Management of Bermuda Buttercup (*Oxalis pes-caprae*) in the Peninsula Watershed of the San Francisco Public Utilities Commission

Prepared by Don Thomas, IPM Specialist, San Francisco Public Utilities Commission

ABSTRACT

Bermuda buttercup (*Oxalis pes-caprae*) is an invasive plant native to South Africa rated as a moderate threat to wildlands by the California Invasive Plant Council. Because the clone present in California does not produce seeds, it is only spread by the movement of bulbs. In spite of this, it has been found to be an aggressive weed of landscapes and agricultural fields. Because of its limited capacity for dispersal, in the past it was not considered a major threat to natural areas. However, it is now increasingly encroaching into wildland areas also. Control has been challenging because bulbs may not be susceptible to some herbicides, and some control techniques actually spread the bulbs.

The present study is a preliminary test of several herbicides and herbicide combinations for the control of *Oxalis pes-caprae*. These herbicide trials seem to indicate high efficacy of imazapyr for control of Bermuda buttercup, including suppression of sprouting of bulbs. Furthermore, combinations of herbicide with different modes of action (glyphosate+triclopyr, glyphosate+imazapyr and triclopyr+imazapyr) appear to be more effective in controlling Bermuda buttercup than applications of single herbicides.

INTRODUCTION

Perhaps the most conspicuous weed of coastal California in late winter and early spring is Bermuda buttercup (*Oxalis pes-caprae*). This low growing geophyte, native to South Africa, is ubiquitous, growing in gardens, commercial landscapes, neglected lots, fields and parks. It sprouts from short vertical underground stems (rhizomes) attached to bulbs, producing rosettes of clover-like leaves and 5-petaled flowers. Many small vegetative propagules (bulbils) form along these stems and facilitate its dispersal.

Bermuda buttercup was originally grown as an ornamental plant. As a garden plant, it has many characteristics that make it a desirable addition to a low maintenance garden. It is well adapted to California's Mediterranean climate, emerging after winter rains and requiring no supplemental irrigation. It competes well with common garden weeds and is persistent in the landscape. It has showy displays of yellow flowers that are a nectar source for a variety of generalist pollinators, such as honey bees, bumble bees and butterflies.

However, *O. pes-caprae* is seldom intentionally cultivated now because it was found to spread rapidly though the garden and invade other plantings. It is a weed not only of ornamental landscapes but also a difficult-to-control pest of orchards, vineyards and agricultural fields (DiTomaso and Kyser et al. 2013). In addition to California, Bermuda buttercup is an aggressive weed in other Mediterranean and warm temperate climate regions of the world, including the Mediterranean basin, Chile, Australia and New Zealand. It has invaded at least 22 countries outside of South Africa.

The form of *O. pes-caprae* growing naturally in South Africa is predominantly a tristylous diploid or tetraploid race. However in the invaded range outside of South Africa it is almost entirely present as a short-styled heptaploid (Ornduff 1987). Bermuda buttercup is self-incompatible and individual clones cannot produce seeds without exogenous pollen. The heptaploid form is generally found to be sterile and reproduces only asexually. However now, in the invaded range, it has been found that there is some pollen exchange among flowers, and sexual reproduction has been observed in the Mediterranean region (Costa et al. 2013, Costa et al. 2016). It is not known whether heptaploidy contributes to the invasiveness outside of South Africa of *O. pes-caprae*. However, it was demonstrated in greenhouse experiments that plants from the invaded region were more competitive against a European native plant, *Trifolium repens*, than were South African plants (Tavares 2014).

Bermuda buttercup has been demonstrated to be allelopathic in laboratory tests, and it has been concluded that this contributes to its competitive ability. Six phenyl cinnamate derivatives were extracted from leaves and stems of Bermuda buttercup, and these compounds were found to have phytotoxic effects on the germination and growth of lettuce seedlings (DellaGreca et al. 2009). Root exudates of *O. pes-caprae* caused 62, 58 and 42% reduction in dry weight of tomato, oat and lettuce plants, respectively (Travlos et al. 2008). The presence of Bermuda buttercup has also been shown to reduce germinability of cereal crops by 63% (Global Invasive Species Database 2015). Trans-cinnamic acid has been shown to act as an anti-auxin (Van Overbeek et al. 1951), and this may explain these effects. Allelopathy has also been demonstrated for other species of *Oxalis* (Shiraishi et al. 2005). In my own test of allelopathy, growing an annual ryegrass seed mixture in potting soil to which minced foliage of *O. pes-caprae* was added reduced grass foliage dry weight by 49%, $p<0.001$ (Figure 1).

In wildland areas these same characteristics also make *O. pes-caprae* an aggressive wildland weed. After escaping from cultivation in the San Francisco Bay Area in the 1960s, it has spread to most coastal counties in California. It is now a weed of coastal sand dunes, where it is encroaching upon the habitat of an endangered plant (Tu 2014), and of natural areas on San Bruno Mountain, where it is invading habitat of an endangered butterfly (San Mateo County Parks 2012). It has escaped from cultivation in the Santa Monica Mountains and has spread extensively (National Park Service 2016). In addition to coastal habitats, it is an invader inland of woodland and forest communities, where it prefers semi-shaded habitats (DiTomaso and Kyser et al. 2013).

An invasive plant assessment by the California Invasive Plant Council (Cal-IPC) notes that Bermuda buttercup increases rapidly locally where there is no management and observes that it outcompetes native vegetation for light and space (California Invasive Plant Council 2003) Also, "due to its extensive occurrence in yards and gardens, Bermuda buttercup has the potential to rapidly spread via the production of bulbs and the movement of contaminated soils into adjacent natural areas" (LeStrange et al. 2010).

Bermuda buttercup is also a wildland weed in many other parts of the world. It invades bushlands in Australia, where it competes with native plants for light and space and inhibits the germination of native seeds (Brooks 2001). In Australia, it "forms extensive almost pure stands and spreads rapidly" and "it invades natural plant communities and displaces native plants by the dense stands" (Weber 2003). In the Canary Islands *Oxalis pes-caprae* "is an exotic species able to cover 100% of the area where established (natural and seminatural)", and is very abundant in the thermophilous forest (Salas-Pascual et al. 2011). In the Mediterranean region, natural areas invaded by *O. pes-caprae* were found to have lower species richness and lower net primary production than uninvaded areas (Petsikos et al. 2007). *Oxalis* invasion in Mediterranean islands has been shown to decrease overall native plant diversity by about 10%, especially with regard to annual grasses (Vilà *et al.*, 2006). In other parts of the Mediterranean it invades communities of tall herbs (Urtico-Smymirtum and *Lavatera arborea* community), riparian woodland and *Ricinus communis* scrub (Brandes 1991). It is listed as an invasive species by the European and Mediterranean Plant Protection Organisation (https://www.eppo.int/). The Global Invasive Species Database describes it as follows: "*Oxalis pes-caprae* can suppress other ruderal weed plants, including native species, smothering them and leading to a reduction in biodiversity" (Global Invasive Species Database 2015). Bermuda buttercup deposits oxalic acid in the soil, which acts as a chelating agent for phosphorus, elevating soil P. Elevated levels of soil P have been found to be associated with decreased species richness in grassland (Ceulemans et al. 2014).

In the Peninsula Watershed of the San Francisco Public Utilities Commission (SFPUC) Bermuda buttercup is now spreading into natural areas. It occurs in grasslands where its distribution tends to be patchy. However in shaded areas, such as the woodland understory, it competes with native plants, such as Pacific sanicle, miner's lettuce, woodland strawberry and ferns. Frequently, its colonies can be observed to occur in pure stands that exclude other plants.

Given this growing recognition of *O. pes-caprae* as a threat to natural areas, researchers in many parts of the world are trying to develop effective approaches to manage it (LeStrange et al. 2010). The present study is a preliminary test of the efficacy of several different herbicides and herbicide combinations for the management of Bermuda buttercup in wildland areas.

Figure 1. Allelopathy test conducted in spring 2017. In this test an annual ryegrass seed mixture was germinated in potting soil to which minced *Oxalis pes-caprae* foliage was added. This treatment was compared with control pots without oxalis. Left: pots filled with potting soil at the time of seeding on March 14. Center: control pots on left and treatment pots on right on March 28. Right: Control pots on left and treatment pots on right at the time of harvest of foliage on May 12.

Date of Application	Herbicide active ingredient or combination of ingredients	Herbicide Product or Products	Application Rate	Location	Effect of Treatment
03/25/16	Imazapyr	Habitat Herbicide	2 fl oz/gal	North San Andreas section of Peninsula Watershed	Almost complete prevention of resprouting of bulbs
03/25/16	Triclopyr	Garlon 4 Ultra	2 fl oz/gal	North San Andreas section of Peninsula Watershed	Partial control of oxalis
03/25/16	Glyphosate	Roundup Custom	2 fl oz/gal	North San Andreas section of Peninsula Watershed	Partial control of oxalis
03/30/16	Glyphosate + Imazapyr	Roundup Custom + Habitat	2 fl oz/gal + 2 fl oz/gal	Millbrae Yard	Almost complete prevention of resprouting of bulbs
03/30/16	Glyphosate + Triclopyr	Roundup Custom + Garlon 4 Ultra	2 fl oz/gal + 2 fl oz/gal	Millbrae Yard	Almost complete prevention of resprouting of bulbs
03/30/16	Imazapyr + Triclopyt	Habitat + Garlon 4 Ultra	2 fl oz/gal + 2 fl oz/gal	Millbrae Yard	Almost complete prevention of resprouting of bulbs

Figure 2. Results of preliminary tests of efficacy of herbicides and herbicide combination for the control of Bermuda buttercup. Herbicide applications were made in late March 2016 and evaluated for efficacy during the winter of 2016-2017.

METHODS

In this study I tested the relative efficacy of different herbicides and herbicide combinations, applied during the current growing season, for the suppression of re-sprouting of Bermuda buttercup bulbs during the subsequent fall and winter. These herbicides were applied as a foliar spray to flowering plants in late winter and spring. Herbicide applications were made to relatively solid clonal stands of oxalis in single unreplicated test plots on SFPUC land in the San Francisco Peninsula Watershed and in the Millbrae Corporate Yard.

The following herbicides or herbicide combinations were tested for effectiveness in controlling Bermuda buttercup: imazapyr, triclopyr, glyphosate, glyphosate + imazapyr, glyphosate + triclopyr and imazapyr + triclopyr. For all of these treatments, CMR Can-Hance was used as an adjuvant. The herbicides applied to *Oxalis pes-caprae*, the date of application, the application locations and the effects of the treatments are listed in Figure 2. The effects of the treatments were visually evaluated through the winter of 2016-2017. Effectiveness of the treatments was assessed as the relative change in cover of *O. pes-caprae*.

RESULTS AND DISCUSSION

As with any invasive plant, the most effective management of *Oxalis pes-caprae* is achieved through the system of integrated pest management. This approach employs a variety of control methods, including cultural, mechanical, physical, biological and chemical control practices. Chemical controls may only be selected after non-chemical methods have been found to be ineffective or impractical. The most effective control measure for *O. pes-caprae*, and for most other weeds, is prevention. Oxalis bulbs or soil containing the bulbs should not be moved from infested to uninfested areas, such along utility and transportation corridors through wildland preserves.

Many method of managing Bermuda buttercup have been employed in an integrated pest management strategy for its control. For small areas manual removal may be effective (Tu 2014). Repeated mowing, tarping (Stringer 2016), mulching, covering with geotextile fabrics, sheet mulching and soil solarization have also been effective for small-scale control (LeStrange et al. 2010, Tu 2014).

A noctuid moth larva native to South Africa, *Klugeana philoxalis*, has been suggested as a possible biological control agent for Bermuda buttercup (Kluge and Claassens 1990). The night-feeding larvae of this species show some specialization for *O. pes-caprae*, though they also feed on a limited number of other species in the genus.

However all of these methods have limitations in wildland settings. Tarping, sheet mulching and soil solarization usually cannot be used where weeds are growing among or near established desirable native plants and in sensitive plant habitats.
Because of the limitations of these control methods, directed applications of herbicides have been viewed as the most effective and practical means of control in some settings, such invaded native plant communities (Lazzaro et al. 2016, Stringer 2016). However, the use of herbicides has been met with mixed results. A University of California Extension publication on control of oxalis species (LeStrange et al. 2010) states: "Several post emergent herbicides including triclopyr and fluroxypyr (selective for broadleaf plants) and glyphosate and glufosinate (nonselective) effectively kill the top growth of this weed but are harmful to most ornamentals, so be careful these herbicides don't drift onto desirable plants. These herbicides don't kill the bulbs, and regrowth from bulbs should be expected." However, a more recent University of California publication (DiTomaso, Kyser et al. 2013) provides recommendations of herbicides for control of *O. pes-caprae*, including glyphosate, glufosinate and imazapyr. Stringer (2016) reported a great reduction in plant density after treatment with triclopyr and glyphosate applied at the 1% rate.

In my preliminary test of herbicides in the present study, imazapyr applied in late March 2016 appeared to completely prevent re-sprouting of *O. pes-caprae* bulbs during the winter and spring of 2016-2017, while triclopyr and glyphosate provided only partial control (Figure 3). One limitation of the traditional approach of managing oxalis with herbicides is that it relies on the use of only a single active ingredient, usually either triclopyr or glyphosate, with a single mode of action, such as hormonal disruption (triclopyr) or aromatic amino acid inhibition (glyphosate). In the present study I tested combinations of herbicides with different modes of action, and these preliminary tests appear to indicate that these provide enhanced control of *O. pes-caprae*.

In addition, application of imazapyr alone appears to provide almost complete control of Bermuda buttercup (Figure 3). The mode of action of imazapyr is the inhibition of branched-chain amino acids. In addition to causing phytotoxicity to the above-ground foliar parts of the plant, imazapyr was found to have high efficacy in preventing re-sprouting from bulbs. This greater efficacy is apparently due to the effect of residual soil activity of imazapyr leached from oxalis rhizomes and roots on dormant bulbs and bulbils.

Because Bermuda buttercup is mainly dispersed through movement of bulbs, it has been considered by some to have limited ability to invade wildland areas. For this reason it has been assigned a Moderate rating in the Cal-IPC Inventory (http://www.cal-ipc.org/ip/management/plant_profiles/Oxalis_pes-caprae.php) However the bulbs float and can be carried by water, and bulbs may also be moved by birds, such as jays, and by rodents, such as gophers. Moreover, humans are very effective and efficient dispersal vectors and are able to move bulbs considerable distances, especially along utility, transportation and recreational corridors.

The difficulty of control of Bermuda buttercup has led some to consider control impractical (Leu 2015). However, as with other very invasive and difficult-to-control exotic plants, such as French broom, veldt grass, Cape ivy and jubata grass, the most effective approach to its management is a strategic one focused on the infestations with the greatest potential to spread (Renz et al. 2012). With this strategy, small outlying and pioneer populations are targeted first, followed by the advancing edge of larger infestations. By prioritizing work at the outer edge, the infestation can be contained or even progressively reduced in size. Herbicidal treatment may be very effective for this purpose.

The use of herbicides may also have high efficacy for habitat restoration of infested fields and woodlands. As with efforts at eradication and containment, prioritization of infestations threatening sensitive resources (the Bradley method) may be the most effective approach. Herbicide can be used to control Bermuda buttercup around the margin of planted or naturally recruited native plants, releasing them from competition.

One disadvantage of using imazapyr for habitat restoration is its long soil residual activity. The soil half-life has been found to be in the range of 24-144 days (McDowell et al. 1997) and of 82-268 days (Douglass et al. 2015). Imazapyr in the soil is degraded largely through microbial breakdown. Therefore edaphic and other environmental conditions conducive to microbial activity promote more rapid degradation. In general, soils with greater moisture content exhibit shorter half-lives, and decreasing half-life correlates with finer soil texture and higher organic matter content. Residual imazapyr can have a persistent phytotoxic effect on native plants installed through active revegetation or through passive recruitment.

In this study no phytotoxic effects were observed on established native plants in the treatment area, including coast live oak and ceanothus and manzanita species. However residual imazapyr in the soil had a pre-emergent herbicidal effect on the germination of annuals and perennials from seed. It has been found that different native species differ in their tolerance to residual imazapyr in the soil, with sensitivity ranging from 10-18% to 2-3% of the application level for more tolerant and less tolerant native species, respectively (Douglass et al. 2015). The selection of native species for restoration and the timing of their planting, therefore, should be determined by the species tolerance to imazapyr.

The pesticide trials in this study are only preliminary tests of the efficacy of either individually applied herbicides or of synergistic effects of combinations of herbicides for the control of Bermuda buttercup. Additional tests will be required to corroborate these findings. In particular, additional tests of imazapyr applied to *O. pes-caprae* are needed to demonstrate its effectiveness for bulb suppression and to evaluate its utility for restoration of native plant habitats invaded by Bermuda buttercup.

Figure 3. Appearance of herbicide treatment sites employed in the tests of efficacy for control of *Oxalis pes-caprae*. From left to right: Habitat Herbicide plot after treatment, Garlon 4 Ultra plot after treatment, Roundup Custom plot after treatment, treatment plots for herbicide combinations before treatment, treatment plots for herbicide combinations after treatment.

REFERENCES

California Invasive Plant Council. 2003. Cal-IPC Plant Assessment Form for Oxalis pes-caprae. http://cal-ipc.org/paf/site/paf/394

Costa, J., V. Ferrero, J. Loureiro, M. Castro, L. Navarro and S. Castro. 2013. Sexual reproduction of the pentaploid, short-styled Oxalis pes-caprae allows the production of viable offspring.

Costa, J., V. Ferraro, M. Castro, A. Jorge, A. Afonso, J. Loureiro and . S. Castro:. 2016. Pollen flow between flowers of the same morph in invasive populations of Oxalis pes-caprae in the Western Mediterranean region. Plant Biosystems: Official Journal of the Societa Botanica Italiana. 150: 923-931.

Brandes, D. 1991. Sociology and ecology of Oxalis pes-caprae L. in the Mediterranean Region with special attention to Malta. Phytocoenologia 19(3): 285-306.

Ceulemans, T. et al. 2014. Soil phosphorus constrains biodiversity across European grasslands. Global Change Biology 20 (12): 3814-3822.

DellaGreca, M., L. Previtera, R. Purcaro and A. Zarrelli. 2009. Phytotoxic aromatic constituents of Oxalis pes-caprae. Chemistry & Biodiversity 6: 459-465.

DiTomaso, J., G. Kyser et al. 2013. *Oxalis pes-caprae* (Bermuda buttercup). Weed Control in Natural Areas in the Western United States. Weed Research and Information Center, University of California. http://wric.ucdavis.edu/information/natural%20areas/wr_O/Oxalis.pdf

Douglass, H., S. Nissan, P. Meiman and A. Kniss. 2016. Impacts of imazapyr and triclopyr soil residuals on growth of several restoration species. Rangeland Ecology & Management 69: 199-205.

Global Invasive Species Database. 2016. Species profile for Oxalis pes-caprae. http://www.iucngisd.org/gisd/species.php?sc=1599

Kluge, R. and M. Claassens. Klugeana philoxalis Geertsema (Noctuidae: Cuculliinae), the first potential biological control agent for the weed Oxalis pes-caprae L. Journal of the Entomological Society of Southern Africa 1990 Vol.53 No.2 pp.191-198

Lazzaro, L., G. Ferretti, b. Foggi, E. Bianchi and R. Benesperi. 2016. Evaluating an effective treatment to control/eradicate the invasive weed *Oxalis pes-caprae*: indications from a field experiment in a Mediterranean island. Poster presented at the 9th International Conference on Biological Invasions, September 14-16, 2016, Vlanden Luxembourg.

LeStrange, E., C. Elmore and D. Cudney 2010. Creeping woodsorrel and Bermuda buttercup. University of California Statewide Integrated Pes Management Program. Pest Notes Publication 7444. http://ipm.ucanr.edu/PDF/PESTNOTES/pncreepingwoodsorrel.pdf

Leu, C. 2015. A natural history of that little yellow flower that's everywhere right now. Bay Nature Magazine, March 2015.

McDowell, R., L. Condron, B. Mainand F. DASTgheib. 1997. Dissipation of imazapyr, flumetsulam and thifensulfuron in soil. Weed Research 37: 381-389.

National Park Service 2016. Wildflowers of the Santa Monica Mountains National Recreation Area. http://www.smmflowers.org/bloom/PDF-species/Oxalis_pes-caprae_UCLA_SantaMonicas.pdf

Ornduff, R. Reproductive systems and chromosome races of Oxalis pes-caprae L. and their bearing on the genesis of a noxious weed. Annals of the Missouri Botanical Garden &$: 79-84.

Ptetsikos, C., P. Dalias and A. Troumbis. 2007. Effects of Oxalis pes-caprae L. invasion in olive groves. Agriculture, Ecosystems and Environment 120: 325-329.

Renz, M., S. Steinmaus, D. Gilmer and J. DiTomaso. Spread dynamics of perennial pepperweed (*Lepidium latifolium*) in two seasonal wetland areas. Invasive Plant Science and Management 5: 57-68.

Salas-Pascual, M., A Naranjo, S Fernández-Lugo, and J. Arévalo. 2011.Effects of Oxalis pes-caprae on ecological aspects of the potential thermophilous canarian forest. Plantas invasoras resistencias a herbicidas y detección de malas hierbas. XIII Congreso de la Sociedad Española de Malherbología, La Laguna, Spain

San Mateo County Parks. 2012. San Bruno Mountain Habitat Conservation Plan - Year 2012 Vegetation Management Activities Report For Endangered Species Permit PRT-2-9818.

Shiraishi, S., I. Watanabi, K. Kuno and Y. Fujii. 2005. Evaluation of the allelopathic activity of five Oxalidaceae cover plants and the demonstration of potent weed suppression by *Oxalis* species. Weed Biology and Management 5: 128-136.

Stringer, L. 2016. Oxalis pes-caprae control trials. Cal-IPC News, Summer 2016. p 4-5

Tavares, D. 2014. Evolution of invasiveness: the case study of the invasive *Oxalis pes-caprae* in the Mediterranean basin. Master's thesis dissertation. Universityof Coimbra, Portugal.

The Nature Conservancy. 2005. Oxalis pes-caprae weed alert. Global Invasive Species Team web site. https://www.invasive.org/gist/alert/alrtoxal.html

Travos, I., E. Paspatis and E. Psomadeli. 2008. Allelopathic potential of Oxalis pes-caprae tissues and root exudates as a tool for integrated weed management. Journal of Agronomy 7 (2): 202-205

Tu, M. 2014. Oxalis pes-caprae. Global Invasive Species Team. Bugwood Wiki. https://wiki.bugwood.org/Main_Page

Van Overbeek, J. R. Bloneau and V. Horne. 1951. American Journal of Botany 38: 589-595.

Vilà, M., M. Tessier, C. Suehs, G. Brundu, L. Carta, A. Galanidis et al. 2006. Local and regional assessment of the impacts of plant invaders on vegetation structure and soil properties of Mediterranean islands. Journal of Biogeography 33: 853-861.