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An Assessment of Control Methods for Cape Ivy in Coastal Riparian Ecosystems

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California State University, Monterey Bay

An Assessment of Control Methods for Cape ivy in Coastal Riparian Ecosystems

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In Partial Fulfillment

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Master of Science

in

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by

Jennifer Stern

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The Undersigned Faculty Committee Approves the
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AN ASSESSMENT OF CONTROL METHODS FOR CAPE IVY
IN COASTAL RIPARIAN ECOSYSTEMS

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DEDICATION

I dedicate this thesis to my Mom, Tracy, who always followed her dreams and encouraged me to do the same.

ABSTRACT

The goals of this research were to quantify the achievable outcomes and associated costs of controlling Cape ivy (*Delairea odorata*), a non-native invasive plant. Current gaps in the knowledge-base limit decision makers from assigning appropriate costs, and therefore funding, for invasive species control (D'Antonio and Chambers 2006). Towards these goals, I measured and compared the success and cost-effectiveness of three control methods on Cape ivy in riparian areas along the Central Coast region of California. The control methods used in this study included hand removal, herbicide application (glyphosate), and a combination of these two methods. Control methods were applied to Cape ivy infestations at three research sites; two within Santa Cruz County and one in Monterey County, beginning July 2008 and concluding September 2009. Success of each control method was measured by comparison of pre and post-treatment vegetation sampling. The costs associated with each method (labor, herbicides, materials) were also recorded for each method. After twelve months, the hand removal method achieved the highest reduction of Cape ivy cover and resulted in the highest native plant cover. However, the most cost-effective method (per dollar) for the first twelve months of Cape ivy control was the herbicide only method. The results of this study will be provided to staff at California State Parks, the Land Trust of Santa Cruz County, and the Big Sur Land Trust to inform future management of Cape ivy on their properties. Additionally, this research will contribute to needed guidelines for restoration of Cape-ivy infested riparian ecosystems, and serve as a resource for researchers interested in control of invasive plants and restoration of disturbed areas.

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This project would not have been possible without the kind people at the Big Sur Land Trust (Sarah Godfrey, Donna Meyers), Big Basin State Park (Tim Hyland), and Circle P Ranch (Diane Cooley) for allowing me do research on their land. I hope the recommendations in this thesis aid you in your management of Cape ivy. The project would also not have been possible with the countless volunteers that helped to set up plots, sample vegetation, and apply treatments. Volunteers: Tim Hyland, Houcine, and Mason (California State Parks); Linda Brodman, Eric Olsen, John Falkowski, and Dave (California Native Plant Society volunteers); Amelia, Phil, Lasse, Mariko, Micheal, Jason, Charlotte, Chris, and Javier (American Conservation Experience volunteers); Tegan, Reba, Andy, Ravi, Elissa, Courtney, Tommy, Jessica, Rebecca, Patrick, Erin, Kelli (Vanderbilt Alternative Spring Break volunteers); Janet Ilse, Joanna Bremser, George McMenamin, Alicia Moss, Alta Anzalone, Emma Dugas, Tamara Doan, Joe Issel, Sarah Godfrey, Tamara Myers, Dan Jones, Kirby Sanchez, Kate Thompson, and John Pritchard (friends and colleagues).

I also would like to thank the California Invasive Plant Council, Maria Alvarez, Joe Balciunas, Carla Bossard, Tom Dudley, Dan Gluesenkaamp, Ken Moore and Ramona Robison for important research and on-the ground work that supplied me with information and ideas for this research. Lastly, I would like to thank my wife, Emma Dugas, for her encouragement, support, editing assistance, and sweet nagging, that helped me to complete this thesis.

INTRODUCTION

Biological invasion by non native species is a worldwide phenomenon that dramatically alters communities and ecosystems (Elton 1958, Mooney and Drake 1989, Luken and Thieret 1997, Levine et al. 2003, Didham et al. 2005). Invasive species are recognized as a serious threat to imperiled species and biological diversity, second only to direct habitat loss and fragmentation (Baker 1986, Mooney and Drake 1989, Bossard et al. 2000, Wilcove et al.1998).

Cape ivy (*Delairea odorata*), native to South Africa, is an invasive plant with considerable impacts to ecosystems (Cal-IPC 2005). This deleterious invasive vine is currently expanding its range in coastal California and Oregon. The California Invasive Plant Council (Cal-IPC) lists Cape ivy on its High List as a "Species with severe ecological impacts on ecosystems, plant and animal communities, and vegetational structure" (Cal-IPC 2005). Cape ivy spreads rapidly and dominates plant communities.

Cape ivy is difficult to control due in part to the brittle nature, and rapid growth of its vegetative structures (long rhizomes and stolons). Because Cape ivy grows vegetatively, one Cape ivy plant can grow as much as one foot per month (Alvarez 1995, Hillis 1994). Cape ivy's brittle nature is a threat because even the smallest piece of stolon, rhizome or root can resprout.

Over the last twenty years, several restoration practitioners have tested control methods for Cape ivy (Bossard and Benefield 1995, de la Torre 1999, Fagg 1989, Forbert 1998, Moore 1997). While some successes have been documented, few studies have evaluated and compared the effectiveness of varying methods. Consequently, there is a lack of replicable, quantitative studies that compare success and the cost-effectiveness of different control methods for Cape ivy in the current scientific literature. A review of all studies related to control and management methods for Cape ivy produced only three publications (Bossard and Benefield 1995, Bossard et al.2005, Fagg 1989) in which the results of control methods were quantified. Each of these studies focused on a particular control method (herbicide treatment or flaming) rather than a comparison of control methods. Additionally, none of the identified studies provided a quantifiable comparison of the cost-effectiveness of control methods for Cape ivy.

Managers of many reserves estimate they spend more than 50% of their annual operating budget on control of non-indigenous species. For example, at Hawaii Volcanoes National Park, Resources Management director Tim Tunison estimates that 80% of their annual budget is spent controlling exotic species (Robison 2006). Likewise, at Golden Gate National Recreation Area and Point Reyes National Seashore, two California parks within a Mediterranean climate region, report that over 60% of the Resources Management budget is spent controlling exotic species (Robison 2006).

Control costs vary according to the method used and number of subsequent re-treatment applications, complicating the allocation of limited funds. Therefore, documented cost of control methods is essential information for resource managers to designate resources, complete management plans, and for policymakers to inform funding allocations.

The cost of achieving pragmatic, realistic goals cannot be set without the knowledge of cost and effectiveness of control methods used to control Cape ivy (D'Antonio and Chambers 2006). Policy goals are currently limited by lack of knowledge of achievable outcomes and the cost of achieving goals related to Cape ivy control. Gaps in the scientific knowledge base limit decision makers from assigning appropriate costs, and therefore funding for invasive species control (D'Antonio and Chambers 2006). Policies which support funding allocations for invasive species control is needed to protect California's wildlands, protect overall quality of life for Californians, and reduce management costs in the future.

The overall goal of this study was to quantify achievable outcomes for reducing Cape ivy cover cost-effectively in riparian ecosystems in coastal Central California. Results from this study will inform policymakers and resource managers of the achievable outcomes and associated costs of first year Cape ivy control. Gaps in evidence-based knowledge on this topic limit decision makers from assigning appropriate costs, and therefore funding, for invasive species control. The principle policymakers expected to benefit from the data collected through this and other evidence-based research include the California Department of Food and Agriculture, United States Department of Agriculture, Environmental Protection Agency, California Department of Fish and Game, National Oceanic and Atmospheric Administration, local foundations, and other federal, state and local funding agencies.

SPECIFIC GOALS AND OBJECTIVES

My goal in this study was to quantify achievable outcomes for three treatment methods, and in particular the results of one year of treatment on Cape ivy and native plant cover. I asked the following questions:

1. What control method achieves the highest reduction of Cape ivy cover after twelve months?
2. What control method is most cost-effective (per dollar) for Cape ivy control over twelve months?
3. What control method results in the highest native plant cover twelve months after initial treatment?

In relation to the third question, if native plant cover does not increase after one year, this may indicate that planting of natives is necessary to reestablish native herbaceous forbs and woody shrubs in areas with pre-existing Cape ivy infestations.

HYPOTHESES

Numerous comparisons were made between pairs of hypotheses about plant cover. These included comparisons between pre- and post-treatment cover within treated plots; comparisons of post-treatment cover between treated versus control plots; and comparisons of post-treatment cover between differently treated plots. In all cases, comparisons were made with respect to both ivy cover and native cover. For each comparison, the two hypotheses to be compared were posed as follows:

H_0: $\mu_i = \mu_0$

H_1: $\mu_i = \mu_A(1-B_i) + \mu_B B_i$

where μ_i denotes the mean plant cover expected for plot i, B_i is an indicator variable {0,1} indicating the status of a plot (e.g. either treated or control, or either pre-treatment or post-treatment), μ_0 represents a constant mean plant cover irrespective of plot status, and μ_A and μ_B are separate mean plant cover values depending on the plot's status. The statistical analysis of data relating to these hypotheses is discussed below, after the treatments and field methods are described.

To analyze cost-effectiveness, I tracked costs for each method, and simply compared average costs between treatments.

METHODS

Study Area Description

Research activities took place at three locations; two in Santa Cruz County and one in Monterey County. I used the following criteria for site selection: infestation size (> 0.12 hectares or 0.3 acres), percent cover of Cape ivy (> 50%), and habitat type (riparian ecosystem), and accessibility. The infestation size was necessary in order for all plots to fit within the infested area, and greater than 50% percent cover was needed in order for plots to be similar enough to serve as replicates. One habitat type was chosen so sites would have similar conditions, and accessibility was important so that volunteers would be able to access all plots safely.

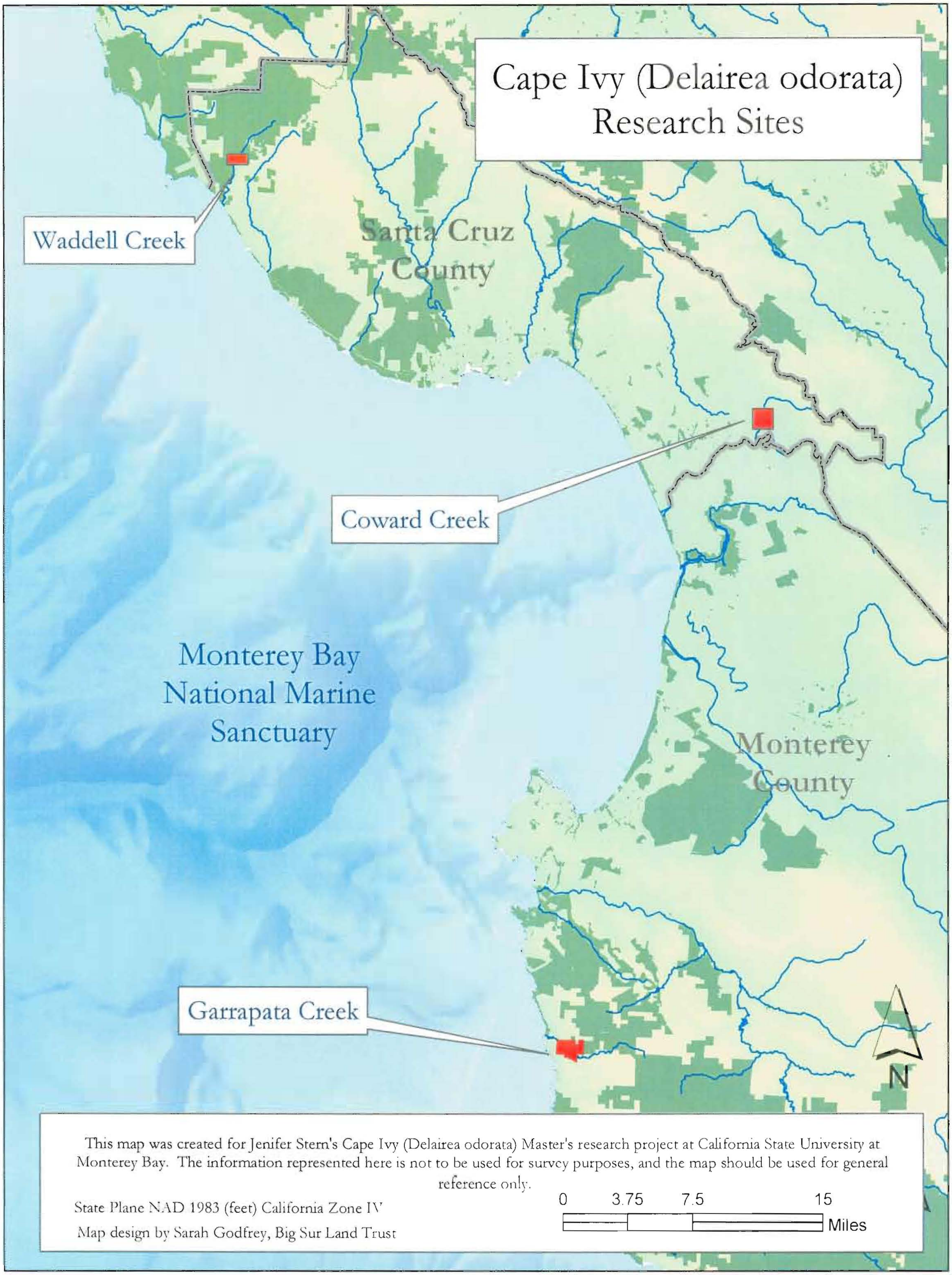
The first site was located on Circle P Ranch, a private property under a conservation easement with the Land Trust of Santa Cruz County. Cape ivy covered 60-70% of this 2.02 hectare (five-acre) sycamore and buckeye-dominated riparian site along Coward Creek, a seasonal stream, in Watsonville, Ca. The adjacent land use at this site was organic row crops with a <100' setback from the riparian corridor.

The second site was located south of the Carmel River on Big Sur Land Trust's Glen Deven Ranch along redwood-dominated Garrapata Creek. Bay Laurel trees also were present at this site. Cape ivy infested 50-60% of this 2.43 hectare (six-acre) site (the riparian portion of the 860-acre Ranch) and the surrounding land was open space utilized for wildlife habitat.

The third site was located in Big Basin State Park along alder-dominated Waddell Creek. Cape ivy infested 60-70% of this 1.26 hectare (three-acre) site and the surrounding land use was state park land utilized for recreation and wildlife habitat. See Figure 1 below for site map.

Since my treatment plots at these sites were infested with greater than 50% cape ivy cover, it is likely that cape ivy would have continued to dominate these areas unless active restoration was done. Active restoration means using top-down control strategies (including manual removal, and herbicides) to directly affect the disturbance, which in this case was undesired vegetation. This is the reason I chose to employ physical and chemical application methods.

Next page: Figure 1. Study Sites. Site 1 is located along Coward Creek; Site 2 is located along Garrapata Creek, and Site 3 is located along Waddell Creek.


Cape Ivy (Delairea odorata)
Research Sites
Waddell Creek
Santa Cruz County
Coward Creek
Monterey Bay National Marine Sanctuary
Monterey County
Garrapata Creek
N
This map was created for Jenifer Stern's Cape Ivy (Delairea odorata) Master's research project at California State University at Monterey Bay. The information represented here is not to be used for survey purposes, and the map should be used for general reference only.
State Plane NAD 1983 (feet) California Zone IV
Map design by Sarah Godfrey, Big Sur Land Trust
0 3.75 7.5 15
Miles

Selection of Treatment Methods

In order to be considered for inclusion in this study, treatment methods needed to meet all five of the following selection criteria:

1. There were documented cases where this method reduced Cape ivy percent cover by at least 50%.
2. The method took into consideration the biology, life history, and growth habits of Cape ivy (i.e. Cape ivy's faster growth in the winter and early spring, fragile roots, and long, breakable rhizomes and stolons).
3. The method was feasible to apply with the limited resources available for this study (i.e. the labor intensity of the method was not outside the means of the research team).
4. The potential drawbacks of applying the method did not outweigh the potential benefit (i.e. the method would not promote the spread of Cape ivy to other locations, or the concentration and ingredients of herbicide have not been proven to negatively affect wildlife potentially occurring at the site).
5. Resource managers consulted would be willing to consider using this method.

After identifying the treatment methods currently used by resource managers and restoration practitioners (Appendix B), and applying all five criteria (above), I reviewed the three treatment methods that were eligible for this study: Scorched Earth (SE), Modified Scorched Earth (MSE) and Rodeo with Activator 90 (R+A90).

As defined here, Scorched Earth (SE) involves hand removal of all plant vegetation, both native and non-native. Post removal all material is left on a tarp on-site to dry and decompose. Cape ivy biomass must be left on a tarp or in other containment system to prevent re-sprouting; any Cape ivy rhizomes or stolons in contact with soil or water are may re-sprout. Modified Scorched Earth (MSE) involves hand removal of Cape ivy only, without the removal of native plant populations. Post removal Cape ivy is also left on a tarp on-site to dry and decompose. Rodeo with Activator 90 (R+A90) involves application of Rodeo® + Activator 90 surfactant mixture to all above ground Cape ivy with a backpack sprayer. When possible, native vegetation is avoided.

Initially I sought to include both SE and MSE treatment methods in this study, which would have allowed me to directly compare their effectiveness. Unfortunately the study sites were unsuitable for this comparison as the low density of native vegetation would have resulted in similar outcomes under either method; very low native plant cover or bare earth. Due to these limitations, and with the intent to preserve native vegetation, I selected MSE as the first treatment method (T1) to study and eliminated SE from consideration (Table 1).

While MSE (T1) did preserve a fair amount of native vegetation during this study, an important consideration when using this method is how this method will affect your site. For example, people removing Cape ivy from stream banks can cause erosion as well as endanger their own safety. The prolonged presence of people in a riparian corridor can also be disruptive to wildlife. Additionally, native plants may need to be removed when embedded in dense Cape ivy. When Cape ivy biomass is removed, it can encourage growth of invasive plants as well as native plants due to the increased availability of sun and resources. Furthermore, if the previous land use at the site was a garden, farm field or even an unmanaged open space, there may be a greater chance for another invasive plant to develop once Cape ivy is removed.

I chose 2% Rodeo®, a form of glyphosate herbicide, and Activator 90 surfactant (both registered for aquatic use in California) as the second treatment method (T2) to study (Table 1). Both the herbicide and the surfactant are unlikely to harm species of concern in the study areas. While the soil field dissipation half-life of glyphosate is 44 - 60 days, it is quickly inactivated through soil absorption and has low leaching potential and very low volatility (Schuette, 1998), Furthermore laboratory studies have shown that glyphosate does not bioaccumulate in terrestrial or aquatic animals, including fish and aquatic invertebrates (Giesy et al. 2000; Williams et al. 2000).

While the herbicide and surfactant used in method T2 did not appear to harm species of concern (flora and fauna) during the course of this study, an important consideration when using this method is how this method will affect non-target flora and fauna on site. Non-target effects of this herbicide can decrease native plant cover. Replanting costs will most likely be higher if a portion of the existing native vegetation has to be replaced. Another consideration for this method is that volunteers will most likely not be willing and/or capable to help implement this method. This will decrease your opportunities to make the treatment site a community stewardship project.

Interest in the effect of combining control methods led me to select a combination of MSE and R+A90 as the third treatment method (T3) to study (Table 1). Following the advice of resource managers and restoration practitioners, I selected R+A90 as the initial treatment and

MSE as the follow up treatment (T. Hyland, B. Delgado, G. McMenamin, K. Moore, personal communications, March 22, 2008 - July 14, 2008).

Lastly, in order to measure the effect of each treatment method, I designated experimental control plots (C), where no treatment was performed (Table 1).

Table 1. Treatment Methods to Be Tested

T1	Modified Scorched Earth, follow up with Modified Scorched Earth
T2	Rodeo® + Activator 90, follow up with Rodeo® + Activator 90
T3	Rodeo® + Activator 90, follow up with Modified Scorched Earth
C	No Treatment

Sampling Unit and Plot Design

My experimental design principally sought to eliminate 'edge effects'; the effect vegetation outside of my treatment plots may have on the sampling unit itself (Figure 2). Edge effects were particularly important to address in this study because of the high density of Cape ivy at each site and the potential for Cape ivy to grow from untreated areas into treatment plots.

First, I needed to establish the size of my sampling unit. Following the Field and Laboratory Methods for General Ecology recommendation for areas with closely spaced herbaceous vegetation, I chose a sampling unit of 0.71 meters x 1.41 meters (Brower et al. 1998). Equivalent to one meter squared, the rectangular shape is preferred because it minimizes the distance between the sampler and the center of the sampling area.

Second, I needed to determine a method to prevent the surrounding Cape ivy from encroaching on the sampling unit. This was necessary to ensure that any Cape ivy in the sampling unit (post-treatment) was attributable to re-growth of the treated plant rather than the spread of nearby non-treated Cape ivy. One technique to limit such an edge effect involves 'nesting' the sampling unit in the center of a treatment plot. While the entire plot is treated (with both initial and follow-up applications), only the center sampling unit is monitored; this allows the treated area surrounding the center sampling unit to act as a buffer against the non-treated Cape ivy which lies just outside of the plot. Knowing that Cape ivy grows one foot per month (Alvarez 1995, Hillis 1994, and confirmed by my own field test), I decided that a three foot (one meter) buffer surrounding the center sampling unit was sufficient to prevent the influence of edge effects between monitoring visits, with monitoring occurring at 3 month intervals. Thus, each treatment plot (including the center sampling unit plus the one meter buffer) equals an area of 2.71 meters x 3.41 meters. This plot size was measured and staked for the control plots as well, despite the fact that there was no treatment to be performed in these plots.

Next, I needed to ascertain the distance required between plots to ensure that the Cape ivy plant(s) in each plot were discrete. Cape ivy's vegetative growth makes differentiating individual plants challenging. If two treated plots contained vegetation from a single Cape ivy plant, the extent of the plant's die-back (post-treatment) could not be attributed to either treatment method individually, preventing a comparison by treatment method. Similarly, if the vines of a single Cape ivy plant extended across a treatment and a control plot, treatment applied to one portion of the plant could cause die-back of leaves within the control plot, negating the comparison. Researchers performing studies similar to mine have placed the spatial correlation of their plots at one to two meters (Peters C. pers comm. Nov. 12, 2008, Baxter T. pers comm. July 15, 2008). In keeping with this standard I chose to space my plots 1.5 meters apart, believing this is sufficient distance to ensure that each plot contains discrete Cape ivy plants.

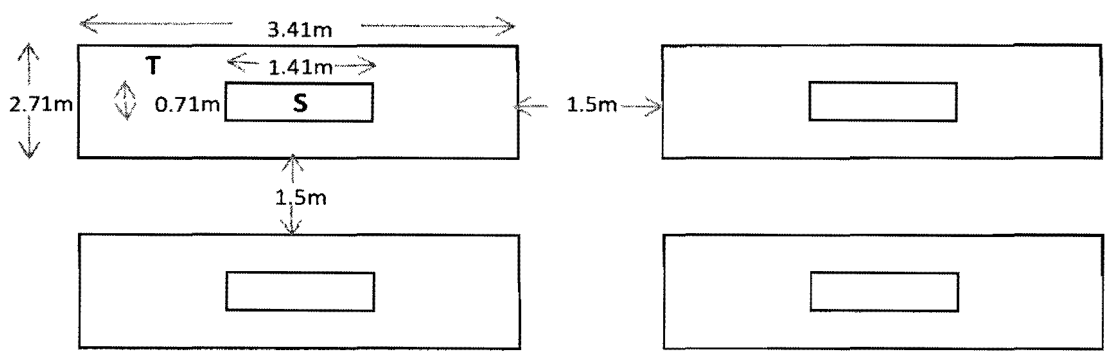


Figure 2. Sampling Unit and Plot Design. S = sampling unit (0.71m x 1.41 m) and T = treatment plot (2.71m x 3.41m).

Finally, I conducted a field test to check my assertion that a one meter buffer surrounding the sampling unit is sufficient to prevent edge effects from surrounding non-treated Cape ivy for an interval of three months. The field test consisted of measuring the 30-day growth of a main Cape ivy stem with a meter tape. To increase the reliability of results the field test was replicated on ten Cape ivy stems, each in separate plots. As illustrated in Figure 3 below the Cape ivy exhibited a mean growth of 28.56 cm (11.24 inches).

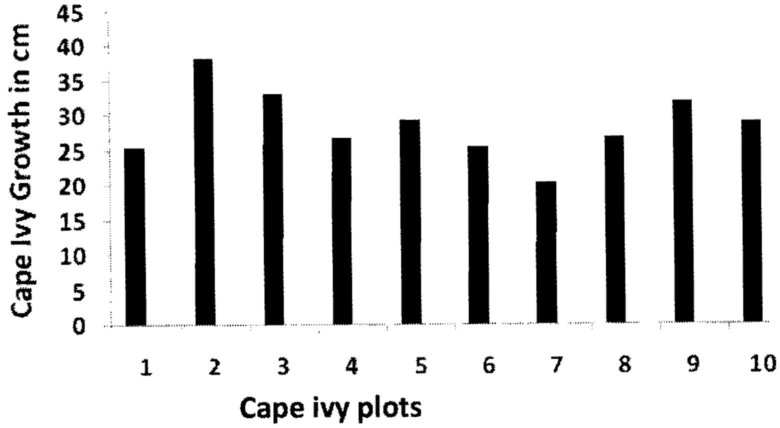


Figure 3. Cape Ivy Growth Over One Month; Mean growth = 28.56 cm
Field measurements collected along Coward Creek in Watsonville, Ca in May 2008.

Results from this field test supported my assertion that a one meter buffer surrounding the sampling unit was sufficient to prevent edge effects from surrounding non-treated Cape ivy for an interval of three months. This field test was performed during a drier rain year therefore the growth of Cape ivy will most likely be faster in wetter rain years due to the plant's affinity for moisture. Researchers conducting similar studies may want to increase buffers around sampling units or spacing between plots for the possibility of a wetter rain year.

TREATMENT TECHNIQUES

Volunteers were used to perform the hand removal technique(s) for the T1 treatment method. While all volunteers had some experience with invasive plant removal, the abilities of volunteers did vary. The volunteers ranged from age 18 to 58. Before hand removal began at sites I gave an explanation and demonstration of the method; explaining the growth patterns of Cape ivy and showing how to remove the Cape ivy by hand including the rhizomes, stolons, and hair-like roots. Volunteers were assigned to teams of three and one person was the timekeeper.

To prevent herbicide drift from affecting nearby non-herbicide treatment areas I placed wind blocks (constructed either from silt fences or similar material) at the edge of treatment plots during R+A90 application. Additionally, R+A90 treatments were not applied prior to, during or after recent rain (24 hours), during periods of wind, or under cold conditions (< 40 degrees C).

Each treatment method was replicated ten times at each site, totaling 40 plots treated per method (T1, T2, T3, C). Treatment plots were placed within accessible areas to allow for removal by volunteers. The treatment applied to each plot was selected randomly, using a randomized block design.

TIMING OF TREATMENT APPLICATIONS

Treatment applications began in July 2008 and concluded in September 2009. I established the timing of treatment applications based on expert advice, knowledge of Cape ivy life history, and species protection measures.

I applied all initial treatments between July and September in accordance with recommended species protection measures and permit constraints (Table 2). Specifically T1 treatment (MSE/MSE) was postponed until after July 1st to prevent the disturbance of California red-legged frogs and T2 (R+A90/R+A90) and T3 (R+A90/MSE) treatments were postponed until after August 1st to avoid impacts to nesting habitat. Furthermore, initial T1 treatment was completed prior to October 15th in compliance with permits governing ground disturbance. Taken together these measures were necessary to observe the 200 foot seasonal buffer surrounding established riparian vegetation which is detailed by the U.S. Fish and Wildlife Service in the Section 7 Consultation (Biological Opinion), the California Department of Fish and Game in the 1602 Streambed Alteration Agreement, and the County of Santa Cruz in the riparian exception permit.

I applied follow up T2 treatment in January and February; the height of Cape ivy flowering and peak time when water is transported from the plant tissues to the roots via passive absorption (Robison 2006). This period in the lifecycle of Cape ivy is regarded by some researchers as the best time to apply herbicide because the passive absorption process is thought to lead to higher likelihood of herbicide absorption in the plant's roots (e.g. Bossard et al. 2000). Follow up T1 and T3 treatments were conducted in March with the aim of removing Cape ivy that re-sprouted from underground roots.

Discussion of minimal differences in results between sites due to the timing of applications can be found in Appendix J.

Table 2. Initial and Follow-up Treatment Times for Methods at all Sites

	T1: MSE / MSE	T2: H+S / H+S	T3: H+S / MSE
Site 1: Coward Crk	Sept. 08, March 09	Sept. 08, Jan. 09	Sept. 08, March 09
Site 2: Glen Deven	Sept. 08, March 09	Aug. 08, Feb. 09	Aug. 08, March 09
Site 3: Big Basin	July 08, March 09	Aug. 08, Feb. 09	Aug. 08, March 09

Vegetation Sampling

To evaluate the effect of treatment on the regeneration of the plant community within each plot, I sampled species-specific percent cover before application of treatments (initial and follow-up) and after a period of twelve months. I estimated percent cover for all plant species with the aid of a 0.71 meter x 1.41 meter quadrat strung with a grid of strings (Bonham 1989). Applying the point-intercept method; I observed what plant(s) laid directly beneath each string intersection and tallied one point for each positive. I recorded the percent cover, within each sampling unit, for all herbaceous and small woody plant species; non-native, native, and Cape ivy. Canopy cover was not included in this sampling of vegetation.

Cost-Effectiveness

The cost-effectiveness of the treatment methods were evaluated in terms of the decrease in cover of Cape ivy per dollar spent. I measured direct costs of implementing each treatment method, including gloves, herbicides, and herbicide spray equipment (based on unit cost for 2008). Labor costs were benchmarked on average crew wages for Santa Cruz County ($10/hr). Costs that I did not track, but which are customary for riparian restoration projects, include re-vegetation, erosion control, and monitoring.

Statistical Analysis

I used mixed effects logistic regression to fit statistical models representing each hypothesis, and I compared these models using Akaike's Information Criterion (AIC) (Burnham and Anderson 2002).

I compared models using evidence ratios (ER) Burnham and Anderson (2002) measuring the relative support in the data for one hypothesis versus another. Two types of comparisons were made: (a) to compare pre-treatment and post-treatment cover, I included as a fixed effect an indicator variable denoting pre- versus post-treatment cover as a fixed effect; and (b), to compare treatments to controls or two treatments to each other, I included as a fixed effect an indicator variable denoting the two treatments to be compared. I also included a random effect for sampling sites (Coward Ck, Glen Deven, or Big Basin), to allow for unaccounted variation between sites. In each comparison, evidence ratios were computed between models including the fixed effects (representing the hypotheses that (a) change occurred or (b) the treatments differed), and models excluding the fixed effects (representing the hypotheses that (a) no change occurred, or (b) the treatments were the same). I computed evidence ratios from AIC weights, which in turn were computed from AIC scores corrected for small sample size (Burnham and Anderson 2002). Study site (1, 2, or 3) was included as a random effect in each model.

In order to facilitate objective, accessible conclusions, I interpreted ranges of evidence ratios using the terms defined in Table 3.

Table 3. General Guidelines for Interpreting Evidence Ratios. The strength of evidence of one model over another can be interpreted by using the evidence ratios. Each descriptive term (e.g. "decisive", "strong", "substantial", or "minimal") is meant to show strength of evidence in favor of the competing *Difference* and *No Difference* hypotheses.

Evidence for Model 2 (M2)		**Evidence for Model 1 (M1)**	
DECISIVE	ER (M1/M2) < 1/100	**DECISIVE**	ER (M1/M2) > 100
STRONG	ER (M1/M2) < 1/10	**STRONG**	ER (M1/M2) < 100
SUBSTANTIAL	ER (M1/M2) < $1/\sqrt{10}$	**SUBSTANTIAL**	ER (M1/M2) < 10
MINIMAL	ER (M1/M2) < 1	**MINIMAL**	ER (M1/M2) < $\sqrt{10}$

For the cost analysis, I compared average costs by method by comparing average direct costs. No statistical analysis was done for cost comparison. All statistical analyses for this study were performed using the R Statistical Program (R version 2.5.1 (2007-06-27)).

RESULTS

EFFECTS ON CAPE IVY COVER

All three treatment methods (T1, T2, and T3) resulted in a reduction in Cape ivy cover compared to control plots. However each treatment method resulted in a different level of reduction suggesting differences in effectiveness between treatment methods. Graphically, a clear reduction in cover was apparent in the treated plots (Figure 4).

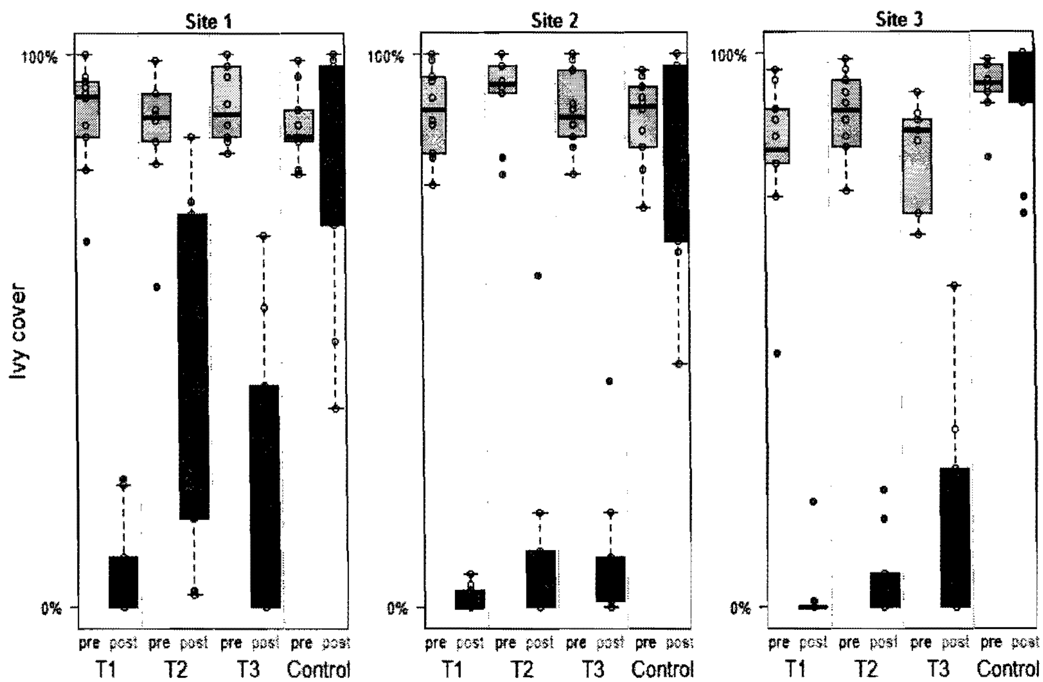


Figure 4. Pre and Post Treatment Cape ivy Cover.
Site 1 is along Coward Creek in Watsonville dominated by sycamores and buckeyes. Site 2 is along Garrapata Creek in Big Sur dominated by redwoods. Site 3 is along Waddell Creek in Big Basin State Park dominated by alders. T1 = MSE + MSE; T2 = Rodeo + Rodeo; T3 = Rodeo + MSE.
The data in this box-and-whisker plot represents the range, mean, and median of cover data for each treatment method at each site. The "box" contains the middle half of the data points. The thick black line in the box is the median of all the data points for that method, at that site. The range of cover data are depicted by the 'whiskers' extending from the box, which extend to the lowest and highest data points, excluding outliers. The small circles are the data points; there are ten data points for each method at each site. An outlier is any value that lays more than one and a half times the length of the box from either end of the box (Tukey 1977).

While there was limited variation, over time, of Cape ivy cover between sites, the potential causes leading to these differences are interesting and informative for those managing Cape ivy. The minimal variability of post-treatment Cape ivy cover among sites may have been partially due to site differences in dominant tree cover, soil moisture, air temperature, treatment timing and personnel abilities. For more details about variation between sites see Appendix J.

The model comparison results (Table 4) decisively support the hypotheses that there was a reduction between pre- and post-treatment cover in treated plots, whereas there was minimal evidence either way for change versus no-change in the control plots.

Table 4. Pre and Post Treatment Cape Ivy Cover Model Comparison. The data presented in this table represents cover averages.

Treatment	Site 1: Coward Creek Pre and Post		Site 2: Glen Deven Pre and Post		Site 3: Big Basin Pre and Post		Avg Cape Ivy Cover % Reduction	Support for Difference Between Pre and Post Cover: Evidence Ratios
1	89.67	4.42	90.00	2.25	80.08	2.08	84.13	15.41×10^8
2	86.67	33.08	92.17	9.00	88.92	4.33	71.73	48.74×10^4
3	90.92	31.83	89.92	9.83	83.67	11.17	73.27	82.64×10^4
C	87.42	79.20	80.00	74.09	93.42	92.08	5.13	1.31×10^{-2}

Comparison between pairs of models (Table 5) provided decisive evidence in support of a difference between post-treatment cover in treated versus control plots.

Table 5. Treatment Method vs Control Comparison Using Evidence Ratios

Treatment Methods Compared	Support for No-Difference Between Methods: Evidence Ratios	Support for Difference Between Methods Evidence Ratios	Descriptive Terms for Interpreting Evidence Ratios
T1:T4	1.35×10^{-10}	7.39×10^9	**decisive** evidence in favor of ***Difference*** hypothesis
T2:T4	1.34×10^{-6}	7.45×10^5	**decisive** evidence in favor of ***Difference*** hypothesis
T3:T4	2.19×10^{-7}	4.56×10^6	**decisive** evidence in favor of ***Difference*** hypothesis

Because all of the "difference" hypotheses were supported, I compared the treatment methods to each other to evaluate if one treatment method was better than the others, and not just better than the control. There was minimal evidence either way for there being a difference or no difference between the treatments (Table 6). Evidence ratios lower than 10 equal minimal evidence. Complete AIC tables showing comparisons between methods can be found in Appendix C.

Table 6. Comparison Between Treatment Methods Using Evidence Ratios

Treatment Methods Compared	Support for No-Difference Between Methods: Evidence Ratios	Support for Difference Between Methods Evidence Ratios	Descriptive Terms for Interpreting Evidence Ratios
T1:T2	0.48	2.08	**minimal** evidence in favor of difference between methods
T1:T3	0.93	1.07	**minimal** evidence in favor of difference between methods
T2:T3	2.81	0.36	**minimal** evidence in favor of no-difference between methods

In summary, there was decisive evidence that all of the treatments reduced Cape ivy cover. The control plots did not change substantially, and no substantial evidence was obtained as to whether treatments differed from each other or not. There was however slight evidence that T2 and T3 did not differ from each other (i.e. that they were equally effective); and slight evidence that T1 led to lower Cape ivy cover than T2 (i.e. that T1 was more effective).

EFFECTS ON NATIVE PLANT COVER

The results for native cover while not yielding decisive evidence did show strong evidence for a change in native plant cover as a result of treatment methods. All three treatment methods (T1, T2, and T3) caused an apparent change in native plant cover, and had varying effects.

Before application of control treatments, native plant cover was inconsistent between plots and sites (Figure 5, Table 7). This was expected due to the patchy growth patterns of most plant populations. Pre-existing native plant populations were mostly comprised of woody stemmed and rhizomatous plant species since they could compete more successfully with the Cape ivy. California blackberry (*Rubus parvifloras*) was common among all three sites. Complete vegetation sampling results for each site can be found in Appendix D.

Some differences in post-treatment native plant cover were apparent, and these differences between treatments can be seen in Figure 5.

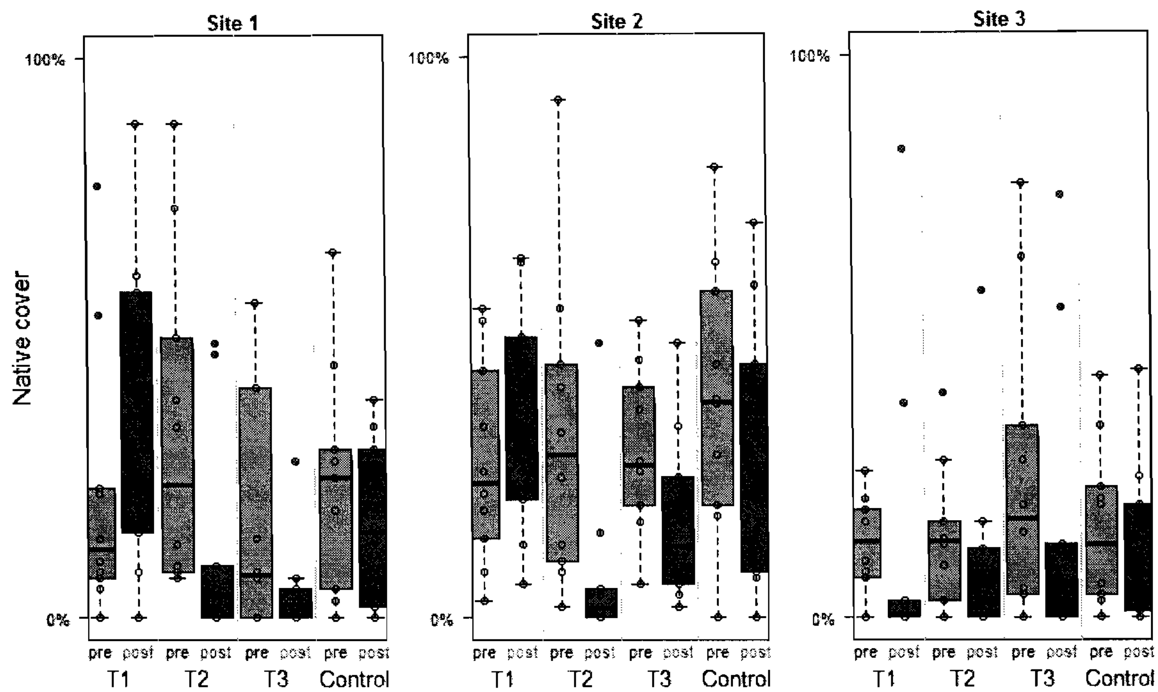


Figure 5. Pre and Post Treatment Native Plant Cover. Site 1 is along Coward Creek in Watsonville dominated by sycamores and buckeyes. Site 2 is along Garrapata Creek in Big Sur dominated by redwoods. Site 3 is along Waddell Creek in Big Basin State Park dominated by alders. T1 = MSE + MSE; T2 = Rodeo + Rodeo; T3 = Rodeo + MSE. This box-and-whisker plot displays the range, mean, and median of native plant cover pre- and post-treatment, for all sites.

All treatment methods (T1, T2, T3) appear to have resulted in a change in native plant cover. While T2 and T3 appeared to decrease native plant cover, T1 appeared to increase the average cover. Reduced cover in T2 and T3 plots is likely due in some part to non-target effects of herbicide. Additionally, T1 was the only treatment method to increase the diversity of native plant cover overall. This change was mostly due to recruitment of native trees on-site.

The variability of post-treatment native plant cover among sites may have been partially due to site differences in seedbank, and initial native plant cover. For more details about variation between sites see Appendix J.

The model comparison revealed ***strong*** evidence in support of a difference between pre- and post-treatment cover for T1 and T2 plots, and ***substantial*** evidence in support of a difference between pre- and post-treatment cover for T3 and C plots (ER=10.9, ER<10 respectively, Table

7). These results agree with expectations, except for the change in the control plots, which was unexpected.

Table 7. Pre and Post Treatment Native Plant Cover Comparison for All Three Sites

Treatment	Coward Creek Pre and Post		Glen Deven Pre and Post		Big Basin Pre and Post		Average Native Plant Cover % Change	Support for Difference Between Pre and Post Cover: Evidence Ratios
T1	22.00	36.00	26.60	45.00	11.80	14.50	**+52.0**	**18.12**
T2	32.90	15.00	36.60	3.19	19.10	9.70	**-65.0**	**10.95**
T3	16.70	4.80	30.70	15.00	27.00	15.90	**-54.5**	**8.23**
C	19.50	16.60	35.20	34.00	22.10	14.50	**-17.6**	**8.54**

Additionally, specific site examples illustrate sizeable differences between treatment effects. For example, at Site 1 the change in cover as a result of T1, T2 and T3 was similar. However, T1 plots exhibited an increase in cover, while T2 and T3 plots showed a decrease in native plant cover (Table 7). T1 plots experienced a 64% increase (22.0% to 36.0%), while T2 plots showed a 54.4% decrease (32.9% to 15.0%) and T3 plots demonstrated a 71.3% decrease from previous levels of native plants (16.7% to 4.8% cover).

Associated Costs Of Treatments

Although both T2 and T3 treatments were not as effective at reducing Cape ivy cover or encouraging native plant growth as T1, they were both less costly than T1. A cost comparison for treatment methods 1, 2 and 3 is shown in Table 8. I have listed the average cost per acre per year for each site. I have also provided alternative costs based on using volunteers and existing staff for herbicide application.

Average T1 annual costs were based on gloves, $10/hour labor costs and two treatment applications. T2 average costs were based on herbicide and surfactant costs, hiring an herbicide applicator at $100/hr and two treatment applications. Average T3 costs were based on T2 costs for the first application and T1 costs for the follow up application. Besides the direct costs of labor and supplies for herbicide application, replanting costs for the treated area should be expected to be higher than non-chemical treatments, possibly due to non-target effects of Rodeo (glyphosate) herbicide. Regarding herbicide treatments, there are new methods that utilize multiple management techniques and are specifically targeted so as to use less herbicide and/or surfactant, reducing the impacts of herbicide application.

Cost tracking tables for each site and each method can be found in Appendix E. A cost breakout of all time and materials for each method, including estimates using volunteers and existing staff for herbicide applications, can be found in Appendix F.

Table 8. Treatment Method Comparison Using Average Cost/Acre/Year

	Coward Creek	Glen Deven	Big Basin	**Average $/acre/year**	Using Volunteers and Vol. Coordinator	Using Staff for Herbicide Application
T1	$65,479	$42,688	$31,128	**$46,592**	$6,160	
T2	$12,661	$9,152	$12,931	**$11,893**		$2,632
T3	$39,822	$37,500	$24,590	**$34,443**	$1,432 + $3,160 = $4,592	

While average costs for treatment methods may seem high, costs can be substantially reduced by using volunteers or existing staff (Table 8). Costs may also be reduced by providing more extensive training for staff or volunteers. Some of the people doing hand removal for this study may have been more efficient if they had more experience or training.

Using volunteers for T1 could reduce costs to $6,160 per acre per year. These costs are based on hiring a part-time volunteer coordinator for $20 to $25 per hour to coordinate volunteer days and the cost of materials (Appendix F). In addition to reducing costs, using volunteers can also to engage the community in stewardship, and provide education to prevent future introduction of invasive plants.

First year costs for T2 could be reduced to $2,632 per acre per year if an employee were to apply the herbicide with a backpack sprayer. These costs are based on paying an employee $20 per hour to apply herbicide. In addition to reducing costs, having an employee familiar with the site resources (native plants, wildlife habitats) apply herbicide could help to protect those resources from herbicide overspray.

DISCUSSION

While most of the results of this study were not surprising, there were a couple of unexpected outcomes. I had expected the combination of herbicide application and hand removal (T3) to be the most cost-effective for Cape ivy control and native plant recovery. However, this did not turn out to be true. While a combination of methods may be most effective for Cape ivy over a longer time period, for the first year of treatment, a considerable amount of increased cost was associated with a small amount of reduced Cape ivy cover (T3 vs. T2). A cost comparison of Cape ivy treatment methods is shown in Table 8. I had also expected to see post-treatment native plant recovery more closely associated with certain treatment methods. While T1 did increase average native plant cover and T2 and T3 reduced average native plant cover, the changes in native vegetation were not statistically decisive.

The results of this study support previous findings from similar studies related to effectiveness of treatment methods and cost. Previous studies have found that cost of invasive species in general is high (Pimental 2000; Robison 2006). The cost results from this study definitely support this result; $46,000 per acre/year is not a low cost for hand removal. While T1 cost results were high for this study, costs can be reduced to less than 1/7 of the cost by using volunteers (Table 8). Costs may be reduced by using crews with more specific training. The volunteers who removed Cape ivy for this study received only basic training and most people did not have previous experience removing Cape ivy by hand.

Results from this study also support the finding that effectiveness of herbicide control methods for invasive species is more effective during certain times of the year (Bossard 1995). This is supported by the differences in effectiveness of herbicide treatments at Site 1 and Site 3 (Appendix J). Due to time restrictions and manpower availability, the initial herbicide treatment at Site 1 was applied one month later than at Site 3, in September 2008. The herbicide was much less effective at Site 1. The Cape ivy at this time was most likely farther along in the "die-back" life stage and not as able to absorb and transport the herbicide to the roots. Cooler temperatures

(~ 65 degrees Fahrenheit), and lower soil moisture at this site most likely further decreased the Cape ivy's ability to absorb herbicide. The results from Site 1 may also differ from Site 3 because the follow up application at Site 1 was applied one month earlier than at Site 3, in January 2009. The Cape ivy at Site 1 therefore had less time between treatments. Environmental conditions (rainfall) may also have been different.

Additionally, this study also maintains that success is dependent on follow-up and monitoring efforts. This is supported by the re-growth of Cape ivy between and following treatments, and the fact that none of the treatment methods were successful in extirpating Cape ivy from all treatment plots within the span of twelve months.

MONITORING

Monitoring costs were not included in the cost tracking for this study. However, monitoring is critical for success in management of any invasive plant species. For Cape ivy a minimum of five years is recommended, and at least twice a year (early winter and mid spring) for the first 5 years. Monitoring of a one-acre site can take 2 to 4 hours (depending on terrain) if no follow-up treatment is needed. If follow-up spray application or hand removal is needed, monitoring time could extend to 4 to 8 hours, depending on the extent of re-growth. If data are being collected, the time spent collecting data is dependent on sampling method. If the sampling method used in this study is employed, sampling of a 1 m^2 plot could take from one minute to 15 minutes. Conservatively speaking, a monitoring budget should contain 8-16 hours a year per acre of treated Cape ivy. A range is given here because more monitoring time may be required in year 3 or 4 as opposed to years 1 or 2 due to re-growth.

MANAGEMENT RECOMMENDATIONS

For those seeking to control Cape ivy, it is important to remember that each site is different therefore the following recommendations should be taken as general approaches and not followed without careful consideration of site specific conditions. Site assessments should be conducted and best practices followed to minimize disturbance to any existing habitat patches.

Generally, I would recommend T2 for first year treatment for large areas highly invaded with Cape ivy (>50% Cape ivy cover) where native plants are suppressed. I would recommend T1 for first year treatment for small areas with >50% Cape ivy cover or large areas with less than 50% Cape ivy cover, especially areas with large amounts of native plants present. I would not recommend T3 for first year treatment as there was no substantial benefit from following up with hand removal as opposed to following up with herbicide application; hand removal also requires a larger labor force and potentially more cost.

T2 is better suited for areas with >50% Cape ivy cover, and where native plants are suppressed due to the lower potential for non-target herbicide effects on native plants. Additionally, the cost-effectiveness of T2 makes this method more advantageous. While T1 was overall more effective, the cost-benefit ratio of T2 is higher. The timing for this method is critical for success. Due to treatment timing and site conditions, there was a considerable difference in the effectiveness between T1 and T2 at site 1 (Coward Creek) (Appendix J). Where herbicide treatments are allowed and not a threat to wildlife and natural resources, T2 is the most cost-effective choice for initial treatment if your long-term management goal is control/eradication.

T1 is well suited for areas with large amounts of natives because this method allows for natives to be worked around and not disturbed. Where using herbicides is not an option or not advisable due to large amounts of native plants, T1 is the best choice. If your management goal is containment of large populations of Cape ivy, T1 or T3 should be considered; as these methods result in a swath of bare ground more conducive to Cape ivy monitoring efforts.

CONCLUSION

The primary goal of this research was to quantify achievable outcomes for reducing Cape ivy cover cost-effectively in riparian ecosystems in coastal Central California. Three treatment methods were tested. Decisive evidence was found that all three treatments reduced Cape ivy cover (ER $\geq$ 1000), and decisive evidence was found that post-treatment Cape ivy cover was less in treated areas than in control areas (ER $\geq$ 1000). Treatment methods 1, 2 and 3 reduced Cape ivy cover by greater than 80%, with costs ranging from $11,582 to $46,592 per acre per year. Strong evidence was found that native plant cover increased with treatment T1, and decreased with treatment T2; and substantial evidence was found that native plant cover also decreased with treatment T3 and in un-treated areas. Treatment effects on native plant cover ranged from a decrease of 65% (likely partially due to non-target herbicide effects), to a 52% increase (likely due to removal of competing Cape ivy).

In summary, treatment method 1 decreased Cape ivy cover by 84%, and increased native plant cover by an average 52%. Treatment method 2 decreased Cape ivy cover by 72%, and decreased native plant cover by an average 65%. Treatment method 3 decreased Cape ivy cover by 73%, and decreased native plant cover by an average 55%.

T1 was the most costly treatment, followed by T3, and T2 was the least costly (Table 8). Costs were collected during this research experiment because cost is a critical driver for the management of Cape ivy on both private and public lands. For more information on cost, see the Results section and Appendix F.

In response to my key research questions:

1) T1 had a slightly higher reduction of Cape ivy cover after twelve months (minimal evidence).
2) T2 is most cost-effective (per dollar) for Cape ivy control over twelve months.
3) T1 was the only treatment for which there was strong evidence for an increase in native cover twelve months after initial treatment.

I have provided recommendations for the future management of Cape ivy at my three study sites. These recommendations can be found in Appendix I: Management Recommendations. These recommendations include first year treatments as well as follow-up treatments and long-term monitoring frequencies.

Cape ivy, like most other invasive plants, requires long-term monitoring and follow-up treatment. In order for land managers to effectively manage invasive plant populations, long-term funding is critical. Invasive species are a leading threat to biodiversity and California's wildlands, second only to habitat destruction, and they cost California hundreds of millions annually in management costs. Furthermore, by only receiving short-term funding, thousands of eradication projects each year are failing due to lack of monitoring. State policies are needed to authorize a minimum of five-year dedicated funding for invasive plant removal and habitat restoration projects, as they are necessary and critical to protect and preserve California's wildlands and economy in the future.

References

Alvarez ME. 1995. The impact of German ivy (*Senecio mikaniodes*) on the richness and composition of three native plant communities. Masters thesis. Sonoma State University, Rohnert Park, CA.

Alvarez ME. 1997. Management of Cape-ivy (*Delairea odorata*) in the Golden Gate National Recreation Area. In: California Exotic Pest Plant Symposium 1997 Proceedings. Kelly M, Wagner E, and Warner P (eds). California Exotic Pest Plant Council, California. p. 91-95.

Alvarez ME, Cushman H. 2002. Community-Level Consequences of a Plant Invasion: Effects on Three Habitats in Coastal California. Ecological Applications, 12(5): 1434-1444.

Archbald G. 1995. Biology and control of German ivy. Report to California Department of Fish and Game, Pesticide Applications Seminar.

Baker HG. 1986. Patterns of Plant Invasions in North America. In: Ecology of Biological Invasions of North America and Hawaii. Mooney HA and Drake JA, (eds). Springer-Verlag, New York, NY. p. 44-57.

Bakker JD, Wilson SD. 2004. Using ecological restoration to constrain biological invasion. Journal of Applied Ecology 41: 1058-1064

Balciunas JK, Smith L. 2006. Pre-Release Efficacy Assessment, in a Quarantine, of a Tephritid (Diptera) Gall Fly Being Considered as a Biological Control Agent for Cape ivy (*Delairea Odorata*). Biological Control: Theory and Application in Pest Management. 39(3):516-524.

Barrett SCH, Richardson BJ. 1986. Genetic attributes of invading species. In: Ecology of Biological Invasions: An Australian Perspective. Groves RH and Burdon JJ (eds). Australian Academy of Science, Canberra. p. 21-33.

Baxter T, Bromberg J. 2005. Cape ivy removal at Golden Gate National Recreation Area and Point Reyes National Seashore. In: California Invasive Plant Council 2005 Proceedings. California Invasive Plant Council, California. Conference poster.

Bazzaz FA. 1986. Life history of colonizing plants: Some demographic, genetic, and physiological features. In: Ecology of Biological Invasions of North America and Hawaii. Mooney HA and Drake JA (eds). Springer-Verlag, New York, NY. p. 96-110.

Berrill M, Bertram S, McGillivray L, Kolohon M, Pauli B. 1993. Effects of low concentrations of forest use pesticides on frog embryos and tadpoles. Environmental Toxicology and Chemistry 13(4):657-664.

Biggerstaff MA, Beck CW. 2007. Effects of English ivy (*Hedera helix*) on seed bank formation and germination. American Midland Naturalist 157:250-257.

Blumenthal D. 2005. Interrelated Causes of Plant Invasion. Science 310: 243-244.

Boggs, J., McMurray, S., Leslie, D., Engle, D., Lochmiller, R. 1991. Influence of habitat modification on the community of gastrointestinal helminths of cotton rats. Journal of Wildlife Diseases. 27(4):584-593.

Bonham CD. 1989. Measurements for terrestrial vegetation. John Wiley & Sons, Inc., New York, NY.

Bossard C, Benefield C. 1995. War on German ivy: Good news from the front. In: Proceedings California Exotic Pest Plant Council 1994 Symposium. Lovich J, Randall J, and Kelly M (eds). Vol.1:1995. p. 63-64.

Bossard C, Randall J.M., Hoshovsky M.C. 2000. Invasive plants of California's wildlands. University of California Press, Berkeley, California.

Bossard C, Moore K, Chabre C, Woolfolk A, King J, and Johanek D. 2005. A test of repeat-flaming as a control method for poison hemlock (Conium maculatum), Cape ivy (Delairea oderata) and periwinkle (Vinca major). In: Proceedings California Invasive Plant Council 2005 Symposium. Skurka G (ed). Vol. 9: 2005. P.29 -34.

Brickell C, Zuk JD. 1997. The American Horticultural Society A-Z Encyclopedia of Garden Plants. DK Publishing, Inc., New York, NY.

Brinson MM, Swift BL, Plantico C, Barclay JS. 1981. Riparian ecosystems: Their ecology and status. U.S. Fish and Wildlife Service Report FWS/OBS-81/17.

Brower JE, Zar JH, von Ende CN. 1998. Field Laboratory Methods for General Ecology, Fourth Edition. WCB McGraw-Hill Companies, Inc.

Burnham KP, Anderson D. 2002. Model selection and multimodel inference: a practical information-theoretic approach. 2nd Edition. Springer, New York, NY.

[Cal-IPC] California Invasive Plant Council. 2003. Proceedings California Exotic Pest Plant Council Symposiums Volume 6: 2000, 2001, 2002 Exotic Plants in the Landscape: Processes and Patterns. http://www.cal-ipc.org/symposia/archive/.

[Cal-IPC] California Invasive Plant Council. 2005. California invasive plant inventory. http://www.cal-ipc.org/ip/inventory/.

[Cal-IPC] California Invasive Plant Council. 2005. Proceedings California Invasive Plant Council Symposium Volume 9: 2005 Prevention Reinvention: Protocols, Information, and Partnerships to Stop the Spread of Invasive Plants. http://www.cal-ipc.org/symposia/archive/.

[Cal-IPC] California Invasive Plant Council. 2006. Proceedings California Invasive Plant Council Symposium Volume 10: 2006 Research and Management: Bridging the Gap. http://www.cal-ipc.org/symposia/archive/.

[Cal-IPC] California Invasive Plant Council. 2007. Proceedings California Invasive Plant Council Symposium Volume 11: 2007 Communication and Conservation: The Human Dimension in Invasive Plant Management. http://www.cal-ipc.org/symposia/archive/.

[Cal-IPC] California Invasive Plant Council. 2008. Cal-IPC News. Quarterly Newsletter of the California Invasive Plant Council. Winter 2007-2008 15(4). http://www.cal-ipc.org/resources/news/.

Catalano S, Luschi G, Flamini P, Cioni L, Nieri EM, Morelli I. 1996. A xanthone from Senecio mikanioides leaves. Phytochemistry 42:1605-1607.

[CDFA and CALIWAC] California Department of Food and Agriculture, California Invasive Weed Awareness Coalition. 2005. California Noxious and Invasive Weed Action Plan. Steve Schoenig (ed.).

[CDFA] California Department of Food and Agriculture. 2006. California weed laws (compiled). California Department of Food and Agriculture Code. Available at: <www.cdfa.ca.gov/phpps/ipc/encycloweedia/ winfo_weedlaws.htm>.

[CDFA] California Department of Food and Agriculture. 2008. Weed Management Areas: Program Details. Available at: http://www.cdfa.ca.gov/phpps/IPC/weedmgtareas/wma_index_hp.htm.

Cleland E, Smith M, Andelman S, Bowles C, Carney K, Horner-Devine M, Drake J, Emery S, Gramling J, Vandermast D. 2004. Invasion in space and time: non-native species richness and relative abundance respond to interannual variation in productivity and diversity. Ecology Letters 7(10): 947.

Cox GW. 1999. Alien species in North America and Hawaii: Impacts on natural ecosystems. Island Press, Washington D.C.

D'Antonio CM, Meyerson L. 2002. Exotic Plant Species as Problems and Solutions in Ecological Restoration: A Synthesis. Restoration Ecology 10 (4): 703–713.

D'Antonio CM, Jackson NE, Horvitz CC, Hedberg R. 2004. Invasive Plants in Wildland Ecosystems: Merging the Study of Invasion Processes with Management Needs. Frontiers in Ecology and the Environment 2(10): 513-521.

D'Antonio CM, Chambers JC. 2006. Using Ecological Theory to Manage or Restore Ecosystems Affected by Invasive Species. In: Foundations of Restoration Ecology. 2006. Society for Ecological Restoration International. Island Press, Washington, DC. p. 260-279.

Davis MA, Grime JP, Thompson K. 2000. Fluctuating resources in plant communities: a general theory of invasibility. Journal of Ecology 88: 528–534.

de la Torre, F., and R. A. Arbesu. 1999. Control of noxious weeds in sensitive areas. In: 10 Encontrol sobre Invasoras Lenhosas, Geres -- Auditorio do Centro de Animacao Terma. p. 203-208.

[DFG] Department of Fish and Game. 2005. Controlling Invasive Species that Affect Native Wildlife. Available at: <http://www.dfg.ca.gov/wildlife/WAP/docs/workshop/invasives.pdf>.

Didham RK, Tylianakis JM, Hutchison MA, Ewers RM, Gemmell NJ. 2005. Are invasive species the drivers of ecological change? Trends in Ecology and Biology 20:470-474.

Drake JA, Mooney HA, di Castri E, Groves RH, Kruger FJ, Rejmanek M, Williamson M. 1989. Biological invasions: a global perspective. John Wiley and Sons, New York, NY..

Elliot W. 1994. German ivy engulfing riparian forests and heading for the uplands. Cal-IPC News. 2(1): 9.

Elton C. [1958] 1972. The Ecology of Invasions by Animals and Plants. Reprint. Chapman and Hull, London.

EO 13112, Executive Order Invasive species. 1999. Federal Register 64(25): 6183-86. Available at: <www.invasivespeciesinfo.gov/laws/execorder.shtml>.

Fagg PC. 1989. Control of Delairea odorata (Cape ivy) in native forest with the herbicide Clopyralid. Plant Protection Quarterly 4:107-110.

Forbert M. 1998. Some tips on herbicide treatment of Cape ivy (Delairea odorata). California Exotic Plant Council News 6:4-5. http://www.cal-ipc.org/resources/news/.

Freshwater V. 1991. Control of English ivy (Hedera helix) in Sherbrooke forest- A practical experience. Plant Protection Quarterly 6:127.

Giesy JP, Dobson S, and Solomon KR. 2000. Ecotoxicological Risk Assessment for Roundup(r) Herbicide. Reviews of Environmental Contamination and Toxicology 167: 35-120.

Gluesenkamp D. 2008. Phone communication regarding Cape ivy control methods.

Haley N. 1997. Weeds in New Zealand. Department of Conservation, New Zealand. Available: http://www.boprc.govt.nz//www/green/weedcopy.htm

Haselwood EL, Motter GG (eds). 1983. Handbook of Hawaiian Weeds. 2nd ed. revised and expanded by Hirano RT, Harold L. Lyon Arboretum, University of Hawaii Press, Honolulu, HI.

Heywood VH. 1989. Patterns, extents and modes of invasions by terrestrial plants. In: Biological invasions: a global perspective. Drake JA, Mooney HA, Di Castri FD, Groves RH, Kruger EL, Rejmanek M, Williamson M (eds). Wiley & Sons, New York, NY. p. 31-55.

Hillis S. 1994. Observed growth rate of Cape ivy in live oak riparian forest in the GGNRA. (unpub. data).

Holling CS. 1973. Resilience and Stability of Ecological Systems. Annual Review of Ecology and Systematics, Vol. 4: 1-23

Holmes PM, Cowling RM.1997. The Effects of Invasion by Acacia saligna on the Guild Structure and Regeneration Capabilities of South African Fynbos Shrublands. The Journal of Applied Ecology 34(2): 317-332.

Howell JT. 1969. Marin Flora Supplement. University of California Press, Berkeley, CA.

Hulme PE, Bremner ET. 2006. Assessing the impact of Impatiens glandulifera on riparian habitats: partitioning diversity components following species removal. Journal of Applied Ecology 43: 43-50.

Johansen J, Geen G. 1990. Sublethal and acute toxicity of the ethylene glycol butyl ether ester formulation of triclopyr to juvenile coho salmon (Oncorhynchus kisutch). Arch Environ Contam Toxicol 19:610-616.

Kreutzweiser D, Thompson D, Capell S, Thomas D, Staznik B. 1995. Field evaluation of triclopyr ester toxicity to fish. Arch Environ Contam Toxicol 28:18-26.

Levine JM, Vila M, D'Antonio CM, Dukes JS. Grigulis K, Lavorel S. 2003. Mechanisms underlying the impacts of exotic plant invasions. Proceedings Royal Society of London Biology: 270:775-781.

Luken JO., and Thieret JW (eds). 1997. Assessment and management of plant invasions. Springer-Verlag, New York, NY.

Luken JO, Mattimiro DT. 1991. Habitat-specific resilience of the invasive shrub Amur honeysuckle (Lonicera maackii) during repeated clipping. Ecological Applications 1:104–109.

Mack RN. 2000. Assessing the extent, status and dynamism of plant invasions: current and emerging approaches. In: Invasive Species in a Changing World. Mooney H and Hobbs R (eds). Island Press, Washington, DC. p. 141–168.

Mason 2006. Impacts of plant invaders and management techniques on native communities: ecological and social perspectives at regional and global levels. PhD Thesis. School of Biological Sciences, University of Wollongong, New South Wales, Australia.

McEvoy PB, Coombs EM. 1999. Biological control of plant invaders: Regional patterns, field experiments, and structured population models. Ecological Applications 9:387-401.

McMenamin G. 2005 – 2009. Phone and in-person communications regarding Cape ivy biology, management techniques, and study design.

McPherson F. 2006. News From the Board. In: The Cypress Cone, The newsletter of the California Native Plant Society, Santa Cruz Chapter (2006).

Mooney HA, Hamburg SP, Drake JA. 1986. The invasion of plants and animals into California. In: Ecology of Biological Invasions of North America and Hawaii. Mooney HA, Drake JA (eds). Springer-Verlag, New York, NY.

Mooney HA, Drake JA. 1989. Biological invasions: A SCOPE program overview. In: Biological invasions: a global perspective. Drake JA, Mooney HA, di Castri E, Groves RH, Kruger FJ, Rejmanek M, Williamson M (eds). Wiley and Sons, New York. p. 491-507.

Moore K. 1997. Battling the kudzu of the West: Controlling Cape ivy (formerly German ivy) by hand removal. California Exotic Pest Plant Council News Fall 1997:4-5.

Mullin BH, Anderson LWJ, DiTomaso JM, Eplee RE, Getsinger KD. 2000. Invasive plant species. Council for Agricultural Science and Technology Issue Paper Number 13:1-18.

Muyt A. 2001. Bush invaders of south-east Australia: a guide to the identification and control of environmental weeds in south-east Australia. R.G. and F.J. Richardson, Australia.

Nelson D. 1999. Cape ivy, Another Problem Plant for the Ventana Wilderness. The Double Cone Quarterly 2(1). Available: http://www.ventanawild.org/-news/se99/capeivy.html.

Newsome AE, Noble IR. 1986. Ecological and physiological characters of invading species. In: Ecology of biological invasions: an Australian perspective. Groves RH, Burdon JJ (eds). Cambridge, Cambridge. p. 1-20.

Neyman J, Pearson ES. 1967. On the Use and Interpretation of Certain Test Criteria for Purposes of Statistical Inference, Part I. Reprinted p.1-66 in Neyman J and Pearson ES Joint

Statistical Papers. Cambridge University Press, Cambridge. 1967 (originally published in 1928).

NISC. 2004. National Invasive Species Council, Executive Order (EO) 13112 (1999).

Noble IR. 1989. Attributes of invaders and the invading process: terrestrial and vascular plants. In: Biological invasions: a global perspective. Drake JA, Mooney HA, di Castri E, Groves RH, Kruger FJ, Rejmanek M, Williamson M (eds). John Wiley and Sons, New York, NY. p. 301-328.

National Park Service. 2011. Invasive Species webpage. Available at: http://www.npca.org/wildlife_protection/biodiversity/report/threats/invasive.html

New South Wales Agriculture. 1993. Noxious Weeds Act of 1993. New South Wales Government. New South Wales. http://www.legislation.nsw.gov.au/viewtop/inforce/act+11+1993+FIRST+0+N

Pearson DE, McKelvey KS, Ruggiero LF. 2000. Non-target effects of an introduced biological control agent on deer mouse ecology. Oecologia 122: 121-128.

Pearson DE, and Callaway RM. 2005. Indirect non-target effects of host-specific biological control agents: implications for biological control. Biological Control 35: 288-298.

Pearson DE, and Callaway RM. 2006. Biological control agents elevate hantavirus by subsidizing deer mouse populations. Ecology Letters 9: 443-450.

Perkins P, Boermans H. Stephenson G. 2000. Toxicity of glyphosate and triclopyr using the frog embryo teratogenesis assay-Xenopus. Environmental Toxicology and Chemistry 19(4): 940-945.

Pimentel D, Lach L, Zuniga R, Morrison D. 2000. Environmental and economic costs of nonindigenous species in the United States. BioScience 50:53-65.

Pinheiro JC and Bates DM. 2000. Mixed-Effects Models in S and S-PLUS. Statistics and Computing Series, Springer-Verlag, New York, NY.

Prezio J. Lankester M, Lautenschlager R, Bell F. 1999. Effects of alternative conifer release treatments on terrestrial gastropods in regenerating spruce plantations. Can. J. For. Res. 29:1141-1148.

R Foundation. 2007. R version 2.5.1 (2007-06-27). The R Foundation for statistical computing.

Robbins W, Weier TE. 1965. Botany: Plant Science, 3rd edition , Wiley International, New York, NY.

Robison R. 2006. Distribution, Growth Analysis and Reproductive Biology of Cape ivy (Delairea odorata Lem syn Senecio mikanioides Walp.) in California. PhD Dissertation. UC Davis, Ca.

Rolando C. 2000. The reproductive biology, natural predators and biological control of Delairea odorata Lem. Masters Thesis. University of Natal, Pietermaritzburg.

Schuette J. 1998. Environmental Fate of Glyphosate. Environmental Monitoring and Pest Management, Department of Pesticide Regulation. Sacramento, Ca.

Searle G, Penman D, Chapman R. 1990. The toxicity of herbicides to the gorse spider mite Tetranychus lintearius. Proceedings 43rd N.Z. Weed and Pest Control Conf: 178-181.

Sheley LE, Krueger-Mangold J. 2003. Principles for restoring invasive plant infested rangeland. Weed Science 51:260-265.

Steel GD and Torrie JH. 1981. Principles and Procedures of Statistics (2nd Edition). McGraw-Hill Book Company, Inc. New York, NY.

Stelljes ME, Seiber JN. 1990. Pyrrolizidine alkaloids in an overwintering population of monarch butterflies (Danus plexippus) in California. Journal of Chemical Ecology 16:1459-1470.

Sweeney BW, Czapka SJ, Yerkes T. 2002. Riparian Forest Restoration: Increasing Success by Reducing Plant Competition and Herbivory. Restoration Ecology 10(2): 392-400.

Tukey JW. 1977. Exploratory Data Analysis. Addison-Wesley, Reading, MA.

[USDA] United States Department of Agriculture. 2006. Exotic and invasive weeds research unit. <www.ars.usda.gov/main/site_main.htm? modecode=53-25-43-00>. Accessed 2006 Sept.

[USEPA] U.S. Environmental Protection Agency, 1998. Reregistration Eligibility Decision (RED): Triclopyr. Office of Prevention, Pesticides and Toxic Substances. EPA 738-R-98-011.

Vitousek PM, D'Antonio CM, Loope LL, Westbrooks R. 1996. Biological Invasions as Global Environmental Change. American Scientist 84(5): 468-78.

Vitousek P.M, D'Antonio CM, Loope LL, Rejmanek M, Westbrooks R. 1997. Introduced species: a significant component of human caused global change. New Zealand Journal of Ecology 21:1-16.

Wagner WL, Herbst DR, Sohmer SH. 1999. Manual of the Flowering Plants of Hawaii. 2 vols. Bishop Museum Special Publication 83. University of Hawai'i and Bishop Museum Press, Honolulu, HI.

Wilcove DS, Rothstein D, Dubow J, Phillips A, Loso E. 1998. Quantifying threats to imperiled species in the United States. Bioscience, 48:607-615.

Williams GM, Kroes R, and Munro IC. 2000. Safety Evaluation and Risk Assessment of the Herbicide Roundup and Its Active Ingredient, Glyphosate, for Humans. Regulatory Toxicology and Pharmacology 31, 117-165.

Williamson M. 1996. Biological invasions. Chapman and Hall, London, UK.

Yates CJ, Hobbs RJ, and Atkins L. 2000. Establishment of Perennial Shrub and Tree Species in Degraded Eucalyptus salmonophloia (Salmon Gum) Remnant Woodlands: Effects of Restoration Treatments. Restoration Ecology 8(2): 135-143.

Appendix A

SCIENCE POLICY CONTEXT, BACKGROUND, APPLICABLE THEORY

SCIENCE POLICY CONTEXT

CAPE IVY AS AN INVASIVE PLANT

Cape ivy (*Delairea odorata*), native to South Africa, is an invasive plant with considerable impacts to ecosystems (Cal-IPC 2005). This detrimental invasive vine is currently expanding its range in coastal California and Oregon. Cape ivy is also listed as a noxious weed in New Zealand (Haley, N. 1997) and Australia (NSW Agriculture 1993). In areas containing predominantly Cape ivy, native species seedling richness has been shown to decrease 75 to 95 percent compared to pre-infestation conditions (Alvarez 1997, Alvarez and Cushman 2002).

ECONOMIC IMPACT

In addition to the ecological impact of ecosystem-damaging plants, the economic costs of managing invasive species are considerable and can lead to lack of appropriate management which in turn contributes to consequent ecological cost. For example, lack of treatment of early infestations can lead to large and costly infestations in the future. One report indicated that the economic cost of invasive species (plants and animals) in the United States is an estimated $137 billion a year nationwide (Pimentel 2000). Due to California's size and resources, the economic impact to California is likely greater than one-fiftieth of $137 billion ($2.7 billion) annually. Invasive species are estimated by the United States Department of Agriculture [USDA] to take over 4,600 acres of public natural lands nationwide daily (2006). As of 2004, over 100 million acres of US land were infested with invasive species (NISC 2004); and this is just the reported amount. In California, noxious (or agricultural) and invasive weeds alone result in hundreds of millions of dollars in control costs and lost productivity annually (CDFA 2005).

LOCAL IMPACT AND PRIORITY

Locally, in coastal Central California, Cape ivy presents a large economic impact and a severe threat to riparian ecosystems (Balciunas 2006) because of its ability to smother native plants and trees and spread quickly. For example, between 1987 and 1997, a 3.5 ha Cape ivy population expanded 87% in the Golden Gate National Recreation Area (GGNRA) in Marin

County, California (Alvarez 1997). The rapid growth rate of Cape ivy coupled with the reduction of indigenous species habitat and species diversity that Cape ivy causes, make control of this species a priority (Alvarez and Cushman 2002).

At the 2006 Cal-IPC symposium, Cape ivy was ranked as one of California's top weeds (along with eleven others). Cape ivy was specifically listed as a threat within riparian areas (Cal-IPC 2006). Riparian ecosystems make up a relatively small portion of total land area in Santa Cruz and Monterey Counties, but typically are more structurally diverse and more productive in plant and animal biomass than adjacent upland areas. Riparian areas supply food, cover, and water (especially important in the arid West) for a large diversity of animals, and serve as migration routes and forest connectors between habitats for a variety of wildlife, particularly ungulates and birds (Brinson et al.1981). Riparian ecosystems, in particular, are threatened by Cape ivy because of the moist soil conditions and shade present in most riparian areas. Cape ivy thrives in these conditions and therefore spreads considerably faster causing more ecological and economic costs.

In Santa Cruz and Monterey Counties, Cape ivy has heavily infested riparian ecosystems along coastal streams and urbanized areas (Robison 2006). California State Parks staff in the Santa Cruz and Monterey Counties (T. Hyland, personal communication, May 1, 2008; M. Paul, personal communication, March 29, 2008), the Big Sur Land Trust (S. Godfrey, personal communication, March 21, 2008), and the California Native Plant Society Santa Cruz Chapter (McPherson 2006) confirm the occurrence of Cape ivy along coastal streams in Santa Cruz and Monterey Counties, and agree that Cape ivy control is a major priority for resource managers, and should be made a priority by funding agencies as well.

FUNDING NEEDS

Several land managers estimate they spend more than 50% of their annual operating budget on control of non-indigenous species. For example, at Golden Gate National Recreation Area and Point Reyes National Seashore, two coastal California parks in the Bay Area, report that over 60% of the Resources Management budget is spent controlling exotic species (Robison 2006). More broadly, the National Park Service's 1999 "Natural Resource Challenge: The National Park Service's Action Plan for Preserving Natural Resources" states that invasive species harm resources at more than 200 parks. The plan identifies tens of millions of dollars in immediate needs for high-priority control and management efforts, but insufficient funding continues to limit the ability of the Park Service to address such widespread concerns (NPS 2011).

Control costs vary according to the method used and number of subsequent re-treatment applications, complicating the allocation of limited funds. Documented cost of control methods is essential information for resource managers to designate resources, complete management plans, and for policymakers to inform funding allocations.

EXISTING POLICY AND POLICY GAPS

Several laws and organizations manage invasive species, yet government funding for invasive species control is limited (DFG 2005). One law in particular is President Clinton's Executive Order (EO) 13112 (1999). This order established the National Invasive Species Council (NISC) charged with developing a plan to monitor and protect against the spread of invasive species, and to aid in the restoration of invaded areas. While a plan was created (NISCP), no funding was allocated for invasive species management. Additionally, the Healthy Forests Initiative and the Great Basin Restoration Initiative, both federal initiatives, have mandates to manage invasive plants, but lack funds to adequately carry out this mission.

California also created a plan, similar to the one established by the National Invasive Species Council (NISC), for addressing the invasive species challenge, named the California Noxious & Invasive Weed Action Plan (CDFA and CALIWAC 2005). Like the federal state of affairs, California is lacking in adequate funding for the implementation of their plan. Funding is needed for prevention, control, and eradication efforts as well as agency and organizational staff time to coordinate these efforts (CDFA and CALIWAC 2005). CDFA's noxious weed program has a well-defined program to aggressively implement control and eradication efforts, however funding for CDFA's noxious weed control has been continuously cut over the last twenty years from millions to $0 starting July1, 2011.

To secure funding necessary for weed management, California needs more substantial policies and a legal framework with clear direction regarding invasive species prevention, control, and eradication, to reduce the effects of invasive species on wildlife (DFG 2005).

NEED FOR DOCUMENTATION OF SUCCESSFUL AND UNSUCCESSFUL CONTROL METHODS

Proven successful and cost-effective control methods are needed to inform the funding needs and management of Cape ivy in riparian areas (C. Spohr (CA State Parks, personal communication, May 1, 2008; B. Delgado (BLM Fort Ord), personal communication, March 22, 2008; G. McMenamin (Restoration Consulting), personal communication, April 18, 2008; Robison 2006). This information is needed to inform policymakers, restoration practitioners, researchers, and resource managers about the effectiveness of tested control methods, the associated costs, and the potential need for post-disturbance treatments.

Within the last twenty years, several restoration practitioners have tested Cape ivy control methods (Bossard and Benefield 1995, de la Torre 1999, Fagg 1989, Forbert 1998, Moore 1997). However, there is a lack of replicable, quantitative studies that compare success of different control methods for Cape ivy in the current scientific literature. A review of all studies related to control and management methods for Cape ivy produced only three publications (Bossard and Benefield 1995, Bossard et al.2005, Fagg 1989) in which the results of control methods were quantified. Each of these studies focused on a particular control method (herbicide treatment or flaming) rather than a comparison of control methods. Additionally, none of the identified studies provided a quantifiable comparison of the cost-effectiveness of control methods for Cape ivy.

HOW KNOWLEDGE GAPS DIRECTLY LIMIT POLICY GOALS

The cost of achieving pragmatic, realistic goals cannot be set without the knowledge of the effectiveness and cost of control methods used to control Cape ivy (D'Antonio and Chambers 2006). Gaps in the scientific knowledge base limit decision makers from assigning appropriate costs, and therefore funding for invasive species control (D'Antonio and Chambers 2006). Policy goals are currently limited by this lack of knowledge of achievable outcomes. Policies which support funding allocations for invasive species control is needed to protect California's wildlands, protect overall quality of life for Californians, and reduce management costs in the future.

HOW THIS RESEARCH WILL INFORM POLICY AND MANAGEMENT

The objectives of this study are to inform policymakers and resource managers of the achievable outcomes and associated costs of Cape ivy control. Gaps in evidence-based knowledge on this topic limit decision makers from assigning appropriate costs, and therefore funding, for invasive species control. The principle policymakers expected to benefit from the data collected through this and other evidence-based research include the United States

Department of Agriculture, Environmental Protection Agency, California Department of Fish and Game, National Oceanic and Atmospheric Administration, local foundations, and other federal, state and local funding agencies.

Background

To identify the key gaps in the scientific knowledge base related to management of Cape ivy, I completed a review of scientific literature, including published and unpublished reports related to the topic, and consulted several resource managers, restoration practitioners, and researchers. The following background information, taken from this review, provides an introduction to Cape ivy life-history and biological characteristics, and management.

Cape Ivy Life History And Biology

Cape ivy, native to South Africa, is part of the Asteraceae Family (Sunflower Family). In California, Cape ivy blooms may be seen as early as September while the majority of flowers develop from December to February (Robison 2006, McMenamin G. pers comm. Oct.14, 2008). By comparison, in South Africa it flowers from May to July (also autumn to winter), indicating that flowering may be induced by short days (Robison 2006). Cape ivy is a climbing perennial vine which grows most vigorously during winter and spring (Balciunas 2006). A single leaf grows from each node and measures 1–3 inches long. The succulent leaves of this vine have a waxy cuticle and are bright green with pointed lobes and purple-colored underground rhizomes.

Cal IPC (2004) reports both the leaves and stems store water, making the plant drought-tolerant. In fact, Cape ivy can survive months without water because the vine stores sugars from photosynthesis in its extensive root system. Under drought conditions a colony of ivy acts as one individual plant; allocating resources to one area while allowing other areas to die back, keeping the entire colony alive and ready for rapid re-growth under more favorable conditions (Bossard et al. 2000). Cape ivy's waxy cuticle also prevents desiccation; fragments of Cape ivy can withstand ten weeks of full sun exposure and still maintain the ability to root and flourish (Bossard et al. 2000). Additionally, Cape ivy leaves contain pyrrolizidine alkaloids and xanthones, toxins which deter insects and herbivores, protecting the plant from predation (Bossard et al.2000). While Cape ivy prefers moist riparian areas with disturbed soil it is able to proliferate over a wide range of ecosystems due to its ability to withstand drought, endure full sun exposure and deter predators (Alvarez and Cushman 2002).

Cape ivy is widely cultivated throughout the world as an ornamental (Wagner et al. 1999) and landscaping has led to long distance dispersal of this plant. Cape ivy disperses vegetatively (Brickell and Zuk 1997, Haselwood and Motter 1983), and has reproduced by seed in a lab study performed by Ramona Robison (Robison 2006). The primary mode of reproduction for Cape ivy is vegetative, through stolons and stem fragments containing nodes (Bossard, Randell & Hoshovsky 2000 and Muyt 2001, Stern personal observation). Stem fragments have been reported to persist for months before setting root under favorable conditions (Blood 2001). Cape ivy plants reach sexual maturity within two years, and large plants can produce more than 40,000 seeds annually (Muyt 2001).

Recent greenhouse research demonstrated that Cape ivy in California produces viable wind-dispersed seed throughout its entire range (Robison 2006). Robison (2006) claims that Cape ivy is able to produce approximately 1% viable wind dispersed seed and the seeds appear to have no induced dormancy mechanism. Cape ivy seeds are on average, about 2 mm long with hairs attached, and can travel distances of more than 1 km via wind dispersal (Muyt 2001). Although Robison's study (2006) has not been replicated, in a lab or the field, and Cape ivy has been found to be largely self-incompatible in California, the seeds have been found to have a larger percentage of viable seed when artificially cross pollinated (Robison 2006). Therefore, it is good to be aware of the potential viability of Cape ivy seeds. Based on low germination rates, propagule longevity has been assumed to be less than 5yrs (Muyt 2001). While viable seed was observed by Robison (2006) throughout Cape ivy's entire range, only a few of the populations sampled in California produced viable seed, suggesting that most infestations are clonal.

Other results found by Robison (2006) included seed weights, and preferential seed germination temperatures, light, and depth. Sampled seed weights ranged from 0.02 mg to 0.39 mg, with the seeds weighing above 0.20 mg experiencing the highest percentage of germination. Temperatures between 17 and 25°C were optimal for germination, and seeds were able to germinate in light or dark. Seeds germinated when planted on the soil surface or when buried 1 cm, but did not emerge when buried below 4 cm.

Evidence of Cape ivy's dispersion success can be seen by reviewing its history in and dominance of California's coast. Cape ivy was originally introduced as an ornamental to

California in the 1950s (Elliot 1994). By the 1960s it had naturalized in Golden Gate Park, San Francisco, and Marin County (Archbald 1995, Howell 1970). Between 1980 and 1995, Cape ivy became a major pest plant in coastal regions the full length of California covering native biological communities (Cal-IPC 1995).

Once established Cape ivy grows at an average speed of one foot per month, and has been found to successfully displace native vegetation through competition (Alvarez and Cushman 2002). Furthermore, as demonstrated by Alvarez and Cushman (2002), the loss of native vegetation results in reduced or degraded habitat which subsequently leads to reduced species diversity. Due in part to research by Alvarez and Cushman (2002) on Cape ivy, in 2005 the California Invasive Plant Council (Cal-IPC) listed Cape ivy as "a species with severe ecological impacts on ecosystems, plant and animal communities, and vegetational structure." The substantial negative impacts of Cape ivy on native vegetation require that methods of ivy removal and the differing methods' subsequent effects on native plant regeneration be explored.

MANAGEMENT OF CAPE IVY IN CALIFORNIA

Management efforts for Cape ivy throughout California have focused on a variety of control methods; however most common have been manual, mechanical and chemical control. Table 1 includes examples of the principle Cape ivy control methods (manual, mechanical, chemical, biological, and integrated weed management) supported by data from field experiments and trials conducted over the last twenty years.

Overall, the potential advantages of manual and mechanical removal, as demonstrated by the case studies in Appendix B, include: greater native plant recovery, less chemical inputs to the system, potentially reduced revegetation costs, and the ability to involve volunteers. Additionally, by removing all parts of the Cape ivy plant, the re-sprouting ability of the plant is diminished as well as effects the plant may have on seedling germination. Some of the drawbacks of manual removal include: increased disturbance of the soil, labor intensity, and terrain accessibility requirements (G. McMenamin (Restoration Consulting), personal communication, April 18, 2008). This technique requires a large amount of person-power and time to be effective, based on one person weeding an average of 3 m^2 of Cape ivy an hour (Gluesenkamp D. (Audubon Canyon Ranch), personal communication, July 16, 2008). In addition, this method leaves large patches of the soil bare, can increase erosion and nutrient leaching potential due to ivy preventing the substantial growth of any other understory vegetation (Alvarez 1997).

Chemical control requires less labor time for application, and can be the best option where native plants have been completely suppressed (Bossard et al.2000). Additionally, the use of herbicides will leave root structure intact, which can prevent soil erosion and nutrient leaching, but may suppress seed germination, recruitment, growth of existing seedlings even though the plant itself is dead. Although herbicides can be effective in controlling ivy, herbicide use introduces a potential environmental contaminant and is nondiscriminatory toward native foliage. Additionally, some herbicides have been shown to be increasing some plant species' genetic immunity, including Asteraceae species. In addition, chemical control can be costly because it often prohibits volunteer involvement, may require multiple applications (Cal-IPC 2004), high revegetation costs (G. McMenamin (Restoration Consulting), personal communication, April 18, 2008), and effect birds, salmonids, amphibians, and other species negatively. Triclopyr, often sold as Garlon, has been proven to have negative effects on fish and amphibians (Kreutzweiser et al.1995, Johansen and Green 1990, Berril et al.1993, Perkins et al.2000). The EPA has labeled the butoxyethyl ester form of triclopyr as slightly toxic to birds, and moderately to highly toxic to fish and aquatic invertebrates (USEPA 1998). To limit impacts to wildlife in this study, Rodeo®, a form of glyphosate herbicide, registered for aquatic use, in combination with Activator 90 surfactant, also registered for aquatic use, was used.

Although flaming may be effective in combination with other methods, I have chosen to not include this method in my study. This is due to the likelihood that hand removal and herbicide application methods will likely be more successful and cost-effective (K. Moore (Wildlands Restoration Team), personal communication, July 14, 2008).

Recent advancements in management strategies for Cape ivy include integrated weed management (IWM) and potential biological control techniques. IWM programs are built on an understanding of the biology of the weed species, the infested ecosystem, and the use of the most effective control techniques available for the weed species and site. IWM is usually a combination of top-down and bottom-up measures. Best management techniques available for the target weed are employed in a planned, coordinated program to limit the impact and spread of the invasive plant. These techniques can vary both within and between sites. Control methods are determined by the use objectives for the land, the effectiveness of the control method on the target plant, topographical factors, environmental factors, economics, policy and legal restrictions, and the extent and nature of the infestation. One example of a Cape ivy IWM program is the Cape ivy management at Audubon Canyon Ranch. The management strategy for Cape ivy at Audubon Canyon Ranch included manual removal of Cape Ivy by volunteers using simple hand tools, supplemented by some goat grazing and periodic paid workers (Cal-IPC 2003). Other common components of IWM programs include herbicides; cultural control methods, including grazing management, and revegetation programs; physical and mechanical methods, including hand removal; and potential biological control, including the use of host-specific insects and plant pathogens (Cal-IPC 2008).

Biological control, the release of carefully selected and tested insects and other natural enemies which originate from the same region as the weed, is currently being studied as a control method for Cape ivy. Dr Joe Balciunas at the USDA-ARS Albany lab has completed host-specificity testing for the two most promising agents, a gall fly and a stem-boring moth. He will begin field-testing the gall fly in the Big Sur area, with simultaneous testing in southern California by UC Santa Barbara collaborators, once permits are obtained. Dr. Balciunas has also conducted pre-release efficacy assessments for the agents (Balciunas 2006). Pre-release efficacy assessments (PREA) tests and in the field tests are crucial when biological control is being used due to the unknown effects biological agents may cause on the ecological processes. For example, recent PREA tests performed in Montana for two flies, *Urophora aynis* Frauenfeld and *U. quadrifasciata* (Meigen) (Diptera:Tephritidae), which were released to control spotted knapweed (*Centaurea stoebe micranthos* (Gugler) Hay) (Asteraceae), (often referred to as *Centaurea maculosa* Lamarck), indicated that these flies may have widespread and significant impacts on mammals and other organisms (Pearson et al., 2000; Pearson and Callaway, 2005, 2006). These kinds of results have caused some ecologists to be wary of biological control. In response to these fears and the lengthy process it takes to get a biological agent approved, many resource managers, restoration practitioners, and individuals have turned to other more accessible methods.

To make sure I had an accurate view of the most recent knowledge related to the management of Cape ivy, I contacted several researchers, resource managers, and restoration practitioners who had studied Cape ivy, or had experience managing Cape ivy. I received several suggestions regarding control methods from: Tim Hyland (Environmental Scientist, California State Parks), Mary Paul (Senior Park Aide, California State Parks), Tanya Baxter (Golden Gate National Recreation Area), Jim Bromberg (Point Reyes National Seashore), Carla Bossard (St. Mary's College), Ramona Robison (Cal-IPC), Ken Moore (Wildlands Restoration Team), Bruce Delgado (Bureau of Land Management), George McMenamin (Restoration Consulting), Cammy Chabre (Elkhorn Slough and Estuarine Research Reserve), and Dan Gluesenkamp (Audubon Canyon Ranch). These suggestions included manual, mechanical, and chemical methods.

I also gathered management information from Cal-IPC symposium proceedings literature over the last eight years (Cal-IPC symposium proceedings 1999-2007). Some of the proceedings literature documented success rate and costs of control methods however, there were no reports found that provided a quantifiable comparison of the cost-effectiveness of control methods for Cape ivy. The Cal-IPC website also provided me invaluable information regarding Cape ivy biology, and life history.

As stated previously, while several trials and some studies have been completed to test effectiveness of control methods, there is a need for studies that compare control methods and their associated costs. There is a lack of replicable, quantitative studies that compare success and the cost-effectiveness of different control methods for Cape ivy in the current scientific literature. This information is needed by resource managers to make management decisions regarding Cape ivy control in riparian areas (Hyland T. pers comm. May 1, 2008, Delgado B. pers comm. March 22, 2008, McMenamin G. pers comm. April 18, 2008, Robison 2006).

Applicable Theory

The ability of invasive non-native plants to out-compete native vegetation has been widely studied by ecologists (e.g. Davis et al.2000, Cleland et al.2004, Blumenthal 2005). Several theories and hypotheses have been developed to explain the success of invasive non-native plants over native species including: the theories of fluctuating resource availability (Davis et al.2000), disturbance (Davis et al.2000), and community invasibility theory; and the hypotheses of diversity-resistance (Cleland et al.2004) and enemy release (Blumenthal 2005). Importantly, all of these theories and hypotheses relate to the resistance and resilience of an ecosystem. The ability of a community to be invaded by invasive plants is predicated on its resistance and resilience to disturbance.

According to Holling (1973), the goal of most resource managers and restoration practitioners is to maintain sustainable ecosystems resistant to invasion and resilient, in that they return to pre-disturbance conditions or a trajectory close to that without large-scale human intervention, and within a reasonable timeframe following a disturbance. However, most resource managers do not have the time or resources to fully attain this goal. More often, resource managers and restoration practitioners have more limited goals including removing or controlling a disturbance, and/ or increasing the diversity and abundance of native flora for general ecosystem function and/or wildlife habitat.

In this study I am removing Cape ivy, the disturbance and cause for transformation in the current ecosystem. This is the first physical step in most restoration efforts, and is essential to begin ecological restoration of any site. By removing Cape ivy, the resistance and resilience of the ecosystem may be improved by giving native flora a chance to establish and compete for resources. Since this study is limited to twelve months, I will not be able to observe ecological succession. However, I may get a glimpse of the beginning trajectory. During this twelve month period, if sufficient natural regeneration of native plants does not occur, it may indicate that re-vegetation following Cape ivy control in riparian ecosystem could be needed. Resource managers who aim to increase diversity and richness of native flora in addition to controlling Cape ivy are likely to need to invest in re-vegetation.

Appendix B

CAPE IVY CONTROL FIELD EXPERIMENTS AND TRIALS

Method	Citation	Study Area and Location	Brief Description of Method	Results	Limitations
Manual Removal					
1	Moore 1997. (Moore K, Wildlands Restoration Team)	3+ acres, Riparian habitat, Big Basin State Park along Waddell Creek	"Scorched earth" cut and clear ALL native and non-native vegetation to the ground level. Follow-up with hand removal of the non-native re-sprouts.	Initial results indicated effective control of Cape ivy (Moore 1997).	Soil disturbance, initial loss of native vegetation.
1	Cal-IPC 2003. (Cal-IPC 2003 Symposium Proceedings: Baxter T, Golden Gate Natl Rec Area; Bromberg J, Point Reyes National Seashore)	2 acres, Riparian habitat, Golden Gate National Rec Area	"Scorched earth" limb and cut back native vegetation, followed by manual removal of the Cape ivy. Rake sites to mineral soil to expose the shallow cape ivy roots and fragments. Leave cut vegetative material on site to decompose, covered in landscape fabric. Follow-up with hand removal 3 weeks after initial treatment and make subsequent visits over several years.	Percent of Cape ivy fell from 40% absolute cover to a 0% cover in the first year.	Noticed increased cover of non-native species especially Holcus lanatus (velvet grass).
2	Cal-IPC 2003. (Cal-IPC 2003 Symposium Proceedings: Gluesenkamp D, Audubon Canyon Ranch)	Approx 6 acres, Riparian habitat, Bolinas Lagoon Preserve, Stinson Beach, CA.	"Modified scorched earth" Manual removal of only non-native vegetation, and native vegetation only when necessary. Simple hand tools were used. Follow-up with hand removal every 4 weeks for the first year and every 6-8 weeks for up to 5 years.	Results indicate that manual removal works (Cal-IPC 2003).	Success of manual removal dependent upon a large volunteer base and a dedicated long-term follow-up effort.

Chemical Control					
3	Bossard et al 2000 (St. Mary's College)	Approx 5 acres, partially tree shaded with sandy loam soil and >85% ground cover of German ivy, Golden Gate Natl Rec Area	In June, apply 0.5 % glyphosate (as Roundup®) + 0.5 % triclopyr (as Garlon 4®) + 0.1 percent silicone surfactant (as Silwit®) in water as a foliar spray at 640 liters/ha. Follow up with a second application one year later.	Eradication was achieved after a second application one year later (follow-up).	Triclopyr is restricted from use in riparian habitats, and other sensitive habitats.
4	C. Chabre pers comm. April 11, 2008. (Elkhorn Slough Research and National Estuarine Research Reserve)	Approx 1 acre, Oak woodland habitat, Elkhorn Slough Research and National Estuarine Research Reserve	In June, apply 2% Roundup Pro + R-11 surfactant as a foliar spray. Follow up with a combination of hand removal and backpack spray application of 0.5 % glyphosate (as Roundup®) + 0.5 % triclopyr (as Garlon 4®) every two months for the first two years.	Cape ivy cover was reduced from 90% to 15% after two years, and native cover was increased from <40% to 80%.	Triclopyr is restricted from use in riparian habitats, and other sensitive habitats.
5	T. Hyland pers comm. July 18, 2008.	Various locations, Santa Cruz County	Apply Aquamaster + Activator 90 surfactant in late summer/fall and follow up with retreatment in January or February.	Results indicate that this method works.	May reduce native plant community regeneration.
6	Fagg 1989	Unknown acreage, Australia	Clopyralid (Lontrel®) (sold in California as Transline®), 150 g/liter at 6-8 liters/ha using the rope wick method of application. Two applications a year apart. Clopyralid substantially damaged non-target species in the Asteraceae, families, but no appreciable damage was found on non-target species of other plant families.	Control was obtained within 11 weeks of treatment, but the plots were re-colonized by Cape ivy 50 to 70% of the original infestation size after 12 months in the absence of follow-up management.	Clopyralid (Transline) is more expensive than other herbicides, and not approved for aquatic use.

7	Forbert 1998	> 2 acres, Coastal scrub habitat, Golden Gate Natl Rec Area, Milagra Ridge Park, Ca	Fobert (1998) applied a mixture of glyphosate and triclopyr (1% Roundup and .5% Garlon 4) on Cape ivy infestations of 500 square meters and larger, where the biomass of Cape ivy exceeded 80% of the surface. This technique employed solo backpack sprayers and follow up was done by hand.	With minimal labor, the amount of Cape ivy was greatly reduced over an eight month period (two applications every four months).	Triclopyr (Garlon) is restricted from use in riparian habitats, and other sensitive habitats.
Flaming process					
8	Bossard et al 2005	Approx 1 acre, Oak woodland habitat, Elkhorn Slough Research and National Estuarine Research Reserve	Flaming Cape ivy, a process where a propane torch is passed quickly over the plants killing them by boiling the water within the cells of the plant. Apply initial treatment in November and repeat treatments every 5-6 weeks.	After six flaming treatments conducted between November 2004 and July 2005, only plants in heavily shaded areas were controlled. In partial to full sun locations the Cape ivy density decreased, but the species was not eradicated in one season.	Found to not be effective in eradicating Cape ivy in partial to full sun locations (Bossard et al 2005).

Appendix C

AIC Tables for Cape Ivy Treatment Method Comparison

Treatment Comparison: T1 and T2

Model	**Model Parameters (k)**	**Log likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
Null	2	-9.173	22.35	22.56	1.465	0.3247
Difference	3	7.332	20.66	21.09	0.000	0.6753

Evidence ratio: **2.08**

Treatment Comparison: T1 and T3

Model	**Model Parameters (k)**	**Log likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
Null	2	6.972	17.94	18.16	0.1283	0.484
Difference	3	-5.799	17.60	18.03	0.0000	0.516

Evidence ratio: 1.07

Treatment Comparison: T2 and T3

Model	**Model Parameters (k)**	**Log likelihood**	**AIC**	**AICc**	**Delta AICc (Δ_i)**	**Akaike Weight (w_i)**
Null	2	-10.52	25.05	25.26	0.000	0.7378
Difference	3	-10.45	26.90	27.33	2.069	0.2622

Evidence ratio: **2.81**

Treatment Comparison: T1 and T4

Model	Model Parameters (k)	Log likelihood	AIC	AICc	Delta AICc (Δi)	Akaike Weight (wi)
Null	2	-29.005	62.01	62.22	45.45	1.353e-10
Difference	3	-5.172	16.34	16.77	0.00	1.000e+00

Evidence ratio: **224.06 x 10^8**

Treatment Comparison: T2 and T4

Model	Model Parameters (k)	Log likelihood	AIC	AICc	Delta AICc (Δi)	Akaike Weight (wi)
Null	2	-24.582	53.16	53.37	27.04	1.342e-06
Difference	3	-9.951	25.90	26.33	0.00	1.000e+00

Evidence ratio: **225.94 x 10^4**

Treatment Comparison: T3 and T4

	Model Parameters (k)	Log likelihood	AIC	AICc	Delta AICc (Δi)	Akaike Weight (wi)
Null model	2	-24.679	53.36	53.57	30.67	2.193e-07
Difference	3	-8.238	22.48	22.90	0.00	1.000e+00

Evidence ratio: **138.21 x 10^5**

Appendix D

Pre- and Post-Treatment Native Plant Cover Sampling Results for each site

Site 1

Initially, the native plant understory at Site 1 (Coward Creek) was mostly poison oak and California blackberry. Results from vegetation sampling of native plant cover pre- and post-treatment are shown in Table 9.

Table 9. Site 1 Pre- and Post-Treatment Sampling Results for Native Plant Cover.

The cover values in this table represent average cover (for 10 plots).

Site 1 Coward Creek	Treatment 1 Pre and Post		Treatment 2 Pre and Post		Treatment 3 Pre and Post		Control Pre and Post	
CA Blackberry	16.9	24.5	12.6	1.1	14.8	3.7	14.4	9.6
Poison Oak	5.0	6.7	19.0	10.1	1.9	0.8	5.1	6.8
Beeplant	0	2.8						
Stinging nettle	0.1	1.2	1.3	0.7			0	0.2
Buckeye			0	0.3	0	0.2		
Willow			0	2.8				
Walnut	0	0.8						
Oak					0	0.1		
TOTAL Native Cover	*22.0*	*36.0*	*32.9*	*15.0*	*16.7*	*4.8*	*19.5*	*16.6*

Site 2

A large amount of the native plant understory at site 2 (Glen Deven) was *Stachys spp.* (hedge nettle) and California blackberry. Results from vegetation sampling of native plant cover pre and post-treatment are shown below in Table 10.

Table 10. Site 2 Pre- and Post-Treatment Sampling Results for Native Plant Cover.

The cover values in this table represent average cover (for 10 plots).

Site 2 Glen Deven	Treatment 1 Pre and Post		Treatment 2 Pre and Post		Treatment 3 Pre and Post		Control Pre and Post	
Ca. Blackberry	11.9	22.7	15.2	0.6	9.9	0.2	20.8	22.1
Hedge nettle	9.4	19.3	21.1	0.2	9.9	6.8	12.5	9.3

Beeplant	0	0.4	0	0.7	1.3	0.8	0.5	0.8
Stinging nettle	2.7	2.1	0	1.2	4.4	6.7	0.7	0.7
Thimbleberry	2.5	0.5	0.3	0	5.2	0.5	0.7	1.1
Alder	0.1	0	0	0	0	0	0	0
Wild Cucumber	0	0	0	0.49	0	0	0	0
TOTAL Native Cover	*26.6*	*45*	*36.6*	*3.19*	*30.7*	*15*	*35.2*	*34*

Site 3

Along with Cape ivy, the site 3 (Big Basin) understory was covered in stinging nettle and California blackberry. Following one year of treatment, there was an increase in hedge nettle. Results from vegetation sampling of native plant cover pre and post-treatment are shown below in Table 11.

Table 11. Site 3 Pre- and Post-Treatment Sampling Results for Native Plant Cover.

The cover values in this table represent average cover (for 10 plots).

Site 3 Big Basin	**Treatment 1 Pre and Post**		**Treatment 2 Pre and Post**		**Treatment 3 Pre and Post**		**Control Pre and Post**	
Ca. Blackberry	7.6	7.9	12.3	7.8	12.9	0.8	17	12.1
Stinging nettle	0.8	1	3.3	1	13.3	14.9	4.8	2
Red Elderberry	2	0	3.1	0.9	0	0.2	0.3	0.4
Hedge nettle	0.2	4.8	0	0	0	0	0	0
Mugwort	1.2	0.5	0.4	0	0.8	0	0	0
CA Bay laurel	0	0.3	0	0	0	0	0	0
TOTAL Native Cover	*11.8*	*14.5*	*19.1*	*9.7*	*27*	*15.9*	*22.1*	*14.5*

The number of dominants remained equal in T1 plots at all three sites, decreased in T2 plots at two of the three sites (the third site remained equal), and decreased in T3 plots at all three sites. For the purposes of this study, I considered any native plant with five percent cover or greater to be a dominant species. The decrease in dominants is correlated to the overall decrease in native plant cover, and could be partially due to non-target effect of herbicides.

Table 12. Pre- and Post-Treatment Results for Dominant Native Plant Species

The values in this table represent average values (for 10 plots).

Treatment	Coward Creek Species Richness		Glen Deven Species Richness		Big Basin Species Richness		Average Change in Dominant Species
T1	2	2	2	2	1	1	**0.00**
T2	2	1	2	0	1	1	**-1.00**
T3	1	0	3	2	2	1	**-1.00**
C	2	2	2	2	1	1	**0.00**

Species richness remained equal in T1 plots at two of the three sites (increased at the third), increased at two of three sites in T2 plots (decreased at the third site), and remained equal in T3 plots at two of three sites (increased at third site). This change in species richness (or diversity) is mostly due to recruitment from native trees on-site.

Table 13. Pre- and Post-Treatment Results for Native Plant Species Richness

The values in this table represent average values (for 10 plots).

Treatment	Coward Creek Species Richness		Glen Deven Species Richness		Big Basin Species Richness		Average Change in Species Richness
T1	3	5	5	5	5	5	**+0.66**
T2	3	5	3	5	4	3	**+1.00**
T3	2	4	5	5	3	3	**+0.66**
C	2	3	5	5	3	3	**+0.33**

Appendix E

COST TRACKING TABLES FOR CAPE IVY TREATMENT METHODS

The labor rates used for the following calculations are:

$10/hr for general labor for hand removal

$100/hr for licensed herbicide applicator

Materials costs added to T1 costs are $160 ($100 for gloves and $60 for tarps)

Materials costs added to T2 costs are $312 ($150 for backpack sprayer, $129 for 2.5 gallons of Rodeo herbicide, $18.30 per gallon of Activator 90 surfactant, and $15 for gloves)

Materials costs added to T3 are $472 (a combination of T1 and T2 costs)

Site 1: Coward Creek

Plot #	Method	Time/Application (min) 9/19/08	Time/Application (min) 3/13-3/24/09
3	1	45	15
6	1	108	17
12	1	33	8.6
14	1	120	18.36
16	1	27	11.06
20	1	106	20.06
25	1	99	20
29	1	42	30.5
31	1	90	21.01
36	1	77	13.05
41	1	192	14.2
47	1	27	9.48
AVERAGE		**80.50**	**16.53**

97.03 min/1 sq m/yr
/60 min/hour
x $10/hour
x 4,049 sq m/acre
$65,479 cost/acre/yr

$65,639 w/ materials

Site 1: Coward Creek

Plot #	Method	Time/Application (min) 9/15/08	Time/Application (min) 01/26/09
1	2	0.95	0.93
4	2	0.86	2.28
13	2	0.93	0.97
15	2	0.92	0.82
18	2	0.92	0.82
24	2	0.74	0.65
26	2	0.65	0.88
28	2	0.73	0.98
35	2	1.05	0.80
39	2	0.94	0.68
42	2	0.85	0.82
46	2	1.12	0.70
Average		**0.89**	**0.94**

1.83min/1 sq m/yr
/60 min/hour
x $100/hour
x 4,049 sq m/acre
$12,349 cost/acre/yr

$12,661 w/ materials

Site 1: Coward Creek

Plot #	Method	Time/Application (min) 9/15/08	Time/Application (min) 3/13/09
9	3	0.78	40
10	3	0.77	30
17	3	0.82	58
19	3	0.89	100
21	3	1.02	58
27	3	NA	NA
30	3	0.85	46.64
33	3	0.77	41.13
38	3	0.96	54
44	3	1.02	27.31
45	3	0.88	47.06
7	3	NA	NA
AVERAGE		**0.88**	**50.21**

0.88 min/1 sq m/yr
/60 min/hr x $100/hr
x 4,049 sq m/acre
$5,939 cost/acre/yr

50.21 min/1 sq m/yr
/60 min/hr x $10/hr
x 4,049 sq m/acre
$33,883 cost/acre/yr

$40,294 w/ materials

Site 2: Glen Deven

Plot #	Method	Time/Application (min) 9/15/08	Time/Application (min) 3/13/09
36	1	93	20
38	1	21	12
7	1	51	8
3	1	66	12.6
12	1	30	8
14	1	33	13.76
15	1	30	5.48
46	1	20	9.64
47	1	60	5.64
27	1	12	22.12
23	1	90	12
21	1	105	16
AVERAGE		**50.92**	**12.10**

63.02 min/1 sq m/yr
/60 min/hour
x $10/hour
x 4,049 sq m/acre
$42,528 cost/acre/yr

$42,688 w/ materials

Site 2: Glen Deven

Plot #	Method	Time/Application (min) 9/15/08	Time/Application (min) 3/13/09
1	2	0.55	0.88
22	2	0.68	0.75
20	2	0.58	0.55
16	2	0.65	0.75
18	2	0.65	0.60
39	2	0.45	0.42
37	2	0.60	0.57
5	2	0.52	0.63
30	2	0.78	0.75
48	2	0.57	0.70
10	2	0.73	0.83
32	2	0.88	0.60
AVERAGE		**0.64**	**0.67**

1.31min/1 sq m/yr
/60 min/hour
x $100/hour
x 4,049 sq m/acre
$8,840 cost/acre/yr

$9,152 w/ materials

Site 2: Glen Deven

Plot #	Method	Time/Application (min) 9/15/08	Time/Application (min) 3/13/09
8	3	0.68	36.56
6	3	0.48	56
33	3	1.03	2
29	3	0.90	89.08
25	3	0.55	129.48
4	3	0.62	36.12
13	3	0.67	52
40	3	0.57	69.68
43	3	0.55	28
45	3	0.83	17.76
31	3	0.47	20.2
17	3	0.78	40
AVERAGE		**0.68**	**48.07**

0.68 min/1 sq m/yr
/60 min/hr x $100/hr
x 4,049 sq m/acre
$4,589 cost/acre/yr

48.07 min/1 sq m/yr
/60 min/hr x $10/hr
x 4,049 sq m/acre
$ 32,439 cost/acre/yr

$37,500 w/ materials

Site 3: Big Basin

Plot #	Method	Time/Application (min) 9/15/08	Time/Application (min) 3/13/09
9	1	60	12.17
45	1	72	5.19
26	1	28	2.42
41	1	28	0.00
28	1	16	1.06
1	1	60	0.00
34	1	24	1.45
19	1	68	6.05
23	1	32	1.10
43	1	56	
24	1	40	0.82
40	1	36	0.47
AVERAGE		**43.33**	**2.56**

45.89 min/1 sq m/yr
/60 min/hour
x $10/hour
x 4,049 sq m/acre
$30,968 cost/acre/yr

$31,128 w/ materials

Site 3: Big Basin

Plot #	Method	Time/Application (min) 9/15/08	Time/Application (min) 3/13/09
3	2	1.00	1.00
6	2	1.00	1.35
10	2	1.00	1.01
13	2	1.00	1.25
15	2	1.00	0.90
22	2	1.00	0.78
25	2	0.75	1.07
29	2	0.75	0.50
32	2	1.00	0.68
44	2	1.00	0.82
46	2	1.00	0.75
47	2	1.00	0.80
AVERAGE		**0.96**	**0.91**

1.87 min/1 sq m/yr
/60 min/hour
x $100/hour
x 4,049 sq m/acre
$12,619 cost/acre/yr

$12,931 w/ materials

Site 3: Big Basin

Plot #	Method	Time/Application (min) 9/15/08	Time/Application (min) 3/13/09
39	3	0.53	42
42	3	0.97	44
48	3	1.42	10
16	3	0.78	33.25
31	3	0.67	24
27	3	0.90	24
30	3	0.78	32
4	3	1.00	3.09
18	3	1.10	39.54
21	3	1.17	17.59
33	3	0.83	34
11	3	0.87	15.02
AVERAGE		**0.92**	**26.54**

0.92 min/1 sq m/yr
/60 min/hr x $100/hr
x 4,049 sq m/acre
$6,208 cost/acre/yr

26.54 min/1 sq m/yr
/60 min/hr x $10/hr
x 4,049 sq m/acre
$ 17,910 cost/acre/yr

$24,590 w/ materials

Appendix F

TOTAL COSTS FOR CAPE IVY TREATMENT METHODS

Treatment method 1 (T1): If hired crews are used for T1 (hand removal only), average costs amount to $46,592 per acre for the first year based on the following:

$46,432	Hired restoration crews ($10/hr x 4,643 hrs)
$100	Gloves, $5/pair x 20 pair = $100
$60	Tarps for piling Cape ivy, $20/tarp x three per acre = $60

First year costs for T1 can be reduced if volunteers are used. If staff is not available to coordinate volunteer days, hiring a part-time volunteer coordinator for $20 to $25/hour is also an option. First year costs for T1 can be reduced to $6,160 per acre per year based on the following:

$6,000 Volunteer coordinator ($25/hr x 240 hrs)

20 hrs/workday x $25/hr = $500 per workday

8 hrs for planning work tasks, gathering gloves and tarps

12 hrs for outreach/advertising

6 workdays per acre, twice a year = 12 workdays

$100 Gloves, $5/pair x 20 pair = $100

$60 Tarps for piling Cape ivy, $20/tarp x three per acre = $60

TOTAL = $6,160 per acre (for the first year).

Additional costs: Follow-up monitoring will be needed for five to seven years, at least twice a year (early winter and mid spring). Depending on the extent of re-growth, a monitoring budget should contain 8-16 hours annually per acre of treated Cape ivy. This is a range because more monitoring time may be required in year 3 or 4 as opposed to years 1 or 2 due to re-growth. Some monitoring cost will be required for any method used.

Treatment method 2 (T2): If a licensed herbicide applicator is hired for this method (herbicide application only), average costs amount to $11,893 per acre per year based on the following:

$11,581	licensed herbicide applicator ($100/hr x 116 hrs)
$129	per 2.5 gallons of Rodeo herbicide
$18.30	per gallon of Activator 90 surfactant

$150	for backpack sprayer
$15	or PVC or Neoprene gloves

First year costs for T2 could be drastically reduced if an employee were to apply the herbicide with a backpack sprayer. The cost per hour for the employee's time is most likely less costly per hour than a licensed herbicide applicator. Estimated first year costs could be $2,632 per acre per year based on the following:

$2,320	ranch employee, herbicide applicator ($20/hr x 116 hrs)
$129	per 2.5 gallons of Rodeo herbicide
$18.30	per gallon of Activator 90 surfactant
$150	for backpack sprayer
$15	for PVC or Neoprene gloves

Besides the direct costs of labor and supplies for herbicide application, replanting costs for the treated area should be expected to be higher than non-chemical treatments, due to non-target effects of Rodeo (glyphosate) herbicide.

Treatment method 3 (T3): Average T3 costs amounted to $34,443 per acre per year based on the following:

$5,580	licensed herbicide applicator ($100/hr x 56 hrs)
$30,214	hired crews ($10/hr x 3,020 hrs)
$129	per 2.5 gallons of Rodeo herbicide
$18.30	per gallon of Activator 90 surfactant
$150	for backpack sprayer
$15	for PVC or Neoprene gloves
$100	Gloves, $5/pair x 20 pair = $100
$60	Tarps for piling Cape ivy, $20/tarp x three per acre = $60

First year costs for T3 could be reduced to $4,592 by using volunteers and an employee for applying herbicide as suggested above for T1 and T2.

$1120	ranch employee, herbicide applicator ($20/hr x 55 hrs)

$129	per 2.5 gallons of Rodeo herbicide
$18.30	per gallon of Activator 90 surfactant
$150	for backpack sprayer
$15	for PVC or Neoprene gloves
$3,000	Volunteer coordinator ($25/hr x 120 hrs)
	20 hrs/workday x $25/hr = $500 per workday
	8 hrs for planning work tasks, gathering gloves and tarps
	12 hrs for outreach/advertising
	6 workdays per acre
$100	Gloves, $5/pair x 20 pair = $100
$60	Tarps for piling Cape ivy, $20/tarp x three per acre = $60

APPENDIX G

R CODE USED IN STATISTICAL ANALYSES

```
# Import data:
d <- read.table("clipboard", header=TRUE)

# Define methods and sites as factors:
d$meth = as.factor( d$meth)
d$site = as.factor( d$site)

# Plot of the raw data, overlaid over box plots of the raw data
# with the model estimates of combined Method and Site effects overlaid (in
red):
par(mfrow=c(1,4))
for( s in 1:3) {
x <- d$meth[d$site==s]
y <- d$cover[d$site==s]
plot( x, y, ylim=c(0,1), xlim=c(1,4), main=paste("Site",s), xlab="Method",
ylab="Cover")
points( x, y )
points( 1:4, inverse_logit( est_meth_effect[1:4] + est_site_effect[s] ),
col="red", pch='+', cex=2)}

# Model fit code:
m<- lmer(coverPost ~ meth - 1 + (1|site),
data=d,
family=binomial(link="logit"))

# Calculate method and site effects:
inverse_logit <- function( x ){ ( 1 / ( 1 + 1 / exp(x) ) ) }
inverse_logit(fixef(m))
inverse_logit(ranef(m)$site[,1])
est_meth_effect <- fixef(m)
est_site_effect <- ranef(m)$site[,1]

# summary(m) will give the AIC value, and the logLik.
summary(m)
```

```
# A useful function that makes neat, complete AIC tables:
AICtable <- function( aic, n) {
K <- aic$df
AICc <- aic$AIC + 2 * K * (K+1) / ( n - K - 1 )
delAIC<- AICc - min( AICc )
AICw <- exp(-0.5*delAIC) / sum( exp(-0.5*delAIC))
data.frame( aic, AICc, delAIC , AICw) }

# Sub-setted data frames for paired model comparisons:
d12<- d[d$meth!=3 & d$meth!=4,]
d13<- d[d$meth!=2 & d$meth!=4,]
d23 <- d[d$meth!=1 & d$meth!=4,]
d24 <- d[d$meth!=1 & d$meth!=3,]
d34 <- d[d$meth!=1 & d$meth!=2,]
d14 <- d[d$meth!=2 & d$meth!=3,]

compare_methods <- function( d ) { m_null <- lmer( coverPost ~ (1|site),
data=d, family=binomial( link="logit" ))
m_diff <- lmer( coverPost ~ meth - 1 + (1|site), data=d, family=binomial(
link="logit" ))
LL_null <- logLik(m_null)
LL_diff <- logLik(m_diff)
df_null <- attr(LL_null,"df")
df_diff <- attr(LL_diff,"df")
aic_null <- AIC(LL_null)
aic_diff <- AIC(LL_diff)
aic <- data.frame(
row.names=c( "Null model", "Difference model" ),
df = c(df_null,df_diff),
LL = c(LL_null, LL_diff),
AIC = c( aic_null,aic_diff ))
aic <- AICtable( aic, length(d$cover) )
aic <- AICtable( aic, length(d$coverPost))
print( aic, digits=4)
winner <- max( aic$AICw )
loser <- min( aic$AICw )
print(paste("Evidence ratio: ", winner / loser ))
return( aic ) }
```

```
# Comparison between methods, yields AIC tables:
compare_methods( d12)
compare_methods( d13)
compare_methods( d23)
compare_methods( d14)
compare_methods( d24)
compare_methods( d34)

# Comparison of pre-treatment Cape ivy cover data:
compare_prepost <- function( d ) {
m_null <- lmer( coverPre ~                (1|site), data=d, family=binomial(
link="logit" ))
m_diff <- lmer( coverPre ~ coverPost - 1 + (1|site), data=d, family=binomial(
link="logit" ))
LL_null <- logLik(m_null)
LL_diff <- logLik(m_diff)
df_null <- attr(LL_null,"df")
df_diff <- attr(LL_diff,"df")
aic_null <- AIC(LL_null)
aic_diff <- AIC(LL_diff)
aic <- data.frame(
row.names=c( "Null model", "Difference model" ),
df = c(df_null,df_diff),
LL = c(LL_null, LL_diff),
AIC = c( aic_null,aic_diff ))
aic <- AICtable( aic, length(d$coverPost) )
print( aic, digits=4)
winner <- max( aic$AICw )
loser <- min( aic$AICw )
print(paste("Evidence ratio: ", winner / loser ))
#return( aic ) }
compare_prepost( d[ d$meth==1, ] )
compare_prepost( d[ d$meth==2, ] )
compare_prepost( d[ d$meth==3, ] )
compare_prepost( d[ d$meth==4, ] )
```

APPENDIX H

JUSTIFICATION FOR STATISTICS METHODS

In order to select my statistical tools, I performed a survey of statistical analyses used to evaluate effects of treatment (removal, control, or restoration) on plant community components (species cover, richness, diversity, and seedling abundance, survivorship, and growth). Analysis of variance (ANOVA) was the most commonly used statistical method in studies looking at effects of treatment. Three-way ANOVAs, repeated measures ANOVAs, nested ANOVAs, and MANOVAs were used to analyze treatment effects (Biggerstaff and Beck 2007, Hulme 2006, Mason 2006, Alvarez and Cushman 2002, Yates 2000). One study (Sweeney 2002) used repeated measures regression models and linear regression models to analyze survivorship and growth of seedlings following treatments (including seedling addition). In a study done in 2004, Bakker used contingency analysis to show rate of invasion difference between restored and un-restored plots. The authors of this study also used regression to analyze the relationship between invasive cover and biotic variables and stepwise regression for relative input variables. Two of the studies using ANOVAs used the Tukey method (Steel and Torrie 1981) to evaluate difference means of treatments (Biggerstaff and Beck 2007, Yates 2000). Biggerstaff and Beck (2007) also used a 2x2 chi-square test to determine the significance of the interaction between removal and seed addition treatments (for native and exotic species).

Similar to the above mentioned studies, this study aimed to quantify the effects of treatment on plant communities. In this study, I measured the effects of treatment methods (fixed effects) on Cape ivy and other plant species cover (response variables). The predictor variables in this study are the treatment methods (fixed effects) and the response variables are cover. The statistical method chosen to analyze cover and cost data collected is dependent on the nature of the predictor and response variables. The predictor variable is a fixed effect therefore there is no constraint for method selection. However, in the case of the percent cover response (of Cape ivy and other plant species) the distribution is constrained, by definition to be between 0% and 100%. Thus methods assuming normal distributions are inappropriate; and instead, methods assuming binomial distributions (e.g. logistic regression) are more appropriate.

In this study, I obtained data by collecting measurements of a response variable (cover) to treatment methods from three separate sites, which I grouped. Site membership was treated as a grouping factor, since it is expected that sample units within the same group were to some extent co-dependent on each other. An essential statistical peculiarity of grouped data is dependence of the response on the experimental unit itself. Since I sampled three "groups" of plots (the three sites) in this study, I addressed grouping and site dependence effects by categorizing my three sample "groups" as random effects. I used mixed effects logistic regression analysis because classical modeling techniques which assume independence of the observations are not appropriate for grouped data (Pinheiro and Bates 2000).

Logistic Regression is based on likelihood therefore I selected Akaike's Information Criteria (AIC), an information-theoretic approach to model selection, to evaluate the differences between treatments. AIC uses each model's log-likelihood as a measure of fit to compare a priori models and test whether two treatments have different effects (Burnham and Anderson 2002). AIC is preferred by many for hypothesis testing approaches to model selection, based on: consistent results, its foundation in maximum likelihood principles, and its ability to provide measures of strength of evidence (evidence ratios) and uncertainty for each model (Burnham and Anderson 2002). I used model comparison, based on likelihood, AIC, and model probabilities to test how different two treatments were to each other.

APPENDIX I

Management Recommendations

The following are recommendations for the future management of Cape ivy at each of my study sites. I have included follow-up treatment and monitoring in these recommendations because monitoring is recommended for 5 years on all Cape ivy treatment sites. Additionally, there was no evidence that any of treatments applied in this study extirpated Cape ivy from any of the sites over this one year research study. Therefore, follow-up treatments and monitoring will be needed at each of these sites in order to prevent re-growth.

Site 1: Coward Creek

For the future management of Cape ivy at this site location, I recommend the existing Cape ivy invasion is treated using a combination of herbicides and hand removal, and monitored for a minimum of five years. I recommend starting with the farthest upstream infestation and continuing downstream; treating one acre or appropriate habitat patches per year in order to limit disturbance to wildlife habitat. For areas with greater than 50% Cape ivy cover and low numbers of herbaceous native plants, I recommend applying the following treatment:

January or February: Apply 2% Rodeo (glyphosate) herbicide + Activator 90 surfactant to Cape ivy leaves using a backpack sprayer; enough to wet the leaves, but not drip.

May or June: If needed, follow up with a second herbicide treatment before leaves begin to wilt and desiccate.

First year following treatment: Every two to three months, track progress of treatments and survey the treated area for re-growth of Cape ivy. Spot treat any Cape ivy re-growth with herbicide or remove plant (including roots) by hand.

Years 3 - 5: Monitor treated area twice a year in early winter and mid spring.

For areas with less than 50% Cape ivy cover, I recommend hand removal as there is likely to be more native vegetation in these areas. To prevent further spread of Cape ivy, hand removal should begin at the outer edges of the infestation. The winter and spring months are the best times to remove Cape ivy by hand because the soil is moist, making it easier to remove plants. Cape ivy biomass should be either removed from site to a waste facility or left on-site to desiccate on top of a tarp.

Average annual hand removal costs were $46,592 per acre based on $10/hour labor costs and two hand removals. These costs were based on volunteer crews; with appropriate training, these labor costs can be reduced. C**osts can also be substantially reduced to an estimated cost of $6,160 per acre by using volunteers.** Hiring a part-time volunteer coordinator for $20 to $25/hour to coordinate volunteer days if existing staff is not available is also an option. You may choose to use volunteers not only for cost reasons, but to engage the community in stewardship, and provide education to prevent future introduction of invasive species.

With these considerations, estimated first year costs are estimated at $6,160 per acre per year based on the following:

$6,000 per acre per year, with volunteer coordinator ($25/hr x 240 hrs)

$20 hrs/workday x $25/hr = $500 per workday

8 hrs for planning work tasks, gathering gloves and tarps

12 hrs for outreach/advertising

6 workdays per acre, twice a year = 12 workdays

$100 Gloves, $5/pair x 20 pair = $100

$60 Tarps for piling Cape ivy, $20/tarp x three per acre = $60

TOTAL estimate = $3,160 per acre per year

For areas with greater than 50% Cape ivy cover and high native plant cover, herbicides will be the most cost-effective treatment method. **Estimated first year costs based on the results of this study are $11,893 per acre per year.** Comparatively, hand removal costs are $46,592 per acre per year and costs for herbicide with follow up hand removal are $34,443 per acre per year.

Herbicide treatment cost estimates are based on the following costs:

$11,581	licensed herbicide applicator ($100/hr x 116 hrs)
$129	per 2.5 gallons of Rodeo herbicide
$18.30	per gallon of Activator 90 surfactant
$150	for backpack sprayer
$15 f	or PVC or Neoprene gloves

However, first year costs could be drastically reduced if a ranch employee were to apply the herbicide with the backpack sprayer. The cost per hour for the employee's time could be less costly per hour than a licensed herbicide applicator and as long as you are a registered agricultural producer, you and your employees are allowed to purchase and apply Rodeo herbicide and Activator 90 surfactant.

With these considerations, estimated first year costs would be $2,632 per acre per year based on the following:

$2320	ranch employee, herbicide applicator ($20/hr x 116 hrs)
$129	per 2.5 gallons of Rodeo herbicide
$18.30	per gallon of Activator 90 surfactant
$150	for backpack sprayer
$15	for PVC or Neoprene gloves

I recommend limited re-planting and allowing natural regeneration of the plant communities to fill in, as an alternative to replanting the whole area. Limited re-planting can include planting a small number of native trees, shrubs and forbs in small groupings in the treated area. Plants should be native and well-suited for shady riparian conditions.

The plant list previously generated by the Resource Conservation District of Santa Cruz County (RCD) from the upper non-Cape ivy infested Coward Creek riparian area should be consulted prior to plant selection. Plants on this list will also be suitable for other areas along Coward Creek. Local nurseries, restoration consultants, and the RCD can assist with plant selection. A low cost option for re-planting would be to partner with a local group such as the RCD, Cabrillo College, California Native Plant Society, or Land Trust to organize a volunteer planting day.

Site 2: Glen Deven

For the future management of Cape ivy at this site location, I recommend the existing Cape ivy invasion is treated using herbicides and hand removal, and monitored for three to five years. I recommend starting with the farthest upstream infestation and continuing downstream; treating one acre per year in order to limit disturbance to wildlife habitat. For areas with greater than 50% Cape ivy cover and low numbers of herbaceous native plants, I recommend applying the following treatment as described for Site 1: Coward Creek. **Estimated first year costs based on the results of this study are $11,893 per acre per year.** The breakout of costs is outlined above in recommendations for Site 1: Coward Creek.

First year costs could be drastically reduced if a Land Trust employee were to apply the herbicide. The cost per hour for the employee's time could be less costly per hour than a licensed herbicide applicator and as long as the Land Trust employee is a licensed herbicide applicator or is being supervised by a licensed herbicide applicator, they are allowed to purchase and apply Rodeo herbicide and Activator 90 surfactant.

With these considerations, estimated first year costs would be $2,632 per acre per year. The breakout of costs is outlined above in recommendations for Site 1: Coward Creek.

For areas with less than 50% Cape ivy cover, I recommend hand removal as there is likely to be more native vegetation in these areas. To prevent further spread of Cape ivy, hand removal should begin at the outer edges of the infestation. The winter and spring months are the best times to remove Cape ivy by hand because the soil is moist, making it easier to remove plants. Cape ivy biomass should be either removed from site to a waste facility or left on-site to desiccate on top of a tarp. Average annual hand removal costs are $46,592 per acre based on $10/hour labor costs and two hand removals. These costs were based on volunteer crews; with appropriate training, these labor costs can be reduced. **Costs can also be substantially reduced to an estimated cost of $6,160 per acre by using volunteers.** Hiring a part-time volunteer coordinator for $20 to $25/hour to coordinate volunteer days if existing staff is not available is also an option. You may choose to use volunteers not only for cost reasons, but to engage the community in stewardship, and provide education to prevent future introduction of invasive species. **With these considerations, estimated first year costs are estimated at $6,160 per acre per year.** The breakout of costs is outlined above in recommendations for Site 1: Coward Creek.

I recommend limited re-planting and allowing natural regeneration of the plant communities to fill in, as an alternative to replanting the whole area. Limited re-planting can include planting a small number of native container stock shrubs and forbs in small groupings in the treated area; approximately 15-20 plants per grouping and 10 groups per acre spaced at least 100 feet apart. Plants should be native and well-suited for shady riparian conditions.

The plant list included in the Glen Deven Ranch Management Plan should be consulted prior to plant selection. Plants on this list will also be suitable for other areas along Garrapata Creek. Local nurseries, restoration consultants, and Land Trust staff can assist with plant selection. A low cost option for re-planting would be to organize a volunteer planting day.

Site 3: Big Basin

For the future management of Cape ivy at this site location, I recommend the existing Cape ivy invasion is treated using a combination of herbicides and hand removal, and monitored for three to five years. I recommend starting with the farthest upstream infestation and continuing downstream; treating one acre per year in order to limit disturbance to wildlife habitat. For areas with greater than 50% Cape ivy cover and low numbers of herbaceous native plants, I recommend applying the treatment as described for Site 1: Coward Creek. **Estimated first year costs based on the results of this study are $11,983 per acre per year.** The breakout of costs is outlined above in recommendations for Site 1: Coward Creek.

First year costs could be drastically reduced if a State Parks employee were to apply the herbicide. The cost per hour for the employee's time could be less costly per hour than a licensed herbicide applicator and as long as the State Park employee is a licensed herbicide applicator or is being supervised by a licensed herbicide applicator, they are allowed to purchase and apply Rodeo herbicide and Activator 90 surfactant.

With these considerations, estimated first year costs would be $2,632 per acre per year. The breakout of costs is outlined above in recommendations for Site 1: Coward Creek.

For areas with less than 50% Cape ivy cover, I recommend hand removal as there is likely to be more native vegetation in these areas. To prevent further spread of Cape ivy, hand removal should begin at the outer edges of the infestation. The winter and spring months are the best times to remove Cape ivy by hand because the soil is moist, making it easier to remove plants. Cape ivy biomass should be either removed from site to a waste facility or left on-site to desiccate on top of a tarp. Average annual hand removal costs are $46,592 per acre based on $10/hour labor costs and two hand removals. These costs were based on volunteer crews; with appropriate training, these labor costs can be reduced. C**osts can also be substantially reduced to an estimated cost of $6,160 per acre by using volunteers**. Hiring a part-time volunteer coordinator for $20 to $25/hour to coordinate volunteer days if existing staff is not available is also an option. You may choose to use volunteers not only for cost reasons, but to engage the community in stewardship, and provide education to prevent future introduction of invasive species. **With these considerations, estimated first year costs are estimated at $6,160 per acre per year.** The breakout of costs is outlined above in recommendations for Site 1: Coward Creek.

I recommend limited re-planting and allowing natural regeneration of the plant communities to fill in, as an alternative to replanting the whole area. Limited re-planting can include planting a small number of native container stock shrubs and forbs in small groupings in the treated area; approximately 15-20 plants per grouping and 10 groups per acre spaced at least 100 feet apart. Plants should be native and well-suited for shady riparian conditions. A plant list should be created for this study site, and should be consulted prior to plant selection. Plants on this list will also be suitable for other areas along Waddell Creek. Local nurseries, restoration consultants, and State Park staff can assist with plant selection. A low cost option for re-planting would be to organize a volunteer planting day.

APPENDIX J

VARIATION BETWEEN SITES

The following is a discussion of factors that may have influenced Cape ivy and native plant population response to treatment methods.

Figure 4 below shows visually the variation in Cape ivy cover between sites for treatment methods T1, T2 and T3. The average Cape ivy cover at each site is illustrated prior to initial treatments (in gray), and twelve months after initial treatment (in red).

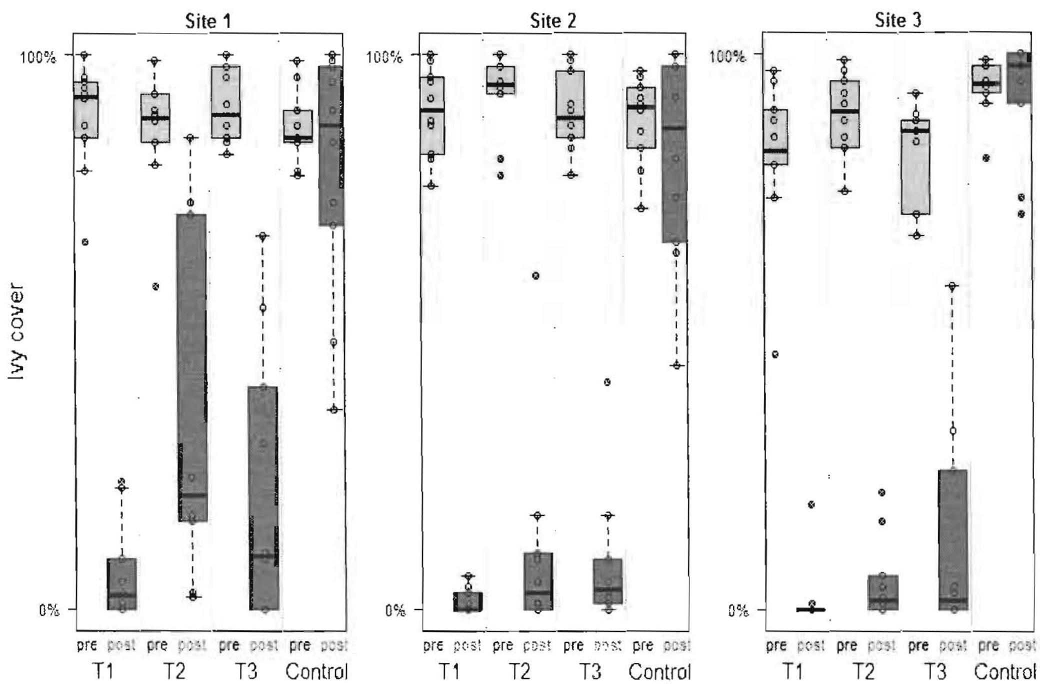


Figure 4. Pre and Post Treatment Cape Ivy Cover.
Site 1= Coward Creek; Site 2= Glen Deven; Site 3= Big Basin.

Although T1 (hand removal only method) results were similar at all sites, there were some outliers in the cost tracking that identified differences in the ability of the volunteers. Hand removal on some plots took longer than should be expected (88 minutes; 4 people working for 22 minutes). A reasonable time per plot is somewhere between 30 and 60 minutes with 3 to 4 people. Experienced volunteers or crews will be able to remove the entire Cape ivy plant in a reduced amount of time. However, less experienced volunteers or crews can require more time to remove Cape ivy, and may be more likely to break rhizomes and stolons in the process;

increasing the likelihood that plant parts will be left in the soil. If the entire Cape ivy plant is not removed, the delicate rhizomes and stolons will re-sprout. In brief, less experienced volunteers or crews can decrease the effectiveness of this method. Dry or hard soil can also affect the effectiveness of this method by increasing the likelihood that rhizomes and stolons will break off in the ground during hand removal.

While T1 was similarly effective at all sites, T2 and T3 were less effective at Site 1 than at Site 2 or 3. The reasons for this difference are likely due to variation in soil moisture, and timing of application. The soil moisture appeared to be high at both site 2 and 3 due to the abundance of moisture loving plants and the presence of perennial streams. Additionally, both sites experience moderate coastal fog and stay cool under canopies of alders (Site 3) and redwoods (Site 2) most of the year. Conversely, Site 1 is located in the foothills outside of Watsonville about 7 miles inland from the ocean, is sycamore and buckeye-dominated, experiences minimal coastal fog and therefore has warm temperatures for much of the year. The soil moisture is likely lower at this site due to low numbers of moisture loving plants, and low to no-flows for most of the year in Coward Creek, a seasonal stream.

August and September is generally the beginning of the "die-back" life stage for Cape ivy. Once Cape ivy begins to "die-back" the leaves desiccate and are less able to absorb herbicide. At sites 2 and 3, initial treatment application for T2 and T3 was done in mid-August (Table 2). This timing was chosen because it was within permit timelines for work in riparian areas. The higher soil moisture at these two sites seemed to allow the Cape ivy leaves to retain water longer, allowing the herbicide to more readily translocate to the roots through absorption. Additionally, warmer temperatures (~75 degrees Fahrenheit) during August could have increased the effectiveness of the herbicide.

Table 2. Initial and Follow-up Treatment Times for Methods at all Sites

	T1: MSE / MSE	T2: H+S / H+S	T3: H+S / MSE
Site 1: Coward Crk	Sept. 08, March 09	Sept. 08, Jan. 09	Sept. 08, March 09
Site 2: Glen Deven	Sept. 08, March 09	Aug. 08, Feb. 09	Aug. 08, March 09
Site 3: Big Basin	July 08, March 09	Aug. 08, Feb. 09	Aug. 08, March 09

At site 1, the initial treatment application for T2 and T3 was done in mid-September. The Cape ivy at this time was most likely farther along in the "die-back" life stage and not as able to absorb herbicide. Cooler temperatures (~ 65 degrees Fahrenheit), and lower soil moisture at this site most likely further decreased the Cape ivy's ability to absorb herbicide.

The initial application of T2 and T3 at site 1 reduced Cape ivy cover to an average 53.2% while Cape ivy cover was decreased to an average 14.7% cover at site 3. At site 1, the follow-up treatment for T2 (herbicide application) resulted in 33% Cape ivy cover, and 4% at site 3. The follow up treatment for T3 (hand removal), resulted in 31.8% Cape ivy cover at site 1 and 11% at site 3 (Table 4).

Table 4. Pre and Post Treatment Cape Ivy Cover Model Comparison. The data presented in this table represents cover averages.

Treat ment	Site 1: Coward Creek Pre and Post		Site 2: Glen Deven Pre and Post		Site 3: Big Basin Pre and Post		Avg Cape Ivy Cover % Reduction	Support for Difference Between Pre and Post Cover: Evidence Ratios
1	89.67	4.42	90.00	2.25	80.08	2.08	84.13	15.41×10^{8}
2	86.67	33.08	92.17	9.00	88.92	4.33	71.73	48.74×10^{4}
3	90.92	31.83	89.92	9.83	83.67	11.17	73.27	82.64×10^{4}
C	87.42	79.20	80.00	74.09	93.42	92.08	5.13	1.31×10^{-2}

It is important to note that site conditions do contribute to the success of native plant population response to treatments. Figure 5 below shows visually the variation in native plant cover between sites for treatment methods T1, T2 and T3. The average native plant cover at each site is illustrated prior to initial treatments (green), and twelve months after initial treatment (red).

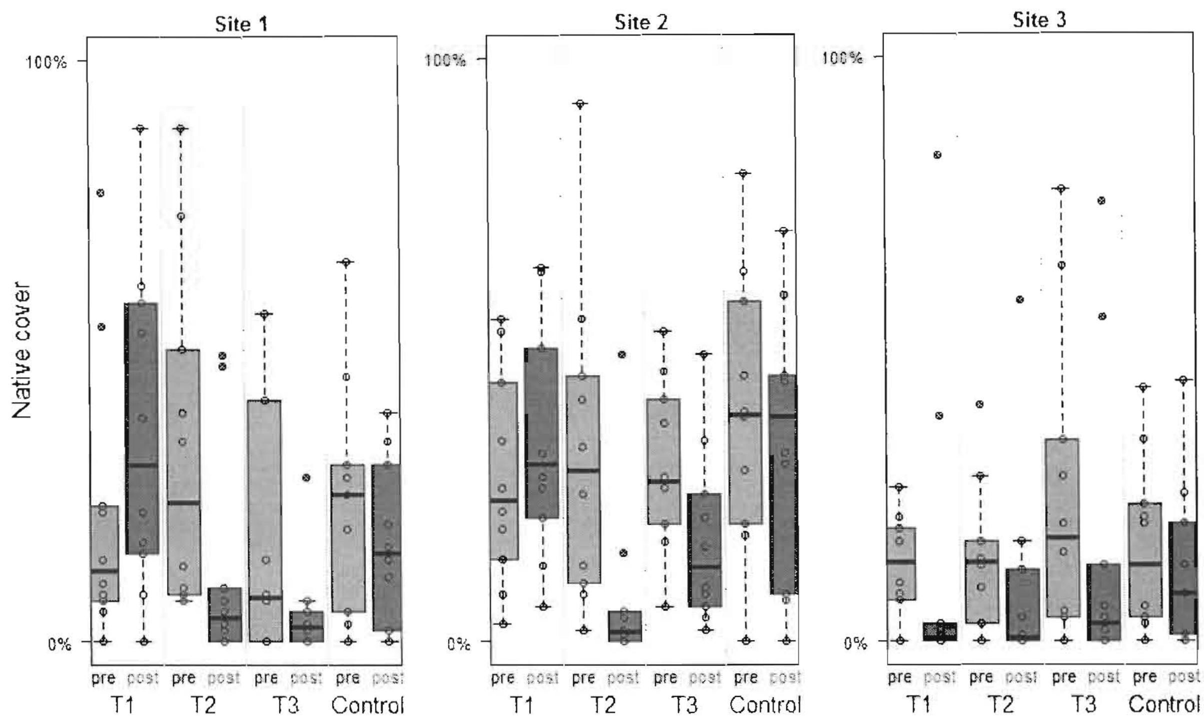


Figure 5. Pre and Post Treatment Native Plant Cover

Site 1 exhibited the highest native plant cover increase as a result of T1. The T1 plots at this site had a fair amount of existing native plant cover (22%) therefore these established natives were able to grow rapidly once the Cape ivy was removed. Furthermore, the post-treatment native plant cover at this site exhibited greater diversity than the initial cover. This was mostly due to recruitment from trees on-site.

Site 2 experienced the greatest reduction in native plant cover as a result of T2 and T3. The T2 and T3 plots at this site in particular displayed a higher initial percent cover of native plants compared to Site 1 and 3. Since the herbicide application was indiscriminant, more natives were impacted at this site due to there being more existing natives. Therefore this site displayed the greatest overall decrease in native plant cover. It is important to note that in time this site may experience an increase in native plant abundance as sunlight and nutrients in the soil is now available.

Site 3 exhibited the lowest increase in native plant cover after application of T1; and the lowest decrease in native plant cover as a result of T2 and T3. This site had the lowest initial native plant cover, on average, of all the sites. This lower native plant cover may have resulted in less herbicide overspray or drift effecting native species. The cause for the low native plant cover may have been the high shade at this site and the surrounding invasive species cover, which would have discouraged the growth of natives. The low initial native plant cover most likely led to the low increase of natives following T1, and low decrease of natives following T2 and T3.

Table 7. Pre and Post Treatment Native Plant Cover Comparison for All Three Sites

Treatment	Coward Creek Pre and Post		Glen Deven Pre and Post		Big Basin Pre and Post		Average Native Plant Cover % Change	Support for Difference Between Pre and Post Cover: Evidence Ratios
T1	22.00	36.00	26.60	45.00	11.80	14.50	**+52.0**	**18.12**
T2	32.90	15.00	36.60	3.19	19.10	9.70	**-65.0**	**10.95**
T3	16.70	4.80	30.70	15.00	27.00	15.90	**-54.5**	**8.23**
C	19.50	16.60	35.20	34.00	22.10	14.50	**-17.6**	**8.54**

APPENDIX K:

PHOTOS

Site 1: Coward Creek, view of horse pasture across driveway from plots

Site 1: Hand removal. T1 method

Site 1: Coward Creek

Site 1: Post-treatment vegetation sampling

Site 1: Mixing herbicide for T2 method

Site 1: Cape ivy leaves after initial herbicide application

Site 2: Garrapata Creek, Glen Deven Ranch

Site 2: Glen Deven Ranch, view of Garrapata Creek Canyon and Pacific Ocean

Site 2: Pre-treatment vegetation sampling

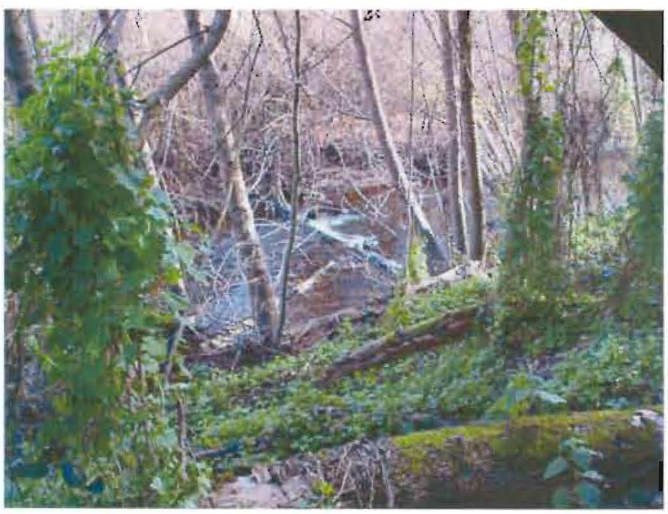
Site 2: Herbicide application, T2 method

Site 2: Hand removal, T1 method

Site 2: Cape ivy leaves after initial herbicide application

Site 2: Post-treatment vegetation sampling

Site 3: Big Basin State Park



Site 3: Waddell Creek, Big Basin State Park

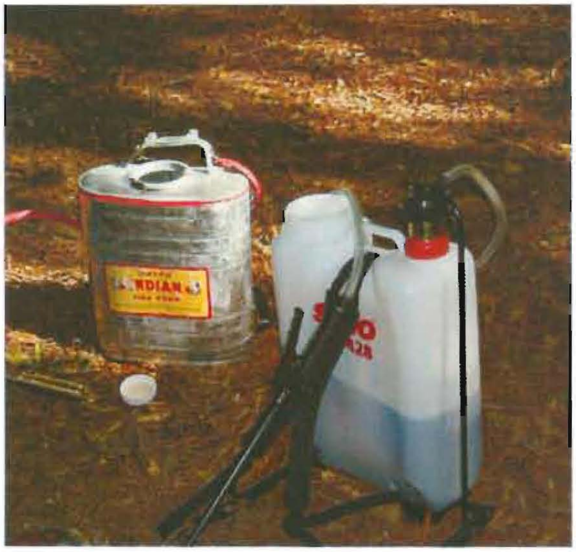
Site 3: Pre-treatment vegetation sampling

Site 3: Hand removal, T1 method

Site 3: Cape ivy leaves after initial herbicide application

Site 3: Herbicide application, T2 method

Herbicide and Adjuvant used for T2 and T3



Solo backpack sprayer and water tank

used for T2 and T3