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

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ABSTRACT

Algerian ivy is an invasive non-native vine that limits native plant biodiversity. In this study I examined three removal techniques for managing Algerian ivy: manual removal, foliar herbicide application (Round Up® Pro), and cut-stem herbicide application. I hypothesized that cut-stem herbicide application would be the most effective removal technique and that both herbicide applications 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 among treatments and no significant difference in native seedling growth between plots. However, 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.

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INTRODUCTION

Non-native invasive plants are the second largest threat worldwide to native plant biological diversity (1). Successful invaders have a high reproductive capacity, rapid growth rate, and a generalist strategy which affords them a competitive advantage (2). 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 (3). Once established, invasive plants cause a number of negative effects; including blocking sunlight and nutrients from reaching sprouting natives (4) and altering nutrient cycles, hydrology, sediment deposition, fire regimes, and erosion patterns (5). For these reasons, the removal of invasive species is common in ecosystem restoration work.

Algerian ivy (Hedera canariensis algeriens) is a perennial vine classified as a weed in California with severe invasiveness, severe distribution implications, and severe impact on native plant life (6, 7). Like other Hedera species, it has a high seed survival rate, rapid vegetative spread rate and high shade tolerance (5, 6), making it a fierce competitor to many native plant populations (5). Algerian ivy has the ability to spread quickly into an area and form a thick ground cover, thereby blocking sunlight from other plants and limiting native seed dispersal (8, 9). It is highly persistent and difficult to permanently remove after establishment as a result of its ability to re-sprout from small stem fragments (5). These characteristics make Algerian ivy a threat to native plants and necessitate its removal via restoration efforts.

Algerian ivy has overtaken much of the riparian zone along Strawberry Creek running through the UC Berkeley campus, and can be seen climbing native trees, weakening their branches and making them more vulnerable to damage in future storms (10). In the past decade restoration efforts focused on manual removal of ivy and planting native vegetation to return campus nature areas to native oak woodlands (12). Despite these efforts, the areas are still largely overrun with Algerian ivy, and there are not sufficient funds or labor to control the ivy through manual removal (10). For this reason, the Strawberry Creek Restoration Project is considering

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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 (3, 9, 13, 14). Biggerstaff and Beck (9) cut the stems of English ivy before herbicide application to open the plant's pores for increased herbicide absorption and found that herbicide application greatly inhibited native plant growth. Derr (14) found that herbicide application was most effective on English ivy in March when new growth was emerging. 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 need to also consider these cold winter months.

I examined the potential of three techniques for riparian habitat restoration and Algerian ivy removal: herbicide application on cut-stems would be the most effective method for reducing ivy growth, and that herbicide application to cut stems and green leaves would not hinder the growth of native seedlings.

MATERIALS AND METHODS

Study Sites

This study took place along Strawberry Creek on the University of California, Berkeley campus (37o52'N 122o15'W). I selected six study sites along the creek within the riparian nature areas (Fig. 1). I selected similar sites to 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)

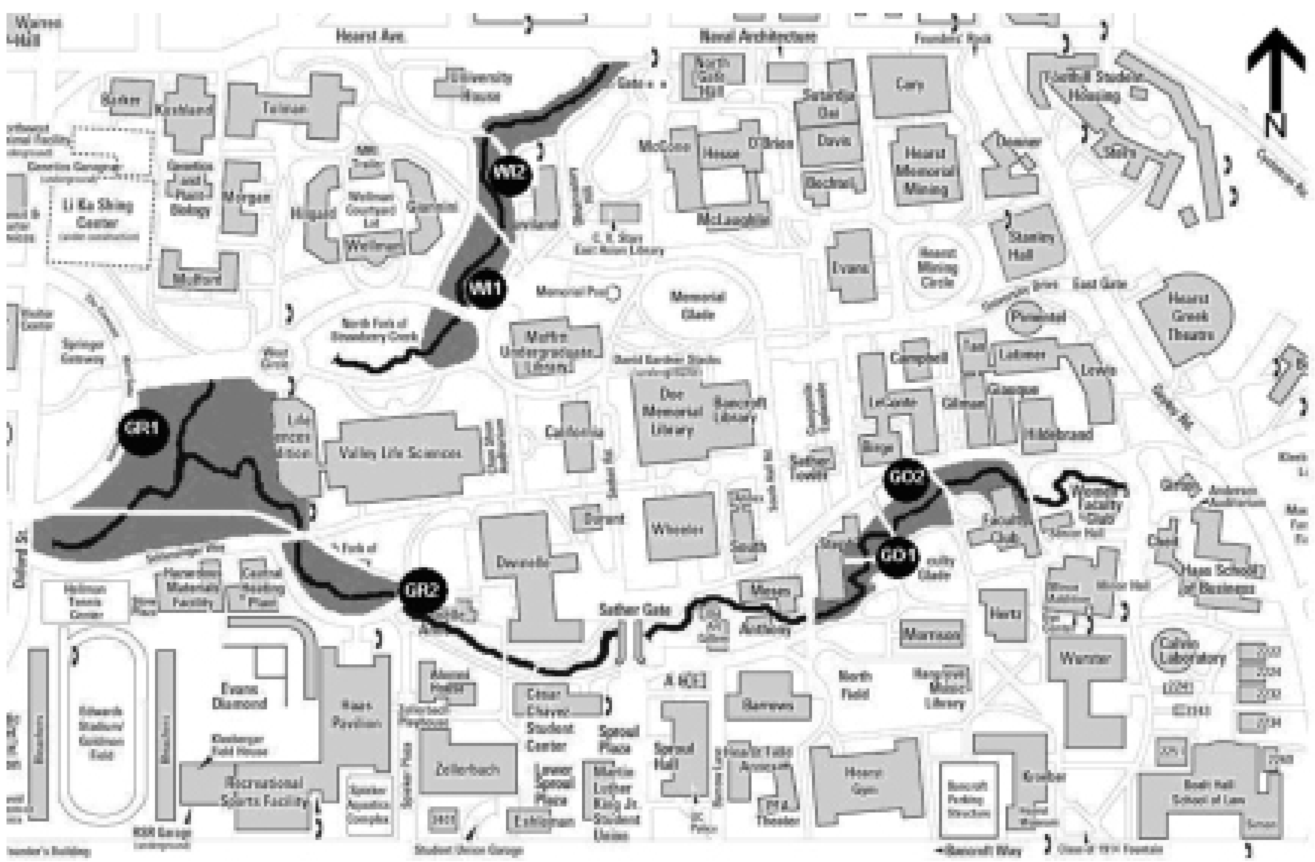

Figure 1. Study sites along Strawberry Creek on the UC Berkeley campus. Sites GR1, WI1, and WI2 were located along the North fork of Strawberry Creek. Sites GR2, GO1, and GO2 were located along the South fork of

manual removal of ivy, foliar herbicide application onto green ivy leaves, and cut-stem herbicide application onto freshly cut green ivy stems. I assessed the effectiveness of habitat restoration by monitoring the re-growth of Algerian ivy after treatment and monitoring the sprouting of native seedlings after treatment. I hypothesized that

(C), manual removal (M), foliar herbicide application (F), and cut-stem herbicide application (S). Within each plot I established a buffer zone of 2ft on all sides to minimize ivy growth from encroaching plants (Fig 2). This experiment took place from November 2009 to April 2010.

Ivy Removal and Herbicide Application

I conducted manual ivy removal from November

11-17, 2009. Manual removal included removal of above-ground foliage and below-ground root systems at all six manual removal plots. For the six cut-stem herbicide application plots, I removed ivy foliage with a weed whacker on November 12, 2009. Leaves were then raked from the plot to provide better access to freshly cut stems during cut-stem herbicide application. Leaves were not raked from foliar herbicide application plots.

I applied herbicide onto foliage at each of six foliar herbicide application plots on November 12, 2009 to determine whether uptake by old leaf cuticles was possible in winter. I applied herbicide at each of 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.

photos in R (19) to determine the percent of the photo containing live ivy leaf. The three photos taken at each plot were assumed to be representative of the entire plot.

Data Analysis

I used a Random Complete Block Design ANOVA with three subsamples from each plot. My primary response variable was the growth rate of vegetation and the sites served as the block. Results were also analyzed using a Tukey-Kramer test to compare differences between each removal method. These analyses were completed in R (19). I quantified native seedling diversity using the Simpson's Diversity Index: where n is the total number of organisms of a particular species and N is the total number of organisms of all species. Results for the SDI were pooled by both site and treatment method.

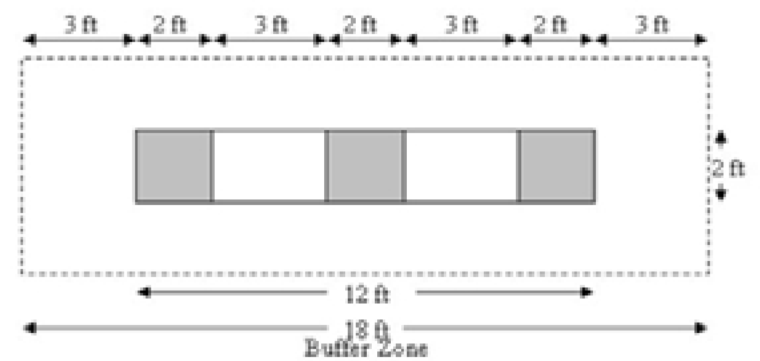

Figure 2. Plot set-up at each site. Sites: GO1, GO2, GR1, GR2, WI1, WI2. There were four treatment plots per site: control, manual removal, foliar herbicide application, and cut-stem herbicide application. Each plot had a buffer zone measuring 18ft by 6ft. Within the buffer zone three 2ft by 2ft samples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

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). I recorded the number of ivy leaves and native plants present and took pictures of the three subsamples (Fig 2) for future calculation of percent ivy cover. I recorded these data directly after treatments were applied and once a month subsequently until April 2010.

Percent Ivy Cover

To analyze the percent ivy cover at each plot I imported the pictures from each sample into Photoshop (17) and edited the photos to identify live ivy leaves. I then analyzed the

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).

After final measurements of percent ivy cover were taken on April 8,

		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

Table 1. Randomized Complete Block Design (RCBD) ANOVA of final percent ivy cover and native plant growth.

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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, while other treatments were not significantly different from each other (Fig. 3). With control included as a treatment method, there was a significant relationship between percent ivy cover and site ($p = 0.0102$). 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.

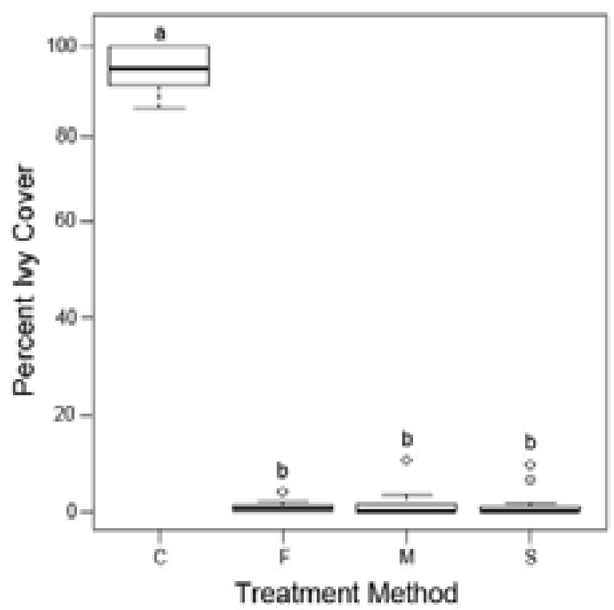

Figure 3. Boxplot of Treatment Method v. Percent Ivy Cover for April 8, 2010. The mean, 1st and 3rd quartiles, and outliers for each treatment method are presented. In this diagram: C=control, F=foliar herbicide application, M=manual removal, and S=cut-stem herbicide application. Results of the Tukey-Kramer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

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 plants were unaffected by this experiment, but were excluded from native seedling counts). After February 4, 2010 native plant growth was observed sporadically within most manual removal and cut-stem herbicide plots, and some foliar herbicide plots. None was observed in control plots (Fig. 4).

The most prominent species found in this study were California bay (Umbellularia California), Coast redwood (Sequoia sempervirens), Knobcone pine (Pinus attenuata), and a species of Wood sorrel (Oxalis).

The Simpson's Diversity Index (SDI) 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). SDI also revealed that site GO2 had the 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, the high diversity of GO2 did not greatly impact the SDI results for Treatment (when GO2 was removed from the SDI calculations for manual treatment, its value was 0.6574).

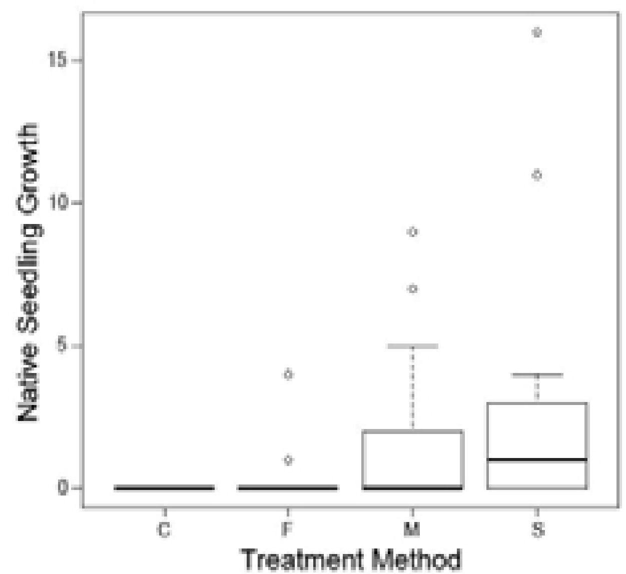

Figure 4. Boxplot of Treatment Method v. Number of Native Seedling for April 8, 2010. The mean, 1st and 3rd quartiles, and outliers for each treatment method are presented. In this diagram: C=control, F=foliar herbicide application, M=manual removal, and S=cut-stem herbicide application.

DISCUSSION

This study was motivated by a desire for the preservation of native plant community biodiversity via invasive plant control. I tested three methods for removal of invasive Algerian ivy in Berkeley, California to determine which removal method had the greatest negative impact on 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. I also hypothesized that plots treated with herbicide would show no difference in native plant growth when compared to plots treated without herbicide.

Percent Ivy Cover

Glyphosate is an effective herbicide for removing invasive herbaceous plants (3, 9, 14, 20). However, herbicide is not always the most efficient method. In this study, both applications of herbicide appeared to be just as effective at ivy removal as manual removal. Atkins and Williamson (2008) found that manual removal was the most effective method for the removal of an herbaceous wetland perennial, and that cut-stems with herbicide did not result in complete removal of the plant. Mechanical removal of Morrow's honeysuckle (Lonicera morrowii) in the spring was found to be the most effective removal method (13). All of these studies involved multiple removals, while my study consisted of only one-time treatment.

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 (14, 22). I applied herbicide in November, a colder month with less efficient herbicide uptake through leaf cuticles (14). However, the herbicide was effective at removing the ivy during November, reducing ivy cover nearly to zero within two months. Many studies examining the effectiveness of herbicide application timing took place in other parts of the country, which have different weather patterns than those observed in the Mediterranean climate of Berkley, California (13, 22).

Variation in ivy growth between plots and sites may have been a result of environmental variation, despite the close proximity of sites to one another along the same riparian corridor. One notable outlier in sunlight availability was site GO2, which had increased sunlight from the west, making the soil very dry. This dry soil made manual ivy removal difficult, and may 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.

Glyphosate was effective for Algerian ivy removal in this study, but its use is still controversial. Perez et al (2007) found that glyphosate may change phosphorous concentrations in soil, leading to implications for the greater riparian ecosystem. Glyphosate has been shown to be harmful to amphibians and fish if it is allowed to enter a water body in high concentrations (23, 24). These risks exist if the herbicide comes into contact with a water body (16). During this study, herbicide was applied with a backpack sprayer away from the immediate riparian zone, and was not followed by rain, so aquatic toxicity risks were minimal. However, when deciding to use herbicide to remove Algerian ivy, it is important to consider the proximity of plots to water bodies to minimize herbicide-water contact.

Native Seedling Growth

I found no significant difference in the number of native plant seedlings growing among treatment plots. Control plots did not show any native plant growth, suggesting that the removal of Algerian ivy from a site by any treatment method improved native plant growth. 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 result suggests that although abundance levels were similar, the seedlings sprouting at manual plots were more diverse than those sprouting in the herbicide treated plots.

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.

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

Native seedling growth in this study was similar to other studies, which have shown a significant difference in native species re-growth and species diversity between removal methods. Biggerstaff and Beck (2007) found that manual removal resulted in higher seedling diversity, and higher seedling density. Hartman and McCarthy (2004) found that the potential for different plant survival rates depended on the removal method used. It is possible that different treatments encouraged the growth of different plant species (9).

The high diversity of native seedlings on manual removal plots in this study could have been caused by many natural and anthropogenic factors. The higher rate of plant growth at manual plots may have been a result of soil disturbance as roots were removed, providing increased air, water, and sunlight to the seedlings, and encouraging growth (28, 29, 30). The soil mixing caused by manual removal may also have carried buried seeds closer to the surface, giving them a better chance of germination, whereas compacted soil at the herbicide treated sites may not have allowed seedlings to mix to the surface (28). Dead ivy on foliar application plots may have continued to block sunlight even though ivy was removed. Any of these factors may have affected the native plant growth rates and diversity observed between treatment plots.

Future Directions

This study was designed to address the effects of herbicide use by the Strawberry Creek Restoration Project on the UC Berkeley campus, and these results can be applied directly to future campus restoration efforts. To use the results of this study for other restoration efforts, differences in climate, rainfall patterns, soil type, and vegetation between the UC Berkeley campus and the site in question would need to be considered.

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. Continued removal efforts by the Strawberry Creek Restoration Project will be necessary, whether manual or chemical, to ensure that cleared areas remain ivy-free for future reintroduction of native seedlings.

Further research should evaluate the effectiveness of removal techniques on multiple invasive species present at one time in a plot. Previous studies have suggested that glyphosate can not effectively enter the pores of ivy leaves during the winter months when the plant is not growing as quickly as in the spring and summer (9, 20, 22). The effectiveness of glyphosate at invasive plant removal in this study should be investigated further to see what discrepancy lies between this and previous studies. Most importantly, a longer-term study on the effectiveness of herbicide application over multiple years, and its impact on native plant growth is necessary. Restoration is a multi-step process, and often involves returning to a location multiple times throughout a year to ensure that an invasive species has been successfully removed (9).

CONCLUSIONS

This study found no significant difference between Algerian ivy removal methods along a riparian corridor in Berkeley, California. All treatment methods resulted in similar native plant abundance, though manual removal plots had a diversity index nearly double that of the cut-stem herbicide and foliar herbicide plots. It is of great importance that invasive plant removal around Strawberry Creek encourages increased native plant biodiversity. The restoration of native plant communities on the local scale of 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 removal continue via manual removal until further research can be done on the potential negative impacts of herbicidal removal methods on the native seed bank and seedling diversity within treated areas.

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