Algerian Ivy Removal Techniques along a Riparian Zone in Berkeley, California

Lindsey Sanders

ABSTRACT

Algerian ivy is an invasive vine not native to Berkeley, California which limits native plant biodiversity. In this study I examined three removal techniques for managing Algerian ivy: manual removal, foliar herbicide application, and cut-stem herbicide application. I hypothesized that cut-stem herbicide application would be the most effective removal technique and that herbicide application would not affect native seedling growth. I measured plots monthly for ivy and native seedling growth and analyzed results using a Random Complete Block Design, Tukey-Kramer analysis, and Simpson's Diversity Index (SDI). I found no significant difference in ivy re-growth between plots, and no significant difference in native seedling growth between plots. I found that manual removal plots had an SDI double that of other treatments (0.7652). Based on these results I recommend that further use of herbicides be ceased until investigations into the effects of herbicide on native plant diversity have been completed.

KEYWORDS

Invasive species, Strawberry Creek, restoration, glyphosate, species diversity.

INTRODUCTION

Non-native invasive plants are the second largest threat worldwide to native plant biological diversity (Scott and Wilcove 1998). Successful invaders have a high reproductive capacity and rapid growth rate, often reproducing asexually and multiple times throughout the year (Cain et al 2008). A lack of natural restraints and a generalist strategy affords many invasive species a competitive advantage (Cain et al 2008). Invasive species typically enter communities after large disturbances such as floods and droughts, which disrupt ecosystem dynamics, and establish themselves before native species can recover (Roques et al 2001). Once established, invasive plants cause a number of negative effects, include blocking sunlight and nutrients from reaching sprouting natives (Levine et al 2003) and altering nutrient cycles, hydrology, sediment deposition, fire regimes, and erosion patterns (Bossard et al 2000). For these reasons, the removal of invasive species is common in ecosystem restoration work.

Algerian ivy (*Hedera canariensis algeriens*) is a largely invasive perennial vine native to the Canary Islands, Portugal, the Azores, and Northern Africa (Bossard et al 2000). It is classified as a weed in California with severe invasiveness, severe distribution implications, and severe impact on native plant life (CIPC 2009, USDA 2009). Like other *Hedera* ivy species, it has a high seed survival rate, rapid vegetative spread rate and high shade tolerance (Bossard et al 2000, CIPC 2009), making it a fierce competitor to many native plant populations with much lower growth rates and more fragile equilibrium conditions (Thomas 1998, Bossard et al 2000). Algerian Ivy has the ability to quickly spread into an area and form a thick ground cover, thereby blocking sunlight from other plants and limiting native seed dispersal (MacDougall 2005, Biggerstaff and Beck 2007). It is highly persistent and difficult to remove entirely once it has become established, as a result of its ability to re-sprout from small stem fragments and nodes (Bossard et al 2000). These characteristics make Algerian ivy a threat to native plants and are cause for its removal in restoration efforts.

Algerian ivy has become a problem within the nature areas on the University of California, Berkeley campus, and has been the center of recent efforts to restore these areas. Algerian ivy has overtaken much of the riparian zone along Strawberry Creek running through the campus, and can be seen climbing native trees, weakening their branches and making them more vulnerable to damage in future storms (*pers. comm., Tim Pine*). In 1969, three nature areas were established on the campus to retain wildlife habitat and provide ecological study areas for students (Unknown Author 1969). In the past decade restoration efforts focused on manual removal of invasive ivy and planting native vegetation to return the nature areas to their original state as oak woodlands (Purcell et al 2007). Despite these efforts, the areas are still largely overrun with Algerian ivy, and there are simply not sufficient funds or labor provided by the University to maintain the nature areas through manual removal (*pers. comm., Tim Pine*). For this reason, the Strawberry Creek Restoration Project is considering the use of an herbicide to inhibit Algerian ivy growth. The product under consideration is the commercially available herbicide, Round Up® Pro.

Various studies have examined the effectiveness of plant removal techniques on English ivy (*Hedera helix*) and similar low-lying woody shrubs (Derr 1993, Roques et al 2001, Biggerstaff and Beck 2007, Love and Anderson 2009). Derr (1993) found that herbicide application was most effective on English ivy in March when new growth was emerging. Biggerstaff and Beck (2007) cut the stems of English ivy before herbicide application to open the plant's pores for increased herbicide absorption during the spring and found that herbicide application greatly inhibited native plant growth. Because restoration work on the UC Berkeley campus takes place primarily during the fall and winter, evaluations of the most effective methods for ivy removal and native replanting, as in this study, need to consider these cold winter months.

In this study, I examined the potential of three techniques for riparian habitat restoration and Algerian ivy removal: (1) manual removal of ivy (2) foliar herbicide application onto green ivy leaves, and (3) cut-stem herbicide application onto freshly cut green ivy stems. I assessed the effectiveness of habitat restoration by (1) monitoring the re-growth of Algerian ivy after treatment and (2) monitoring the sprouting of native seedlings after treatment. I hypothesized that (1) herbicide application on cut stems would be the most effective method for reducing ivy growth, and (2) herbicide application would not hinder the growth of native seedlings.

METHODS

Study Sites

This study took place along both the North and South forks of Strawberry Creek on the University of California, Berkeley campus (37°52'N 122°15'W). I selected six sites along Strawberry Creek within the campus nature area riparian zones (Fig. 1). I selected similar sites to

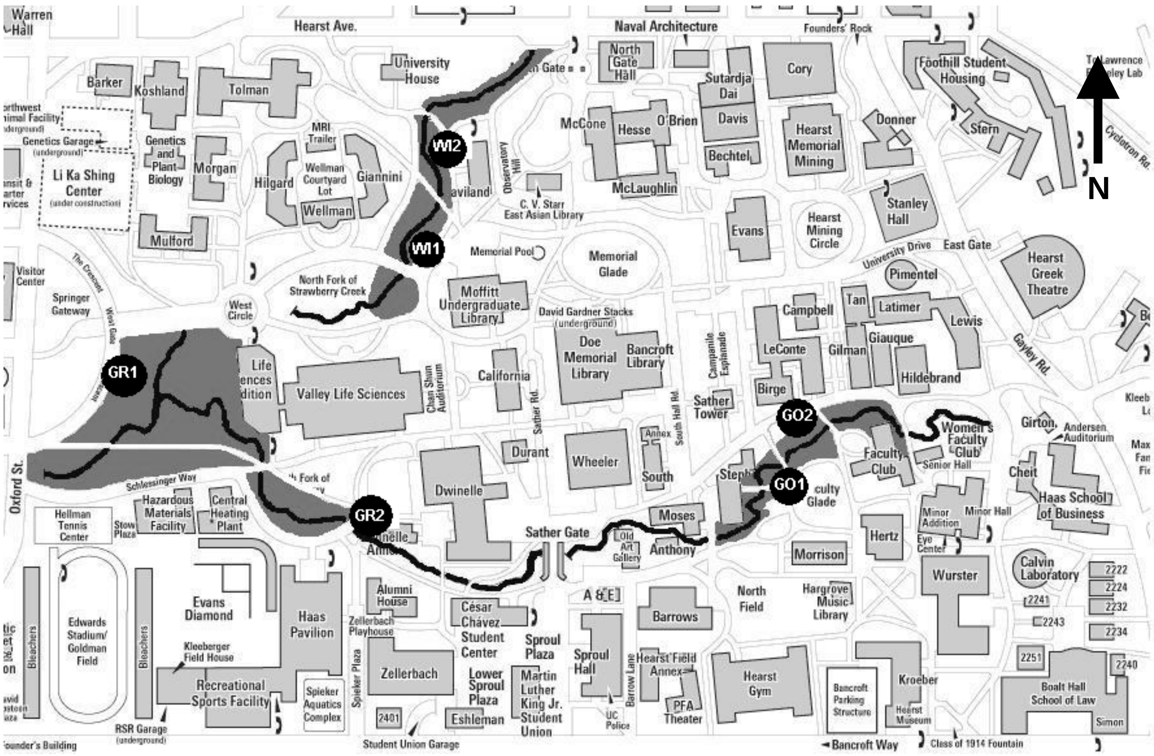

Figure 1. Study sites along Strawberry Creek on the UC Berkeley campus. Sites GR1, WI1, and WI2 were located along the North fork of Strawberry Creek. Sites GR2, GO1, and GO2 were located along the South fork of Strawberry Creek.

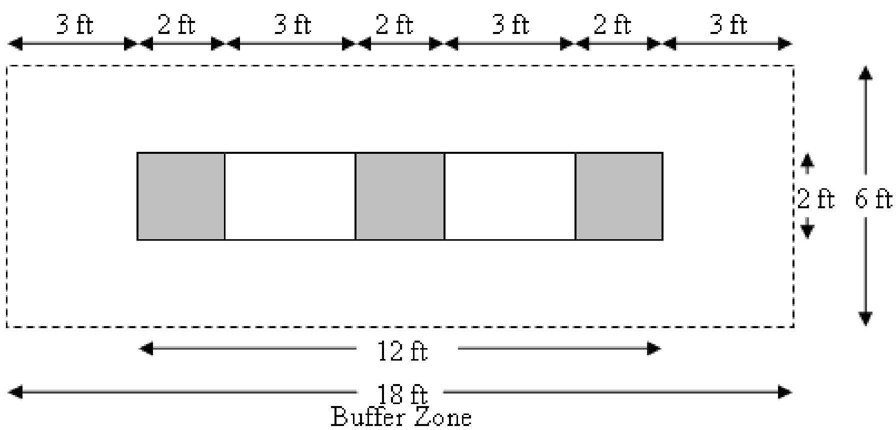

Figure 2. Plot set-up at each site. Sites: GO1, GO2, GR1, GR2, WI1, WI2. There were four treatment plots per site: control, manual removal, foliar herbicide application, and cut-stem herbicide application. Each plot had a buffer zone measuring 18ft by 6ft. Within the buffer zone three 2ft by 2ft samples (indicated here by grey blocks) were taken per plot at 3ft intervals.

control for variation in slope, vegetation cover, and sunlight availability, whereby most sites had near 0% slope, 100% vegetation cover, and low sunlight availability.

I established four plots per site measuring 6ft by 18ft (Fig. 2). I designated these plots as: control (no ivy removal), manual removal, foliar herbicide application, and cut-stem herbicide application. I arranged the plots in varying patterns to fit into study sites and thus their positioning relative to one another was not consistent. Within each plot I established a buffer zone of 2ft on all sides to minimize ivy growth from encroaching plants. This experiment took place from November 2009 to April 2010.

Herbicide

Glyphosate, the active ingredient of Round Up® Pro, is the world's leading agrochemical (Woodburn 2000). It is a broad spectrum, systemic herbicide, used both in agricultural and home garden applications and can control a wide range of weed species (Franz et al 1997, Baylis 2000, Woodburn 2000). After application, glyphosate binds strongly to soil particles preventing dispersal into groundwater (Baylis 2000). Because it remains stable in soil after application, it does not affect post-emergence plants (Franz et al 1997). Glyphosate has a short half life between 5 and 7 days, making its presence in soil relatively harmless (Perez et al 2007). Glyphosate enters surface water when bound soils are eroded into waterways, primarily during rainfall within 24 hours of application (Monsanto 2003).

Glyphosate has a unique mode of attack among herbicides, affecting the production of essential aromatic amino acids phenylalanine, tyrosine and tryptophan (Schönbrunn et al 2001). It enters the plant through open cuticles on foliage and freshly cut stems and occupies the substrate binding site for the enzyme ESPS (5-enolpyruvylshikimate 3-phosphate synthase), an enzyme on the shikimate pathway essential to the production of aromatic amino acids in plants, bacteria, algae, and fungi (Schönbrunn et al 2001). EPSP is not found in animals, which ingest aromatic amino acids in their food (Kishore and Shah 1988). For this reason glyphosate is lethal to plants, but harmless to animals.

Ivy Removal and Herbicide Application

I facilitated ivy removal for the manual removal plots at each of the six sites from November 11-17, 2009. For the manual removal treatment, I removed above-ground foliage and below-ground root systems with a group of four volunteers.

For the six cut-stem herbicide application plots, I removed ivy foliage with a weed whacker on November 12, 2009. Leaves were cut to expose fresh stems and then raked from the plot to provide better access to the freshly cut stems during herbicide application. Leaves were not raked from foliar herbicide application plots.

I applied herbicide to the plots on November 12, 2009. I applied herbicide onto foliage at each of the six foliar herbicide application plots to determine whether uptake by the old leaf cuticles was possible in November. I applied herbicide at each of the six cut-stem herbicide application plots within minutes of ivy foliage removal to allow uptake by the newly opened pores. In all cases I sprayed a solution of 8% Round Up® Pro and water onto the plots until leaves and stems were dripping.

Plant Growth

To monitor plant growth differences between treatment methods I took three samples measuring 2ft by 2ft per plot at regular intervals (Fig. 2) and recorded the approximate number of ivy leaves present, the number of native plants present, and took pictures of the sample for future calculation of percent ivy cover. I took pictures of all native plants for identification purposes. I recorded this data directly after treatments were applied, two months after treatments were applied, and once a month subsequently until April 2010. During the first two months after application there was minimal ivy growth, and vegetation cover on the plots was not expected to vary greatly, thus monthly observations were not deemed necessary.

Percent Ivy Cover

To analyze the percent ivy cover at each plot I imported the pictures from each sample into Photoshop and edited the photos to distinguish between live ivy leaves and everything else (other plants, bare soil, vines, dead leaves). I then analyzed the photos in R (R 2009) to determine what percent of the photo contained live ivy leaf. The three photos taken at each plot were assumed to be representative of the entire plot.

Data Analysis

To analyze both ivy and native plant growth, I used a Random Complete Block Design ANOVA with the three subsamples from each plot. My primary response variable was the growth rate of vegetation (of both Algerian ivy and native seedlings) and the sites served as the block. Both ivy and native plant growth results were also analyzed using a Tukey-Kramer test to compare distinct differences between each removal method. These analyses were completed in

R (R 2009). I measured native seedling diversity using the Simpson's Diversity Index: $SDI = 1 - D = 1 - \frac{\sum n(n-1)}{N(N-1)}$ where *n* is the total number of organisms of a particular species and *N* is the total number of organisms of all species.

RESULTS

Percent Ivy Cover

Prior to treatment (November 11, 2009) all plots averaged 96.4% ivy cover. After initial herbicide and manual removal treatments (December 1, 2009) manual and cut-stem herbicide application plots measured 0% ivy cover, and foliar herbicide application plots averaged 96.9% ivy cover. By February 4, 2010 all treatment plots had greatly reduced ivy presence (average C: 95.9%, F: 2.1%, M: 0.0%, S: 0.2%). New ivy growth was recorded monthly until April 8, 2010, at which time percent ivy cover at treatment plots averaged as follows (average C: 95.3%, F: 0.90%, M: 1.29%, S: 1.25%) (Fig. 3).

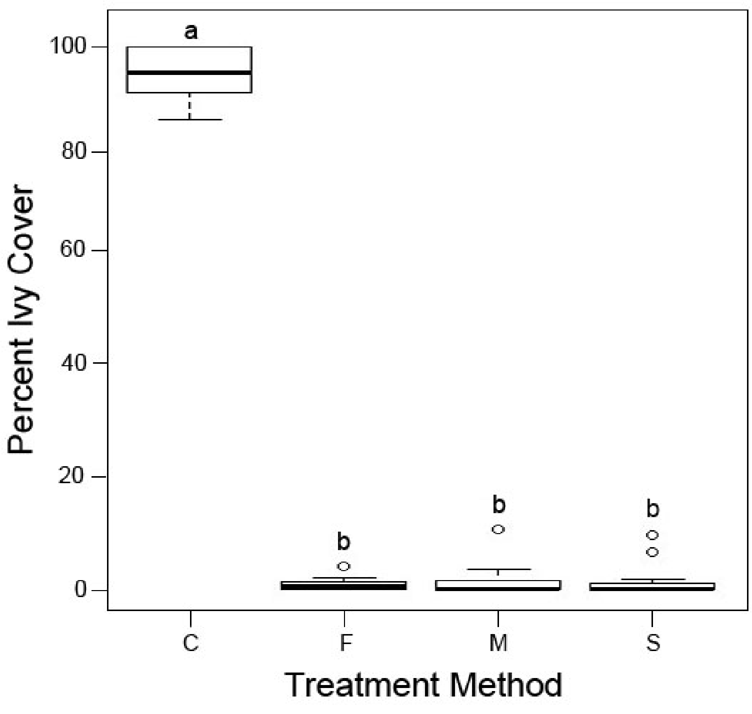

Figure 3. Boxplot of Treatment Method v. Percent Ivy Cover for April 8, 2010. The mean, 1st and 3rd quartiles, and outliers for each treatment method are presented. In this diagram: C=control, F=foliar herbicide application, M=manual removal, and S=cut-stem herbicide application. Results of the Tukey-Kramer test revealed that 'a' (control) was significantly different from 'b' (foliar herbicide, manual removal, and cut-stem herbicide treatments).

Table 1. RCBD ANOVA of final percent ivy cover and native plant growth.

		Source	df	F	P
With Control	Percent Ivy Cover	Site	5	4.5361	0.0102*
		Treatment	3	4841.7774	<0.001***
	Native Growth	Site	5	1.7585	0.1822
		Treatment	3	1.514	0.2514
Without Control	Percent Ivy Cover	Site	5	3.0780	0.0614 .
		Treatment	2	0.1261	0.8829
	Native Growth	Site	5	1.9427	0.1738
		Treatment	2	0.9564	0.4168

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1.0

After final measurements of percent ivy cover were taken on April 8, 2010, the control plots had significantly higher ivy cover than all three removal treatments ($p<0.001$) (Table 1). Tukey-Kramer analysis revealed that the control treatment was significantly different from all three other treatment methods, but none of the other treatments were significantly different from each other (Fig. 3). When the control was excluded from the analysis, no significant differences were observed between removal methods in relation to percent ivy ($p = 0.0614$) (Table 1). With control included as a treatment method, there was a significant relationship between percent ivy cover and site ($p = 0.0102$). Looking at data for individual sites this can be explained by one particular site (GO2) which had significantly higher levels of ivy re-growth than any of the other five sites.

Native Seedling Growth

Before treatments were applied (November, 11 2009) all plots had zero visible native plant growth, with two exceptions: plot GO2F (these seedlings were killed by the herbicide treatment and were no longer present after February 4, 2010) and plot GO1M (these natives were unaffected by this experiment, but were not included in native seedling counts because they never fell inside of sub-sampling quadrats). After herbicide and manual removal treatments were initially performed (December 1, 2009) a few smaller seedlings, which had been hidden by the previous dense ivy cover, were revealed at one site (plot GO2M). After February 4, 2010 native plant growth was observed sporadically within most manual removal and cut-stem herbicide plots, and some foliar herbicide plots, though none were observed in control plots (Fig. 4).

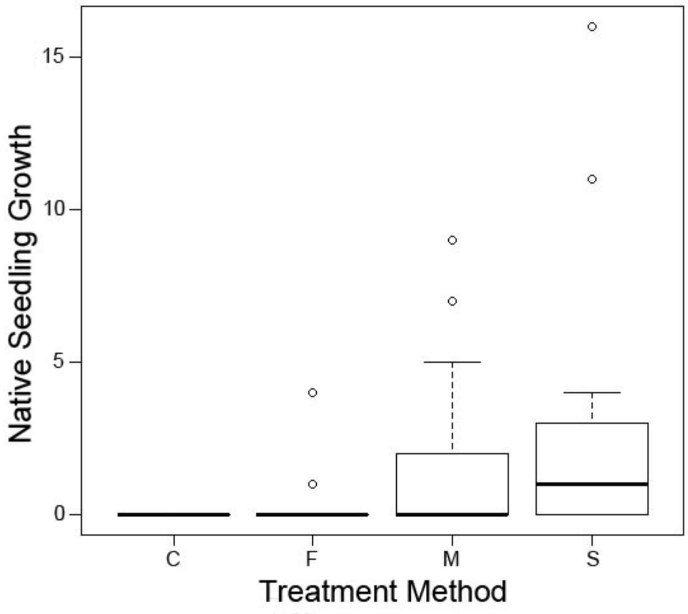

Figure 4. Boxplot of Treatment Method v. Number of Native Seedling for April 8, 2010. The mean, 1st and 3rd quartiles, and outliers for each treatment method are presented. In this diagram: C=control, F=foliar herbicide application, M=manual removal, and S=cut-stem herbicide application.

. The most prominent species found at treatment plots were California bay (*Umbellularia California)* and the Coast redwood (*Sequoia sempervirens)*. For a complete list of plant species found during this study on study plots and in the overhanging canopy see Appendix A.

The Simpson's Diversity Index showed that manual removal plots averaged a higher diversity rating (0.7652) than cut-stem herbicide application plots (0.3644) and foliar herbicide application plots (0.00) (Table 2). Simpson's Diversity Index also revealed that site GO2 had the

Table 2. Simpson's Diversity Index of native seedling growth for treatment plots and for experimental sites.

Treatment	# Species	SDI (1-D)
Control	0	--
Foliar Herbicide	1	0
Manual Removal	6	0.7652
Stem Herbicide	2	0.3644

Specific Site	# Species	SDI (1-D)
GO1	2	0.2521
GO2	5	0.7398
GR1	0	--
GR2	2	0
WI1	2	0.2857
WI2	1	0

See Fig. 1 for locations of specific sites.

highest diversity levels of all the sites (0.7398). The only other sites which had more than one species of native plant present within the sub-sampling quadrats were GO1 (0.2521) and WI1 (0.2857). However, it is important to note that the high diversity of GO2 did not greatly impact the Treatment results for Simpson's Diversity Index (when GO2 was removed from the SDI calculations for manual treatment, its value was 0.6574).

DISCUSSION

This study was motivated by the importance of controlling invasive species, specifically for the preservation of native plant community biodiversity. I tested three methods for removal of invasive Algerian ivy along the riparian corridor of Strawberry Creek on the University of California, Berkeley campus to determine which removal method had the greatest negative impact Algerian ivy growth, and which most supported native seedling growth. I hypothesized that herbicide application onto cut-stems would be the most effective removal technique. However, results showed that no one treatment method was better than the others at removing ivy. I also hypothesized that plots treated with herbicide would show no difference in native plant growth when compared to plots treated without herbicide. I found that although there was no significant difference in the abundance of native seedlings between treatment plots, plots treated with manual removal had a higher level of native plant biodiversity than foliar herbicide and cut-stem herbicide plots. My findings suggest that among the three treatments tested, manual removal is equally effective at ivy removal, and will have the most positive impact on native plant community diversity. Therefore, manual removal of Algerian ivy should be continued until the potential negative effects of herbicide application on native seedling growth have been investigated further.

Percent Ivy Cover

I found no observable difference in percent ivy cover between treatment plots which received manual ivy removal, foliar herbicide application, and cut-stem herbicide application. The two applications of herbicide appeared to be just as effective at ivy removal as the manual removal method. Control plots did not exhibit any changes in ivy cover throughout the experiment.

Glyphosate has been shown in previous studies to be an effective herbicide for removing invasive herbaceous plants (Derr 1993, Roques et al 2001, Biggerstaff and Beck 2007, Back and Holomuzki 2008). However, herbicide is not always the most efficient method. Atkins and Williamson (2008) found that manual removal was the most effective method for removal of *Colocasia esculenta (L) Schott*, an herbaceous wetland perennial, and that cut-stems with applied herbicide did not result in complete removal of the plant. Love and Anderson (2009) found that mechanical removal of Morrow's honeysuckle in the spring was the most effective removal method, while cutting stems and applying herbicide in the autumn was the least effective. It is important to note that all of these studies involved multiple removal treatments, while my study only consisted of one series of removal treatments. This difference could be the source for some of the discrepancy between my results and previous research.

Seasonality of herbicide application may be influential in the success of invasive plant removal. Glyphosate has been shown to be most potent on ivy species when applied in March, when maximum uptake by the leaf cuticles occurs (Neal and Skroch 1985, Derr 1993). Therefore the results of this study could have been more pronounced, and the death of ivy could have occurred more quickly if the herbicide had been applied in March instead of November. However, it is important to note that the herbicide was incredibly effective at removing the ivy during the winter months in this study, reducing ivy cover nearly to zero within two months. This is an effect not seen in previous studies (Love and Anderson 2009). Many studies which looked at the effectiveness of herbicide application timing also took place in other parts of the country, which have different seasonal weather patterns than those observed in Berkley, California (Neal and Skroch 1985, Biggerstaff and Beck 2007, Love and Anderson 2009). For instance, in a climate where rain is more common in the spring than the winter and where there may be freezing temperatures in the winter months, I would expect to see differences in the effectiveness of herbicide application at different times of the year as compared to those observed in the Mediterranean climate of Berkeley.

It is possible that variation in ivy growth between plots and sites was a result of environmental variation, and not due to the applied treatments. However, most obvious environmental factors were probably randomized or non-significant because I placed all sites for this study along the same riparian corridor with a 1-3 foot distance between plots (with the exception of GR2M, which was placed across the creek from other GR2 plots), leaving little room for environmental variation among sites from sources such as weather conditions. Some sites had slight variation in slope and aspect and sunlight availability, but overall they were relatively uniform. One notable exception in terms of uniform sunlight availability was site GO2, which had increased sunlight availability from the west, making the soil very dry. This dry soil in turn made the manual ivy removal very difficult, a fact which could account for this site's higher levels of ivy re-growth. This type of variability between sites is representative of the variability seen in practical application of removal techniques on the UC Berkeley campus. Each site had a slightly different vegetation pattern, ground slope, and light availability. In no case was this variability so strong as to warrant removal of the site from this study. Biggerstaff and Beck (2007) found that glyphosate application did not noticeably change the soil composition. Therefore, differences in soil composition before and after herbicide application likely would not account for the differences in ivy growth.

The herbicide Glyphosate has been proven to be effective for the removal of invasive Algerian ivy in this study, but its use is slightly controversial. Perez et al (2007) found that glyphosate may change phosphorous concentrations in soil, and this change in soil nutrients could have implications for the greater riparian ecosystem. Glyphosate has also been shown to be harmful to amphibians and fish if it is allowed to enter a water body in high concentrations (Folmar et al 1979, Relyea and Jones 2009). Amphibians have been found to have slowed mobility and remain on the bottom of a water body when high concentrations of glyphosate are present (Bernal et al 2009, Relyea and Jones 2009). Glyphosate has also been shown to be toxic to fish, especially in higher temperature waters (Folmar et al 1979). These studies on the impact of glyphosate on aquatic organisms all acknowledge that to have the negative effects observed under lab conditions, glyphosate would need to be present in very high concentrations in the water. These concentrations are not often found because of the dispersing characteristic of streams. Although these risks exist, they are only of concern if the herbicide comes into contact with a water body (Monsanto 2003). During this study, herbicide was applied with a backpack sprayer away from the immediate riparian zone of the creek. Therefore, aquatic toxicity risks are of low concern for this study. However, when deciding to use herbicide to remove Algerian ivy in locations beyond the UC Berkeley campus, it would be important to consider the proximity of plots to the creek and the application method used to minimize the herbicide's contact with the body of water.

A complete analysis of each ivy removal technique needs to be approached not only from a scientific, but also from a social and economic perspective. Herbicide application is much less time and labor intensive a procedure than manual removal. However, herbicide needs to be purchased for use in the campus natural areas, which requires funding. It also needs to be approved for use within the natural areas, and applicators need to be given proper training on herbicide application procedures (Monsanto 2003). Although manual removal is labor intensive, it also provides an opportunity for the campus community to come together in a physical activity while improving the aesthetics of UCB (Purcell et al 2007). This experience of social interaction would be lost with the implementation of herbicide application procedures for ivy removal. While manual removal is the most labor intensive of the three treatment methods, it is also the cheapest and least environmentally controversial on the University of California, Berkeley campus.

Although both glyphosate application and manual removal were shown in this study to be effective tools for minimizing invasive plant presence, neither completely eliminated the invasive organism. Invasive plant removal requires continued efforts to ensure that the plants do not reenter an area after they have been removed (Wootton et al 2005). Although this study has identified the effectiveness of three methods for the initial removal of Algerian ivy, continued removal efforts will be necessary, whether manual or chemical, to ensure that cleared areas remain ivy-free for future re-introduction of native seedlings. For the Strawberry Creek Restoration Project, this means that there is no one solution to the current problems cause by invasive plant species at UC Berkeley. Long-term observation of removal sites and a continuous input of human labor will be needed to ensure the success of the Restoration Project, regardless of which removal method is employed.

Native Seedling Growth

I found no significant difference in the number of native plant seedlings growing between treatment methods. Control plots did not show any native plant growth, suggesting that the removal of Algerian ivy from a site by any of the three treatment methods improved the growth of native plant species. The Simpson's Diversity Index (SDI) showed a higher level of native plant diversity at manual treatment plots than at foliar herbicide and cut-stem herbicide plots. This suggests that although abundance levels were similar, the seedlings sprouting at manual plots were more diverse than those sprouting in the other treatment plots.

The results of this study in terms of native plant growth and species diversity are in accordance with other studies, which have shown a significant difference in native species re-growth based on removal method. Biggerstaff and Beck (2007) found that manual removal resulted in higher seedling diversity. However, Biggerstaff and Beck (2007) also found manual removal plots to have higher seedling densities, a result not found in this study. Hartman and McCarthy (2004) found that the potential for different survival rates between plants depended on the removal method used. It is possible that different treatments encouraged the growth of different plant species (Biggerstaff and Beck 2007). Given the short time period of this study, it is also very possible that some seeds present in the seed bank simply did not have enough time or the right environmental conditions to sprout before the study's completion.

The high diversity of native seedlings on manual removal plots in this study could be caused by a variety of natural and anthropogenic factors. The higher rate of plant growth could be a result of soil disturbance as roots were removed, which provides increased air and water to the seedlings, encouraging their growth (Luken 1990). Disturbance caused by manual removal increases soil light availability and temperature which are better conditions for germination (D'Antonio and Meyerson 2002). Removal of large shrubs can also lead to increased light levels on the forest floor and increased seedling germination (Luken et al 1997). The soil mixing caused my manual removal may also inadvertently bring buried seeds closer to the surface, giving them a better chance of germination. During manual removal I explicitly tried to reduce soil mixing by removing vines slowly and following stems to their source, but complete prevention of mixing was unavoidable with this intrusive removal technique. Dead ivy on foliar application plots may have continued to block sunlight even though ivy was removed. This particular pattern would make sense, given that dead leaves on cut-stem herbicide sites were raked away to provide for better sunlight access, though not as much as on manual plots, and cut-stem herbicide plots had the second highest SDI. Compacted soil at the herbicide treated sites also may not have allowed seedlings to mix to the surface and lowered their chances of germination (Luken 1990). Any of these factors may have affected the native plant growth rates and diversity observed between treatment plots.

Future Directions

This study was designed specifically to address the effects of herbicide use on the UC Berkeley campus for the purpose of restoration work with the Strawberry Creek Restoration

Project. The results of this study can therefore be applied directly to help with current restoration efforts taking place in Berkeley, California. In order to base restoration projects elsewhere around the results of this study, considerations would need to be made for any differences in climate, rainfall patterns, soil type, or vegetation between the UC Berkeley campus and the site in question.

Further research should include manual re-seeding (as in Biggerstaff and Beck 2007) to observe the effectiveness of additional restoration efforts under each of these treatments. Future studies could also look into the effectiveness of removal techniques on multiple invasive species present in the same area. One interesting result of this study was the effectiveness of glyphosate in killing old growth of Algerian ivy during November via the foliar herbicide application. Previous studies had all suggested that glyphosate could not effectively enter the pores of leaves during the winter months when the plant is not growing as quickly as in the spring and summer (Neal and Skroch 1985, Biggerstaff and Beck 2007, Back and Holomuzki 2008). The effectiveness of glyphosate at invasive plant removal in this study should be investigated further in areas of similar climate to see what discrepancy lies between this and previous studies. A more long term study on the effectiveness of herbicide application yearlong, and its impact on native plant growth would be ideal. Restoration is a multi-step process, and often involved returning to a location multiple times throughout a year to ensure that an invasive species has been successfully removed from the area (Biggerstaff and Beck 2007). This fact should be taken into consideration in future studies, and multiple removals should take place over the course of a year to determine which treatment methods are most effective at ivy removal and which most enhance the native seed bank.

Conclusions

This study found that there was no significant difference between treatment methods in terms of Algerian ivy removal along a riparian corridor in Berkeley, California. Although all treatment methods also had similar native plant abundance levels, the manual removal treatment plots had a diversity index nearly double that of the cut-stem herbicide and foliar herbicide plots. Given that the ultimate goal of our restoration efforts is to restore the Strawberry Creek riparian corridor back to a native habitat, it is of great importance that the removal method for the invasive plant species encourages increased native plant biodiversity. The restoration of native plant communities on the local scale of Strawberry Creek and the UC Berkeley campus is essential to the preservation of biodiversity on a much larger scale, throughout the state of California and across the globe. For this reason, this study recommends that Algerian ivy continue to be removed primarily via manual removal until further research can be performed regarding the potential negative impacts of other removal methods on the native seed bank and seedling diversity within treated areas.

ACKNOWLEDGMENTS

I would like to thank the following people for their input to this study. My advisor, Tim Pine (EH&S, UC Berkeley), for his insight into my study design and assistance in obtaining materials and training for herbicide application. Karl Hans (EH&S, UC Berkeley) for his flexibility in the implementation of this project. Patina Mendez (ESPM, UC Berkeley) and Lucy Diekman (ESPM, UC Berkeley) for their assistance in developing my study design and analytical methods. Theron Klos (PPCS, UC Berkeley) for access to plot setup materials and gardening supplies. The Strawberry Creek Restoration Project for allowing me to use their space within the campus natural areas and the use of gloves and tools for invasive plant removal. Robert Rankin for assistance with site setup, analytical methods development, and occasional data collection. Brad Kaellner, Mary Chesus, Tyler Grinberg, and Lori Burns for their help in the manual removal of Algerian ivy from treatment plots.

REFERENCES

Atkins, E., and P. Williamson. 2008. Comparison of Four Techniques to Control Elephant Ear. Journal of Aquatic Plant Management, **46**: 158-162.

Back, C.L., and J.R. Holomuzki. 2008. Long-term Spread and Control of Invasive, Common Reed (Phragmites australis) in Sheldon Marsh, Lake Erie. Ohio Journal of Science **108**: 108-112.

Baylis, A.D. 2000. Why glyphosate is a global herbicide: strengths, weaknesses and prospects. Pest Management Science **56**: 299-308.

Bernal, M. H., K. R. Solomon, and G. Carrasquilla. 2009. Toxicity of Formulated Glyphosate (Glyphos) and Cosmo-Flux to Larval Colombian Frogs 1. Laboratory Acute Toxicity. Journal of Toxicology and Environmental Health, Part A: Current Issues **72**: 961.

Biggerstaff, M. and C. Beck. 2007. Effects of English Ivy (*Hedera helix*) on Seed Bank Formation and Germination. The American Midland Naturalist **158**: 250-257.

Bossard, C.C., J.M. Randall, and M.C. Hoshovsky. 2000. Invasive Plants of California's Wildlands. University of California Press, Berkeley, California, United States.

Cain, M. L., W. D. Bowman, and S. D. Hacker. 2008. Ecology, 1st edition. Sinauer Associates, Inc.

California Invasive Plant Council [CIPC]. 2009. Inventory Database. www.cal-ipc.org/ip/inventory/weedlist.php

D'Antonio, C., and L. A. Meyerson. 2002. Exotic Plant Species as Problems and Solutions in Ecological Restoration: A Synthesis. Restoration Ecology **10**:703-713

Franz, J. E., M. K. Mao, and J. A. Sikorski. 1997. Glyphosate. American Chemical Society.

Folmar, L. C., H. O. Sanders, and A. M. Julin. 1979. "Toxicity of the herbicide glyphosate and several of its formulations to fish and aquatic invertebrates." Archives of Environmental Contamination and Toxicology, **8**: 269-278

Hartman, K., and B. McCarthy. 2004. Restoration of a forest understory after the removal of an invasive shrub, Amur honeysuckle (Lonicera maackii). Restoration Ecology **12**: 154-165

Kishore, G. M., and D. M. Shah. 1988. Amino Acid Biosynthesis Inhibitors as Herbicides. Annual Review of Biochemistry **57**: 627-663.

Levine, J. M, M. Villa, C. M. D'Antonio, J. S. Dukes, K. Grigulis, and S. Lavorel. 2003. Mechanisms underlying the impacts of exotic plant invasions. Proceedings of the Royal Society of London Series B- Biological Sciences **270**: 775–781.

Love, J. P., and J. T. Anderson. 2009. Seasonal Effects of Four Control Methods on the Invasive Morrow's Honeysuckle (<i>Lonicera morrowii</i>) and Initial Responses of Understory Plants in a Southwestern Pennsylvania Old Field. Restoration Ecology **17**: 549-559

Luken, J. O. 1990. Directing ecological succession. 251. Chapman and Hall. London

Luken, J., L. Kuddes, and T. Tholemeier. 1997. Response of understory species to gap formation and soil disturbance in *Lonicera maackii* thickets. Restor. Ecol **5**: 229–235

Monsanto. 2003. Glyphosate and Water Quality. Backgrounder: 1-3.

Neal, J.C. and W.A. Skroch. 1985. Effects of timing and rate of glyphosate application on toxicity to selected woody ornamentals. J. Amer. Soc. Hort. Sci. **110**: 860-864

Perez, G., A. Torremorell, H. Mugni, P. Rodriguez, M. Vera, M. Do Nascimento, L. Allende, J. Bustingorry, R. Escaray, M. Ferraro, I. Izaguirre, H. Pizarro, C. Bonetto, D. Morris, and H.

Zagarese. 2007. Effects of the herbicide roundup on freshwater microbial communities: A mesocosm study. Ecological Applications **17**: 2310-2322.

Purcell, A.H., J. Corbin, and K.E. Hans. 2007. Urban riparian restoration: an outdoor classroom for college and high school students collaborating in conservation. Madroño **54**: 258-267.

R Development Core Team [R]. 2009. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing: Vienna, Austria. <http://www.R-project.org>

Relyea, R. A., and D. K. Jones. 2009. The toxicity of Roundup Original Max ® to 13 species of larval amphibians. Environmental Toxicology and Chemistry **28**: 2004

Roques, K.G., T. O'Connor, and A.R. Watkinson. 2001. Dynamics of shrub encroachment in an African savanna relative influences of fire, herbivory, rainfall and density dependence. Journal of Applied Ecology **38**: 268-280.

Schönbrunn, E., S. Eschenburg, W. Shuttleworth, J. Schloss, N. Amrhein, J. Evans, and W. Kabsch. 2001. Interaction of the herbicide glyphosate with its target enzyme 5-enolpyruvylshikimate 3-phosphate synthase in atomic detail. Proceedings of the National Academy of Sciences of the United States of America **98**: 1376-1380..

Scott, J. M., and D. S. Wilcove. 1998. Improving the Future for Endangered Species. BioScience **48**: 579-580.

Thomas, L.K. 1998. Topographic alterations, forest structure, and invasion by English ivy (Hedera helix L.) in the Rock Creek floodplain. Natural Areas Journal **18**: 164–168.

Unknown Author. 1969. Five Campus 'Nature Areas' Designated. The Daily Californian.

University of California, Berkeley [UCB]. 2009. Standard campus map. <www.berkeley.edu/map>

United States Department of Agriculture [USDA]. 2009. Natural Resources Conservation Science PLANTS Database; Plants Profile: *Hedera helix L*, <http://www.plants.usda.gov/english ivy.html>

Woodburn, A. 2000. Glyphosate: production, pricing and use worldwide. Pest Management Science **56**: 309-312.

Wootton, L., S. Halsey, K. Bevaart, A. McGough, J. Ondreicka, and P. Patel. 2005. When invasive species have benefits as well as costs: Managing Carex kobomugi (Asiatic sand sedge) in New Jersey's coastal dunes. Biological Invasions **7**: 1017-1027

APPENDIX A

Appendix A: List of native plant species found across sites and plots:

Scientific Name	*Common Name*	*Plots with identified specimens*
Alnus incana tenufolia	Mountain Alder	WI2M$^{\wedge}$
Corylus cornuta californica	California hazel	GO1M^{+},
Sequoia sempervirens	Coast Redwood	GO1(C, F, M, S) $^{\wedge}$, GR2(C, F, M, S) $^{\wedge}$, WI1(C, F, M, S) $^{\wedge}$, WI2(C, F, M, S) $^{\wedge}$
Quercus agrifolia	Coast Live oak	GR1C$^{\wedge}$, WI2M^{+}
Acer macrophyllum	Bigleaf maple	GR1(C, F) $^{\wedge}$, WI2S+,
Aesculus californica	California Buckeye	GO1(C, F)$^{+}$, GR2(C^{+}, F$^{\wedge}$), WI1S$^{\wedge}$
Heteromeles arubutifolia	Toyon	WI1S^{+}
Oxalis	Wood sorrel	GO1M, GO2M
Pinus attenuata	Knobcone Pine	GO2M, GO2(C, M, F, S)$^{\wedge}$
Polystichum munitum	Western Sword Fern	GO1M*
Umbellularia californica	California Bay	GO1(C,F,M,S)$^{+}$, GO2F$^{\wedge}$, GR1(C,M) $^{+}$, GR2F^{+}, WI1(F, M) $^{+}$, WI2(F, S) $^{+}$

* Refers to the species found in a plot, but not within the subsampling quadrants

$^{+}$ Refers to a species found on the edge of the plot

$^{\wedge}$ Refers to a canopy species