Cross-shaped grid scratched on the convex surface of the mirror to delineate a plot overhead. Each square is 1/4 inch on a side (Lemmon 1956). A leveling bubble is also included for accurate positioning. Convex surface was slightly offset when used to avoid blocking on the grid by head.

For litter depth assessment, I assumed that the depth of litter was homogenous 3 inches out from each base root. I measured the depth within that range using a centimeter ruler and took one measurement for each plant. At North Ridge Trail restoration sites, the litter is mainly composed of eucalyptus and acacia leaf, bark, and pods.

In addition to canopy density and litter depth assessment, I analyzed each plant's proximity to trails at each restoration site. Since foot and bike traffic in the trail system that increases soil compaction might result in changes of interior conditions and consequent disruptions in soil structure which may have and influence on plants (Lehvävirta et al. 2014), I measured the distance from each plant to the nearest trail. I estimated the width of the trail perpendicular to each plant, and took the middle point to measure the distance from using tape measurement. The restoration sites are intended to be accessible by volunteers, thus the inventoried *R. sanguineum* in this study are particularly close to North Ridge Trail.

Statistical analyses

To calculate the relative growth rates of *R. sanguineum*, I took the difference between the final and the initial leaf count for each plant, then divided it by the sum. Similarly, I calculated the relative growth measured from the plant's height using the same equation as the leaf count calculation. I ran ANOVA tests to assess the difference between relative growth rates at selected restoration sites. I repeated the same test to evaluate any significant difference for canopy density, litter accumulation, and proximity to trail data at different restoration sites. I conducted all statistical analyses in this study using R commander in R studio. To determine explicit difference between the means of relative growth rates at different restoration sites I ran Tukey's honest significant difference test (Tukey's HSD) as a post-hoc analysis.

To determine the relationship between relative growth rates of *R. sanguineum* and the three ecological factors, I conducted multiple linear regression analyses by setting the relative growth rates as response variable and each of the three ecological factors (canopy density, litter accumulation, and proximity to trail) as explanatory variable using R commander.

RESULTS

Analyses of relative growth

I found that the relative growth rates of *R. sanguineum* between three restoration sites were significantly different based on both leaf count and height data (P = 0.0253, F = 4.147). The measurements using leaf count showed greater growth rates at Realignment "Wet" Area (mean = 0.548, SD = 0.153) compared to Realignment Switchback (mean = 0.303, SD = 0.305) and Above Realignment (mean = 0.359, SD = 0.170)

Similarly, the growth rates measured using height data is the greatest at Realignment "Wet" Area (mean = 0.266, SD = 0.156) compared to Realignment Switchback (mean = 0.088, SD = 0.117) and Above Realignment (mean = 0.132, SD = 0.084) (Figure 4). The height data growth rates also differed significantly (P = 0.004, F = 6.718). It follows that using Tukey's post-hoc analyses, *R. sanguineum* plants at Realignment Switchback showed significantly different growth rates compared to those at Realignment "Wet" Area based on both leaf count and height measurements.

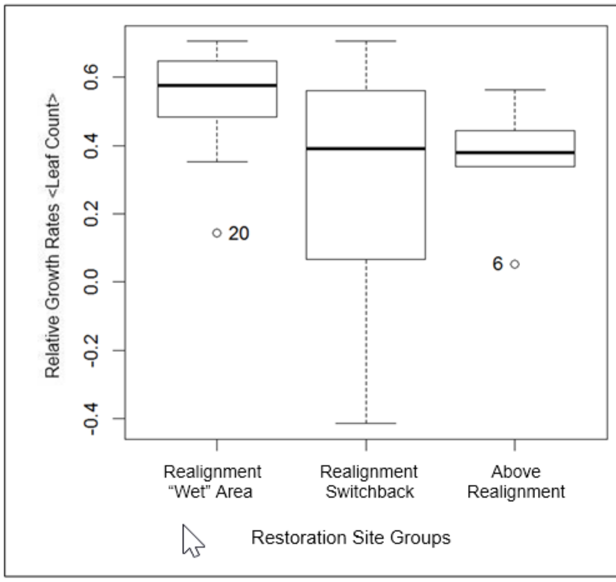

Figure 3. Relative growth of *R. sanguineum* from leaf count data at different restoration sites.

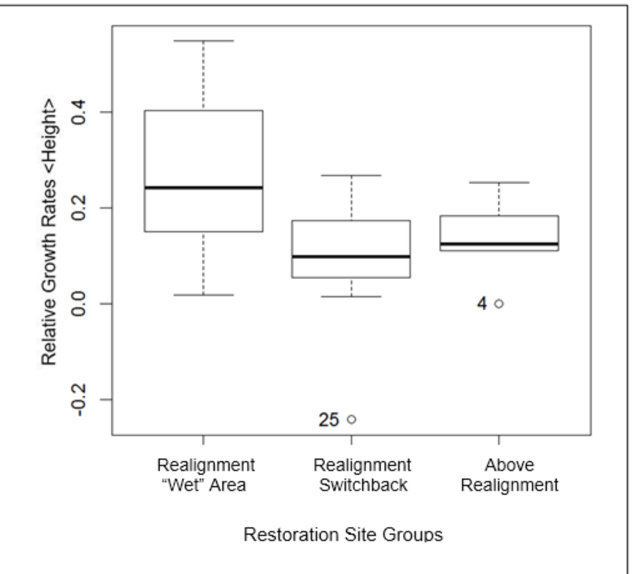

Figure 4. Relative growth of *R. sanguineum* from height data at different restoration sites.

Canopy density assessment

Canopy at different restoration sites differed strongly in their percentage cover over sampled *R. sanguinemum* plants ($P < 0.001$, $F = 29.03$), regardless of the tree species that existed at each site. The percentage cover at Realignment "Wet" Area was the smallest (mean = 56.11%, SD = 6.461) while the percentage cover at Realignment Switchback (mean = 70.23%, SD = 3.836) and Above Realignment (mean = 68.43%, SD = 4.125) the percentage covers were relatively closer (Figure 5). Further test using Tukey's HSD yielded significant differences in percentage cover between Realignment "Wet" Area and Realignment Switchback, as well as between Realignment "Wet" Area and Above Realignment. I found a significant correlation between relative growth rates and canopy density using linear regression analyses (P leaf count = 0.0458, $R^2 = 0.0468$; P height < 0.001, $R^2 = 0.285$).

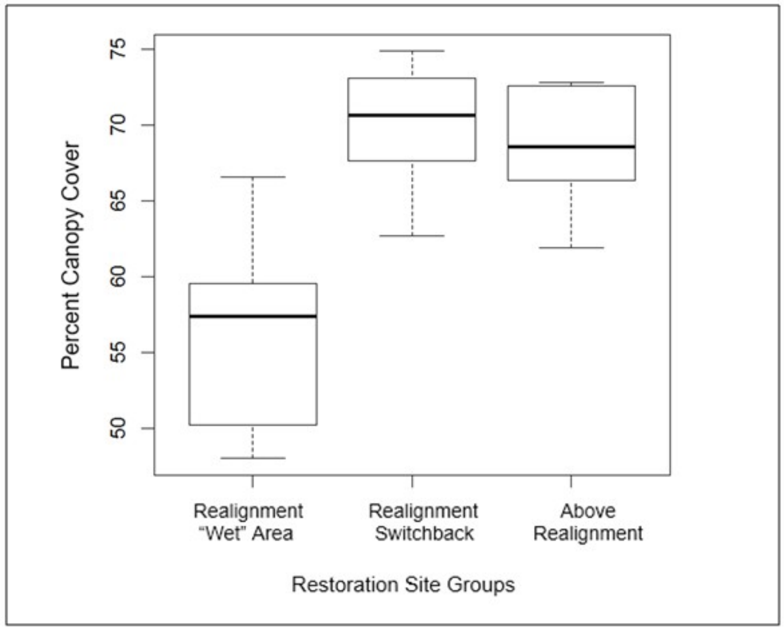

Figure 5. Canopy density at different restoration sites. The differences between the number of different tree species were not considered in this study. The trees were located either inside or outside the restoration sites in proximity to the sampled *R. sanguineum.*

Litter depth assessment

The accumulation of litter is approximately similar between Realignment "Wet" Area (mean = 3.29 cm, SD = 1.59 cm), Realignment Switchback (mean = 3.21 cm, SD = 1.36 cm), and Above Realignment (mean = 3.00 cm, SD = 0.89 cm) (Figure 6) despite the difference in number of trees at each site. Further test using linear regression analyses showed that litter depth had no significant relationship with relative growth rates of *R. sanguineum* (*P* leaf count = 0.9648, *P* height = 0.4025).

Figure 6. Average litter depth at different restoration sites. Litter represents leaves, barks, and other dead vegetation with a distinguishable structure from undecomposed or partially decomposed stems, roots, and leaves that accumulates on top of mineral soil ("Forest Inventory and Analysis National Program - FIA Library" n.d.).

Distance to trail assessment

According to the mean distance between each plant to the nearest trail, *R. sanguineum* plants at Realignment "Wet" Area is in greatest proximity to trail (mean = 68.71 in, SD = 43.92 in) compared to Realignment Switchback (mean = 113.14 in, SD = 43.04 in) and Above Realignment (mean = 107.67 in, SD = 34.75 in). There was a significant difference between the three proximity to trails ($P = 0.0206$). In addition, I plotted distance from trail in correlation to *R. sanguineum* relative growth rates (Figure 7) and calculated the R^2 for trendlines that represent distance distributions at different restoration sites. The Realignment "Wet" Area showed significantly smaller negative correlation ($R^2 = 0.0367$) compared to Realignment Switchback ($R^2 = 0.1207$) and Above Realignment ($R^2 = 0.2048$).

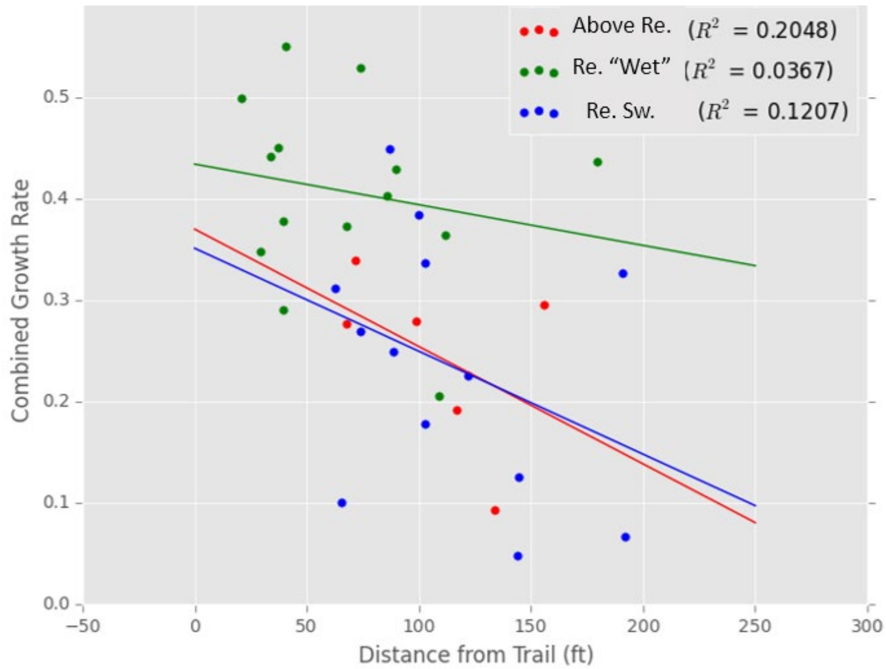

Figure 7. The effects of *R. sanguineum* proximity to trail on growth rates. The combined growth rate were the averages of leaf count and height growth rates of each sample, then plotted in correlation to distance to trail of the respective sample.

DISCUSSION

My results indicate that the relative growth rates of *R. sanguineum* are different across restoration sites in Mount Sutro. I found canopy density of invasive trees to affect relative growth rates of *R. sanguineum* in the restoration sites, with site Realignment "Wet" Area relative growth means that were significantly different from other sites. Compared to Realignment Switchback and Above Realignment, Realignment "Wet" Area growth rates were higher and the percentage of canopy cover lower, and these were significantly correlated to each other based on linear regression analyses. Other independent variables studied, however, did not seem to affect the native shrub's growth rates. Linear regression analyses of litter accumulation and growth rates did not show significant correlation, contrary to the presumed deleterious effects of invasive trees litter on soil. Similarly, plants that were placed in proximity to trail across different restoration sites did not seem to affect *R. sanguineum* growth rates. The varying outcomes of native species growth rates in response to presence of invasive species and anthropogenic factor at restoration sites in Mount Sutro can potentially redirect restoration efforts and future managements for bettering the ecological impacts.

Canopy density

Overstory gaps that affect canopy density are created by mature tree mortality, which allows for the establishment of seedlings in the understory, enhancing their growth, and providing other trees adequate space to develop larger sizes in old-growth stands (Gray et al. 2012). I found that the differences in canopy density significantly affected the plants' relative growth rates across different restoration sites. The low invasive trees' canopy density at Realignment "Wet" Area was correlated to higher relative growth rates of *R. sanguineum* in the same site. In contrast, the canopy densities in Realignment Switchback and Above Realignment, which were greater than that in Realignment "Wet" Area, likely lowered the native shrub's relative growth rates at the two sites.

Reductions in canopy density of blue gum eucalyptus in the area have been extensive due to pests such as long-horned borer (*Phoracantha* spp.), snout beetle (*Gnipterus scutellatus*), and tortoise beetle (*Trachymela sloanei)* (Draft Vegetation Management Plant). Conditions of monoculture and extended drought over the past years further exacerbate the stressors, which under normal circumstances would not have been significant. The reduced eucalyptus canopy was present at the Realignment "Wet" Area, where eucalyptus the dominant invasive tree. The canopy cover was denser at Realignment Switchback and Above Realignment because there were several acacias that were not attacked by the pests that were also present at the sites, along with a few eucalyptus stands. While open canopies from unhealthy eucalyptus allow for good growing conditions for species at the understory, it is also important to note that with declining eucalyptus health overtime, it could also affect the health of vegetation and habitat for wildlife, as well as potential fire hazard posed by availability of fuels from both dead standing and downed materials.

Leaf litter accumulation

The three restorations sites at Mount Sutro, which were managed as natural environments with no treatments on litter, accumulated similar amount of litter across restoration sites. I expected greater accumulation of litter to result in lower growth rates of the native shrub. Based on the statistical analyses, however, I found that the relative growth of *R. sanguineum* was not correlated with the amount of litter accumulated.

Litter can reduce plant establishment in many ways: shading, change in soil moisture, availability of nutrients, and phytotoxins from litter decomposition (Facelli and Pickett 1991). The effect of leaf litter is not always negative; in some cases nutrients obtained from leaf litter can improve seedlings growth and reduce the establishment and survival of invasive species in old-growth forests (Brearley et al. 2003, Bartuszevige et al. 2007). In this study, however, the accumulation of litter is similar throughout all study sites, thus the litter effects are likely less prevalent on the cumulative growth rates compared to the individual rates.

Proximity to trail

Urban forests are used for a variety of activities, including recreation, exercise, play and shortcuts (Lehvävirta et al. 2014). Mount Sutro with its frequent hikers, bikers, and volunteers all year-long is highly vulnerable to damages caused by trampling and fragmentation, which might reduce plant cover and damage plant growth by creating extensive path networks. Based on my results, however, there is no statistically significant relationship between relative growth of *R. sanguineum* over three different sites with different proximity to trail. This is contrary to my expectation, where the closer the plants to trails, the more susceptible they are to damages caused by trampling.

The trendlines from plotted correlation between distance to trail and *R. sanguineum* growth rates showed slight trend of negative correlation, where the greater the distance or the more distant the plant from hiking trail, the lower the growth rates. These trends might suggest that frequent uses of hiking trail could contribute in planting seeds by ensuring good seed-to-soil contact, breaking soil crusts, pruning plants to keep them productive, knocking down weeds, mulching the soil that are prone to erosion due to steep slopes and unlevel surface, and fertilizing the soil (Animal impact n.d.). Grasslands, which is a combination of both intensively managed and undisturbed area, also inhibit these characteristics that are maintained by grazing animals. Because the R^2 values and linear regression analyses have proven neither significance on growth rates of *R. sanguineum*, it is still unknown whether the anthropogenic effects in association to trampling and fragmentation at Mount Sutro hiking trail might affect plant establishment and growth in proximity to the trails.

Limitation and ecological implications

One major limitation of my study design is that there are only limited number of sample that I used for the purposes of this project, which might contribute to confounding in my results. Restoration efforts made by Sutro Stewards have been carried out by volunteers over the years and there are only enough resources and ongoing restoration treatments that I could use as my study subject.

I measured the plants over the course of winter season and early spring, which might be another significant constraint considering that weather and temperature affect plant growth differently. *R. sanguineum* at the restoration sites were planted at around the same time and did not develop until mature age at the end of my study, which might be another factor that I needed to exclude in this study.

Conclusion

Based on my study, invasive trees' canopy density appears to be the greater determinant of *R. sanguineum* growth rates compared to both litter accumulation and proximity to trail. Although there may be other factors that could affect the establishment of this species in Mount Sutro, my study implies that restoration efforts to rehabilitate *R. sanguineum* need further assessment in terms of canopy cover treatment to increase its growth potential, but without as much concern on litter nor distance to trail. One suggestion would be to prioritize restoration efforts on sites where the canopy density is lower, or to crown-thinning as opposed to stand thinning, especially in areas near the summit where canopy density is greater than that at lower elevation.

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