Weed Technology. 2004. Volume 18:1194-1202

Symposium

The Control of a Highly Invasive Tree *Cinchona pubescens* in Galapagos[1]

CHRISTOPHER E. BUDDENHAGEN, JORGE LUIS RENTERIA, MARK GARDENER, SARAH R. WILKINSON, MONICA SORIA, PATRICIO YANEZ, ALAN TYE, and RENE VALLE[2]

Abstract: Red quinine tree has been recognized as a serious weed in the Galapagos National Park for three decades. During this time, a variety of control methods have been implemented, initially with poor results. In this article, we reviewed past efforts to control red quinine tree and tested a variety of herbicides and selective application methods. A mixture of picloram and metsulfuron (240 and 15 g ai/L, respectively) killed 73 to 100% of trees when applied to connecting machete cuts around the circumference of tree trunks (hack and squirt [HS]) at concentrations of 5, 10, and 20% in water, with larger trees requiring higher concentrations for best results. Although this herbicide mixture also was effective when applied using other methods, HS was the least labor intensive and costly. The control methods developed could be used to combat this weed in other locations including Hawaii and Tahiti.
Nomenclature: Metsulfuron; picloram; red quinine tree, *Cinchona pubescens* Vahl.
Additional index words: *Cinchona succirubra*, Galapagos National Park, Hawaii.
Abbreviations: BB, basal bark; CDRS, Charles Darwin Research Station; CS, cut stump; DBH, diameter at breast height; GNP, Galapagos National Park; GS, girdle and squirt; HS, hack and squirt; H, hack only; MASL, meters above sea level; WS, wide-band hack and squirt.

INTRODUCTION

Approximately 550 plant species are known to have been introduced to Galapagos by people. Of these species, 221 have naturalized, with 100 of these becoming established in intact native vegetation, and approximately 40 are recognized as having an effect on native vegetation (Charles Darwin Research Station [CDRS] Herbarium Database 2003; S. Henderson, unpublished data). Most weeds originate, establish, and spread from the agricultural zones in the humid highlands of the four largest islands, where introductions are more frequent and conditions more favorable than the semiarid lowlands. Only 5% of hectarage in the Galapagos Archipelago is zoned for agricultural and urban use, and the remaining 95% is Galapagos National Park (GNP), Galapagos, Ecuador. A number of introduced plant species have spread from the agricultural zones into the GNP and appear to have changed species composition and community structure. Among these are a number of tree species, including guava *(Psidium guajava* L.), West Indian cedar *(Cedrela odorata* L.), rose apple *(Syzigium jambos* (L.) Alston), sauco *(Cestrum auriculatum* (L.) Her.), and red quinine tree; a number of woody shrubs, including lantana *(Lantana camara* L.), hill raspberry *(Rubus niveus* Thunb.), and Andean blackberry *(Rubus glaucus* Benth.); and a number of vines, including yellow passionfruit *(Passiflora edulis* Sims.), sweet granadilla *(Passiflora ligularis* Juss.), and fragrant Dutchman's pipe *(Aristolochia odoratissima* L).

Originally from the Andean countries in the northern part of tropical South America, red quinine tree was first introduced in 1946 to the agricultural zone on the island of Santa Cruz. It was planted at an altitude of 350 m above sea level (MASL) in an area close to the current boundary of the GNP, which was established in 1956 (Hamann 1974). It may have been introduced for its medicinal qualities and as a shade tree or a live fence. Quinine *(Cinchona officinalis* L.) is commonly used worldwide for quinine production; red quinine tree bark in Galapagos also contains 1 to 4% of quinine on a dry weight basis (T. Buchler, unpublished data). Currently,

[1] Received for publication December 23, 2003, and in revised form August 28, 2004.
[2] First, second, sixth, and seventh authors: Research Scientists, Charles Darwin Research Station, Puerto Ayora, Galapagos; third author: Research Scientist, Key Centre for Tropical Wildlife Management, Charles Darwin University, Darwin, Northern Territory 0909, Australia; fourth author: Research Coordinator, Department of Renewable Resources, University of Alberta, Edmonton, Alberta, Canada; fifth author: Tecnico Enlace, Galapagos National Park, Puerto Ayora, Galapagos; eighth author: Park Ranger, Galapagos National Park, Puerto Ayora, Galapagos. Corresponding author's E-mail: chrisb@fcdarwin.org.ee.

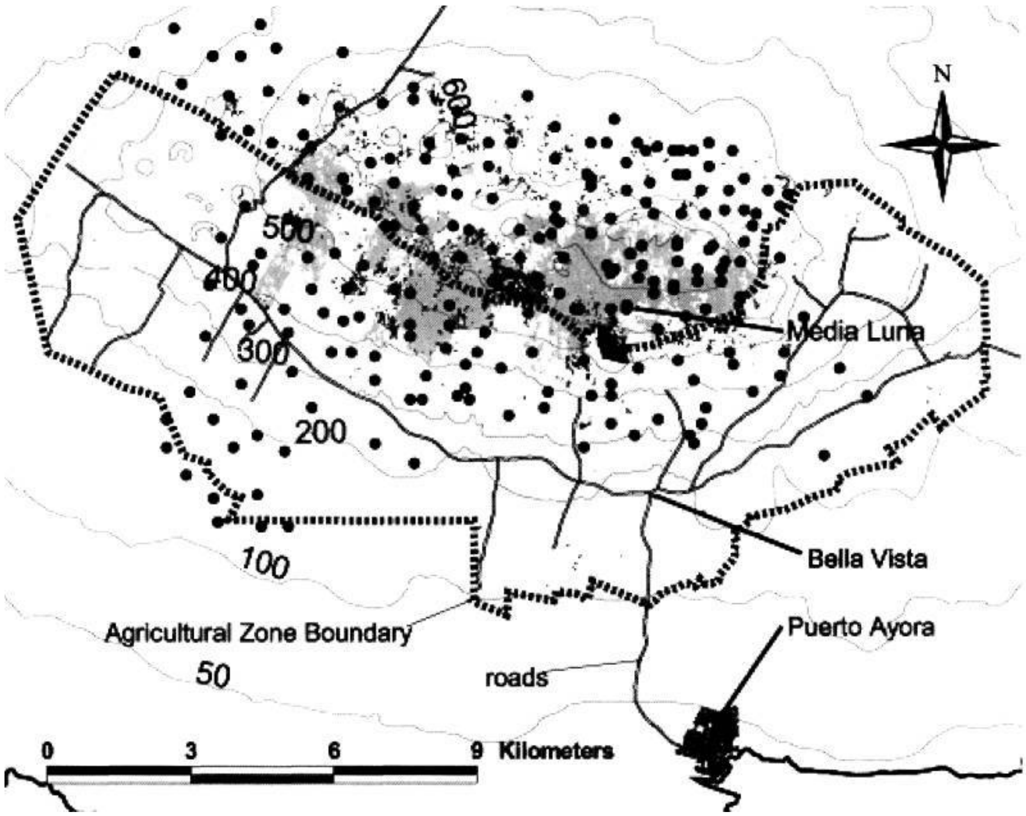

Figure 1. The area infested by red quinine tree on Santa Cruz is described using shaded areas and points. Points represent field observation of occurrences of the tree before April 2002. Using a satellite photograph taken in March 2000, we found a color range that corresponded to two levels of infestation of red quinine tree. Dark gray is a dense level and light gray an intermediate level.

red quinine tree is not known to occur on any other island in Galapagos.

Spread of red quinine tree on Santa Cruz was rapid because of its numerous winged wind-dispersed seeds, capability to reproduce vegetatively, and shade tolerance of seedlings (Jager 1999). By 1965, its presence had been noted in the "fern-sedge zone" (Kastdalen 1982) perhaps as far as 500 m from the agricultural zone where it was planted, suggesting that it occupied as little as 400 ha. It occupied 4,000 ha in 1987 (Macdonald et al. 1988), 8,500 ha in 1990, and now has a range of more than 11,000 ha (Jager 1999), covering almost 10% of the island's area. Rentería (2002) found that 54% of the area infested was in the agricultural zone and the rest inside the GNP, occupying an altitudinal range of 180 to 860 MASL. Using a satellite photograph taken in March 2000, we found a color range that corresponded to two infestation densities. The densest infestations occupied approximately 376 ha and those of medium density about 1,366 ha. When sampled in 2003, the heavy and medium infestations contained 24,150 and 11,600 stems/ha, respectively, with stems taller than 150 cm (Figure 1). The invasion of red quinine tree has resulted in complete structural change to the vegetation from low open scrub, fernbrake, and grasslands to a closed forest canopy of 5 to 8 m tall. On Santa Cruz, many areas have not yet reached the maximum densities recorded or are not yet invaded.

Red quinine tree was reported as invasive on St. Helena Island (Cronk and Fuller 1995) but currently is only naturalized in a few areas of the island (Q. Cronk, personal communication). It is generally unmanaged as a weed in Hawaii and Polynesia, where it has naturalized in "virgin forests" (Meyer 2000). It is starting to show its potential to become invasive on Maui with approximately 6,000 ha infested (F. Starr, personal communication). Spread in Hawaii has not been as rapid possibly because of many of the plantations being surrounded by tall forest (F. Starr, personal communication).

The failure to prevent the spread of red quinine tree on Santa Cruz is the result of three main factors: not recognizing the invasive potential early enough, ad hoc control activities, and the lack of an effective and economical control method. During the past 25 yr, various manual, mechanical, and chemical control methods have been used by the GNP and CDRS staff to control red

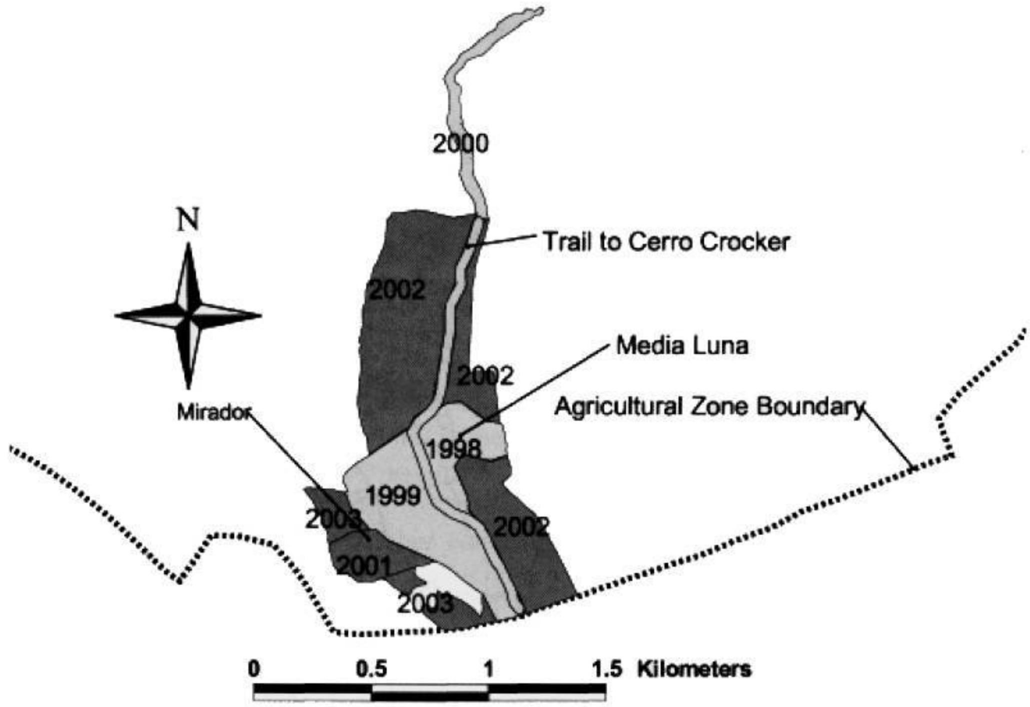

Figure 2. A total of 109 ha were controlled by the GNP staff before September 2003 using manual (light gray) and chemical (dark gray) methods in the area around Media Luna; numbers indicate the year in which the work was undertaken. Details about the number of hectares controlled each year are described in Results and Discussion.

quinine tree. During this time, trials were developed to determine the most effective methods; however, no specific methodology was followed, and trials often consisted of a treated infestation marked out for monitoring within regular control operations.

Informal trials such as those conducted in Galapagos are commonplace elsewhere. Managers of natural areas more often deal with different weeds than the well-studied species of agricultural sites. In many cases, managers undertake informal trials that produce effective methods to control such invasive species; these methods are then adopted for local use without ever being published. Consequently, distant conservation managers often repeat control trials that have already been undertaken elsewhere.

In this article, we compiled data from a range of unpublished studies evaluating control and management of red quinine tree on the island of Santa Cruz. We also present the results of a series of field trials that we initiated in 1998 to determine the most effective methods to control red quinine tree.

MATERIALS AND METHODS

We reviewed technical reports, archived notes, and published documents that describe the historical attempts to limit the spread of red quinine on Santa Cruz. Recent control efforts were mapped in September 2003 using a handheld global positioning system unit (Figure 2).

Review of Previous Unpublished Studies (1974 to 1996). We reviewed unpublished accounts of control trials from a variety of sources, including personal communications, notes, files, observations, and internal field reports of the GNP and CDRS. Most trials tested a number of herbicides and applied them using one or more methods and concentrations (Table 1). In many cases, the information recorded during a trial was incomplete. Herbicides tested were picloram and 2,4-D in diesel fuel (two trials), different 2,4-D formulations (six trials), picloram and 2,4-D mixed with glyphosate (one trial), picloram and 2,4-D (four trials), glyphosate (eight trials), unknown active ingredient herbicide (one trial), and imazapyr (one trial). Specific herbicide concentrations tested are provided in Table 1.

Where application methods described in these unpublished accounts were the same as those described for our 1998 to 2003 study, we used the same terminology and abbreviations described in Treatment Methods. Application methods unique to these unpublished studies included (1) branch filling, cuts in the crux of branches were filled with herbicide; (2) microinjection, herbicide

Table 1. Unpublished studies to determine methods of control for red quinine tree between 1974 and 1996 were reviewed from a number of sources of information; they used a variety of herbicides containing the active ingredients grams per liter in the original unmixed product. Often, a number of concentrations (sometimes mixed with a carrier) were applied implementing one of nine methods of application. Trials were normally undertaken by marking out plots or individual trees. Concluding observations about the effectiveness of the application methods used were noted.[a]

Source of information[b]	Date	Active ingredient[c]	Rates	Concentration (mix)	Methods of application	Area or number of trees	Effectiveness of control
			g ai/L				
Andrew Schmidt and Luis Ortiz	1974	No data	No data	20% (diesel fuel)	CS	1.6 ha	All trees survived
Luong Tan Touc, Elizabeth Potts, and C. Arturo	1983	Picloram/2,4-D	64/240	No data	CS, GS, HS, BB, and BrF	180 trees	CS gave 100% control. No differences in control were observed between herbicides. GS and BrF were only effective on trees less than 10-cm DBH
		2,4-D	480	No data	CS, GS, HS, BB, and BrF		
		2,4-D	No data	No data	CS, GS, HS, BB, and BrF		
		2,4-D	No data	No data	CS, GS, HS, BB, and BrF		
Luis E. Cruz	1986	Picloram/2,4-D	64/240	25% (diesel fuel)	CS	280 trees	44% control
		2,4-D	480	25% (diesel fuel)	CS		34% control
		Picloram/2,4-D + 2,4-D	64/240 + 480	25% (diesel fuel)	CS		31% control
Andrew Schmidt and Luis Ortiz	1987	Picloram/2,4-D	64/240	5, 10, 15, and 20%	JG	720 trees	Picloram and 2,4-D gave 41% mortality, and other herbicides gave less than 10%. Multiple applications gave poor results
		2,4-D	480	5, 10, 15, 20%			
		Picloram/2,4-D + 2,4-D	64/240 + 480	5, 10, 15, and 20%			
Mark Otto	1988	Picloram/2,4-D	64/240	10 and 20%	CS and HS	75 trees	50% control
		Glyphosate	240	5 and 10%			No data
		Picloram/2,4-D + Glyphosate	64/240 + 240	No data			No data
Pat Whelan	January 1993	Glyphosate	No data	100 and 50%	HS	166 trees	Small trees (1- to 3-cm DBH) were effectively killed
Pat Whelan	May 1993	Glyphosate	240	1.5%	HS and FS		HS was ineffective but FS was effective for trees <l-cm DBH
Raul Pozo	June 1994	Glyphosate	0.18 g/capsule	One capsule per 10-cm diameter	EZ	No record	Poor control
		Glyphosate	480	41%	MI	68 trees	All trees resprouted after a year
GNP Memo	1994	Glyphosate	0.18 g/capsule	One capsule per 10-cm diameter	EZ	294 trees	All trees survived
GNP Memo	November 1996	Imazapyr	No data	No data	EZ	10 trees	No data

[a] Abbreviations: HS, hack and squirt; BB, basal bark; CS, cut stump; GS, girdle and squirt; BrF, branch filling; EZ, Ez-Ject® system; FS, foliar spray; JG, Jim-Gem© Tree Injector; MI, microinjection; GNP, Galapagos National Park; DBH, diameter at breast height. For more details see Materials and Methods.

[b] All sources of information are unpublished internal reports or memos from Charles Darwin Research Station or GNP Service.

[c] Herbicides were mixed with water when diesel is not mentioned, except in the case of the Ez-Ject lance, in which case capsules of herbicide were used.

administered to the cambium using the Tree Tech® microinjection system,[3] which constitutes a pressurized plastic container containing herbicide with a narrow nozzle that is inserted into small holes in the cambium; (3) Ez-Ject® system,[4] a lance is used to place capsules of herbicide under the cambium; (4) foliar spray, foliar applications of herbicide using unidentified spray system; and (5) Jim-Gem© Tree Injector,[5] measured amounts of herbicide are injected into cuts in the bark in a similar way to the hack and squirt (HS) method, which is described in a subsequent section.

Latest Study (1998 to 2003). A series of three herbicide trials to control red quinine tree were carried out between 1998 and 2003 in the GNP (Table 2). Trials were located within *Miconia* and fern-sedge vegetation zones in the highlands of Santa Cruz between 450 and 680 MASL. The *Miconia* zone was historically dominated by the Galapagos endemic shrub Galapagos miconia *(Miconia robinsoniana* Cogn.) (Melastomataceae) and exclusively occurs on the islands of Santa Cruz and San Cristobal (Wiggins and Porter 1971). Red quinine tree has been a major codominant in the area since the early 1990s. The density of red quinine trees greater than 1.5 m in height can be as high as 40,000 stems/ha in this area. Stem density is high because of extensive suckering from adult trees, and the density of individual plants may actually be similar to that found by Jager (1999), where densities ranged from 50 to 1,100 plants/ha.

Three series of related trials were undertaken, each using different methods for selecting trees and assigning treatments and each started in a different year, but all were monitored using the same criterion. Each series is hereafter described as a "trial set" to distinguish them from previous trials not carried out by the authors and those described in Review of Previous Unpublished Studies (1974 to 1996). The treatment methods summarize the methods used in these three trial sets. In trial set 1, nine adjacent plots were established, each of which contained 45 trees, 15 in each of three diameter at breast height (DBH) classes (<7 cm, 7 to 10 cm, and >10 cm). One of nine treatments was randomly assigned to each of the plots, and all trees in a plot received the same treatment. In trial set 2, 10 plots containing 15 trees were established, with five trees in each DBH class. Treatments were assigned randomly to each plot, and all trees in a plot received the same treatment. In trial set 3, 280 trees of DBH >10 cm were selected and seven treatments were randomly assigned to individual trees so that 40 trees were treated. In all trial sets, if multiple stems were present, all were treated. For the purpose of this article and comparison between trial sets, diameter class data were pooled where trees had multiple stems, e.g., a tree with two stems with a DBH of 3 and 7 cm was considered for our purposes equal to a tree with a single stem of 10-cm DBH.

Treatment Methods. Specific herbicide treatments, their use rates, and methods and date of application are indicated in Table 2. The volume of herbicide mix applied to each tree depended on the diameter of the tree and the treatment method used. Herbicides were mixed according to registration instructions and applied to individual trees using a hand-pumped backpack sprayer or handheld squirt bottles. Herbicides were applied using water or diesel fuel (Table 2) as a carrier. The six application methods were (1) HS, herbicide was applied with a squirt bottle to a series of joining machete cuts, which passed through the cambium at a downward 45° angle around the circumference of the tree at a height of 20 to 50 cm above the ground until the herbicide filled the cuts, (2) basal bark (BB), herbicide was applied with a diesel-resistant backpack sprayer to the bark of trees in a 20-cm ring that completely encircled the trunk 30 cm from the base of the tree, (3) wide-band hack and squirt (WS), herbicide was applied with sprayer or squirt bottle to overlapping machete cuts around the circumference of the tree similar to the HS method; however, the cuts were made in a 20- to 30-cm-wide band from the ground upward, (4) girdle and squirt (GS), herbicide was applied with a squirt bottle or a sprayer to a 10-cm-wide band of stripped bark 30 to 50 cm from the ground (girdled or ring barked) until the surface was wet, (5) cut stump (CS), trees were cut with a chain saw about 20 cm from the surface of the ground, herbicide was applied with a squirt bottle or a sprayer to the cut surface of the stem until complete coverage was achieved, and (6) hack only (H), the nontreated control consisted of trees cut only with a ring of joined machete cuts placed 20 to 50 cm above the ground.

In 2003, we compared the amount of herbicide mixture required for each of the treatment methods except the BB method, which would require a greater volume of herbicide than the GS method because it requires a band twice as wide to be covered. Using 23 trees between 3.3- and 10.2-cm DBH, we determined the average amount of mixture required to treat trees of a given

[3] Florida Silvics Inc., 950 South East 215th Avenue, Morriston, FL 32668.
[4] Odom Processing Engineering & Consulting Inc., P.O. Box 829, Waynesboro, MS 39367.
[5] Forestry Suppliers Inc., P.O. Box 8397, Jackson, MS 39284-8397.

Table 2. Control of red quinine tree after treatment with herbicides containing the active ingredients indicated, using five methods of application, in three sets of trials monitored for a number of DAT on Santa Cruz between 1998 and 2003. Resprouting after treatment is indicated by a "+" in the shoots column.[a]

Application method	Herbicide[b]	Dates	Mean DBH	Number of DAT	Number of treated trees	Control	Shoots
Trial set 1			cm	d		%	
HS	Picloram salt 25% (60 ai g/L)	April 24, 1998-June 12, 1999	9.11	414	41	37	+
HS	Picloram salt 50% (120 ai g/L)	April 23, 1998-June 12, 1999	10.61	415	45	71	–
BB	Triclopyr ester 20% (80.8 ai g/L)	January 11, 1999-June 12, 1999	8.84	152	40	38	–
BB	Triclopyr ester 30% (121.2 ai g/L)	April 18, 1998-June 12, 1999	8.50	189	43	77	–
HS	Triclopyr salt 50% (150 ai g/L)	April 18, 1998-June 12, 1999	9.76	420	44	45	+
HS	Triclopyr salt 100% (300 ai g/L)	April 18, 1998-June 12, 1999	11.41	420	43	74	–
HS	Glyphosate 50% (240 ai g/L)	April 29, 1998-June 12, 1999	10.12	348	38	0	+
HS	Glyphosate 100% (480 ai g/L)	April 29, 1998-June 12, 1999	9.02	409	43	2	+
BB	Diesel fuel	December 18, 1998-June 12, 1999	10.04	176	40	0	+
H	No herbicide	April 21, 1998-June 12, 1999	9.50	490	38	0	+
Trial set 2							
HS	Picloram + metsulfuron 5% (3.2 + 0.2 ai g/L)	January 12, 2000-June 21, 2002	3.03	891	15	100	–
HS	Picloram + metsulfuron 10% (6.4 + 0.4 ai g/L)	January 12, 2000-June 21, 2002	2.04	891	15	100	–
HS	Picloram + metsulfuron 20% (12.8 + 0.8 ai g/L)	January 12, 2000-June 21, 2002	2.04	891	15	100	–
HS	Picloram + metsulfuron 5% (3.2 + 0.2 ai g/L)	January 12, 2000-June 21, 2002	6.67	891	15	100	–
HS	Picloram + metsulfuron 10% (6.4 + 0. 4 ai g/L)	January 12, 2000-June 21, 2002	7.12	891	15	100	–
HS	Picloram + metsulfuron 20% (12.8 + 0.8 ai g/L)	January 12, 2000-June 21, 2002	7.18	891	15	93	+
HS	Picloram + metsulfuron 5% (3.2 + 0.2 ai g/L)	January 12, 2000-June 21, 2002	10.92	891	15	73	+
HS	Picloram + metsulfuron 10% (6.4 + 0.4 ai g/L)	January 12, 2000-June 21, 2002	10.68	891	15	87	+
HS	Picloram + metsulfuron 20% (12.8 + 0.8 ai g/L)	January 12, 2000-June 21, 2002	9.98	891	15	100	–
CS	Picloram + metsulfuron 4% (2.5 + 0.16 ai g/L)	January 12, 2000-June 21, 2002	10.56	891	80	94	+
Trial set 3							
GS	Picloram + metsulfuron 10% (6.4 + 0.4 ai g/L)	February 21, 2001-January 17, 2003	14.57	695	40	88	–
HS	Picloram + metsulfuron 10% (6.4 + 0.4 ai g/L)	February 21, 2001-January 17, 2003	13.57	695	40	83	–
WS	Picloram + metsulfuron 20% (12.8 + 0.8 ai g/L)	February 21, 2001-January 17, 2003	13.11	695	40	100	–
GS	Triclopyr ester 20% (120 ai g/L)	February 21, 2001-January 17, 2003	12.68	695	40	10	+
HS	Triclopyr ester 20% (120 ai g/L)	February 21, 2001-January 17, 2003	13.68	695	40	38	+
WS	Triclopyr ester 10% (60 ai g/L)	February 21, 2001-January 17, 2003	13.11	695	40	50	+
H	No herbicide	February 21, 2001-January 17, 2003	12.75	695	40	0	+

[a] Abbreviations: HS, hack and squirt; BB, basal bark; CS, cut stump; GS, girdle and squirt; WS, wide-band hack and squirt; H, hack only; DAT, days after treatment; DBH, diameter at breast height (1.2 m). For more details see Materials and Methods.

[b] Herbicides were mixed with water except for BB application, in which case the carrier was diesel fuel.

diameter by measuring the volume of liquid used for each tested method.

Control was assessed based on observations of the physical health (color and texture) of the cambium of the trunk and roots and the presence or absence of live shoots. The cambium of live trees was pale yellow to white and soft in texture, whereas dead or dying trees gradually came to have a cambium that was brown-orange and hard in texture. The cambium was checked by cutting the bark with a pocketknife or machete above and below the treated parts of the trunk. Most trials were monitored for more than 1 yr, an average of 637 d after treatment (Table 2). One to three visits were made annually to monitor the fate of treated trees; however, only the final observations of the condition of treated trees are presented in this study.

RESULTS AND DISCUSSION

Historical Attempts to Limit the Spread of the Red Quinine Tree on Santa Cruz. In 1971, the GNP initiated control of red quinine tree, and in the 1980s, control programs (mainly manual hand pulling of seedlings and saplings) were directed at tens of thousands of trees (40,000 between 1980 and 1981) (Tuoc 1983) in an "intensive control area" of about 1,000 ha (Macdonald et al. 1988). Control efforts, however, ceased in the late 1980s. In 1998, after a pause of approximately 10 yr, the GNP again began control of the species using manual methods; 6.5 ha of red quinine tree on Media Luna (a small crater) and 27 ha to the west of it were controlled by hand (Figure 2). The endemic Galapagos petrel *(Pterodroma galapagensis)* nests in burrows on the crater, and there was concern that the change from a Galapagos miconia-dominated shrubland to a red quinine tree-dominated forest would lead to changes in burrow structure or the way in which birds reach their burrows. In 2000, trees were manually removed with hand tools 25 m either side of a trail between the park boundary and the top of Cerro Crocker (the highest point on the island) in an area of approximately 13 ha (Figure 2). The manual control method that was used in 1998 and 2000 by the GNP was as follows: tree roots greater than 2 cm in diameter were cut out in a 25-cm radius from the base of the tree (the rocky soils make for a shallow root system), and the tree was uprooted, the stem cut off, and the stump turned upside down. According to field managers, fragments less than 2 cm in diameter do not resprout and therefore were left in place. Manual methods killed trees on Media Luna but were labor intensive. In areas with approximately 222 large trees/ha (Jager 1999), one worker could only clear about 400 m^2/d. Furthermore, this method created large holes in the ground, which could be open to invasion by red quinine tree and other weeds, and damaged adjacent native vegetation.

A long history of control of red quinine tree on Santa Cruz island has not prevented the spread of the species. This has, in part, been attributed to a lack of effective chemical control methods and inconsistent investment in effort over the years.

Review of Previous Unpublished Studies (1974 to 1996). Before our 1998 to 2003 trial sets, more than 20 yr were spent searching for an effective method to control red quinine tree by testing a variety of herbicides and application methods. Some methods were tested more than once but showed inconsistent control results between trials (Table 1). Documentation and monitoring to measure treatment efficacy were often not consistent and usually inadequate, and data were often incomplete. Some reports or archives did not contain quantitative results of control effectiveness but contained only descriptors such as "good," "effective," or "poor."

Most trials were not monitored for more than 1 yr; thus, conclusions are based on visual assessments 2 to 12 mo after treatment. Resprouting of trees was common where trees were monitored for more than 6 mo. In the 1983 trial, CS application provided 100% control at all concentrations implemented when using a mix of picloram and 2,4-D or 2,4-D alone (Table 1). Perhaps, this is because trees were cut as close to the ground as possible. Other CS applications in 1986 and 1988 using the same herbicides typically gave less than 50% control (Table 1). Foliar applications of glyphosate (3.6 g ai/L) were recorded as "effectively" controlling small trees (1 to 2 cm in diameter and 1 to 2 m tall) in one trial, but no information about control rates was found (Table 1). However, glyphosate in other trials (480 g ai/L) was not effective, especially when applied using the HS method and even at high concentrations (50 to 100%) (Table 1).

Latest Study (1998 to 2003). For trees that were completely controlled by certain herbicide treatments, 1 yr was often required to obtain 100% tree kill (Table 2). In some cases, trees without leaves that seemed dead resprouted 1 yr after treatment.

In trial set 1, triclopyr ester applied at 30% using BB application resulted in 77% control and no resprouting. Control using HS, however, was low (38%), and resprouting occurred. Picloram salt at 50% and triclopyr salt at 100% applied using the HS method resulted in >70% control in large trees without evidence of resprouting. Glyphosate produced results little different from the nonherbicidal H treatment (2 vs. 0% control).

In trial set 2, a mixture of picloram and metsulfuron (240 and 15 g ai/L, respectively) was equally effective (100% control) when applied using any of the methods described (CS, HS, WS, or GS) and at concentrations ranging from 4 to 20%. In all treatments, trees took at least 6 mo to die. There was no difference between the 5, 10, and 20% concentrations of the product where DBH was <7 cm (Table 2).

In trial set 3, application of triclopyr ester using GS, HS, and WS was not effective on large trees in comparison with the metsulfuron-picloram combination. The WS application method, using a lower concentration but greater volume of herbicide than HS or GS methods, was, however, more effective. Concentrations of 20% picloram-metsulfuron product were tried with the WS method and were more effective than the HS and GS method using 10% concentrations.

Application Rates and Cost. The amount of herbicide applied to each tree depended on the tree diameter and the method used, i.e., HS (1.5 ml/cm DBH), WS (4.01 ml/cm DBH), GS (0.99 ml/cm DBH), and CS (0.7 ml/cm DBH). The HS method used about 35% less herbicide than the WS method, and there was little difference in treatment efficacy. The only differences between these two methods are the number of cuts and the care with which they need to be applied. The other application methods required less herbicide but, in general, were not as effective for controlling red quinine tree and were more labor intensive. For the HS method to be correctly applied, cuts must be connecting around the trunk. If the number of overlaps and therefore cuts can be reduced, the volume of herbicide and cost also can be reduced. WS and HS may allow greater absorption of the herbicide because the herbicide mixture is held in the freshly made cuts for a period during which the herbicide can be absorbed into the cambium.

Over all trial sets, the GS and CS methods with picloram and metsulfuron (trial set 2) required the least volume of herbicide mixture and effectively controlled red quinine tree. The amount of work, however, required to fell trees or remove a band of bark makes these methods costly. The CS method also damaged the surrounding vegetation more and may provide further opportunities for reestablishment of red quinine tree and establishment of other weed species. A method that produces less disturbance, although it may result in slower death of standing trees, is more desirable.

The highest red quinine tree control was obtained with a mixture of picloram and metsulfuron using the HS method, which also required the least effort. Trees >8-cm DBH did not die as readily, except when a 20% concentration was used. The GS method could be as effective for red quinine trees >10-cm DBH, but we suggest the HS or WS method at a concentration of 10 to 20% be used instead because they are less labor intensive.

Although high concentrations of picloram or triclopyr (trial set 1) were effective, the picloram and metsulfuron combination is less costly and more readily available in Ecuador. Prices in Ecuador for the picloram-metsulfuron product were $37/L, whereas triclopyr (480 g ai/L) was $24/L. In Ecuador, there are currently no sources of picloram alone, and it is always sold mixed with other herbicides such as 2,4-D or metsulfuron. We imported the picloram-alone product specifically for these experiments. Glyphosate and diesel fuel, although readily available, were ineffective treatments.

By 2003, the GNP staff working to control introduced plants had successfully controlled large areas of red quinine tree using the WS application method and an application rate of 6.75% of the picloram-metsulfuron product (C. Carvajal, personal communication). By late September 2003, approximately 109 ha had been controlled near Media Luna (Figure 2) near the highest part of the island. Our studies show that the HS method provides the same control as WS but uses 35% less herbicide; thus, one of the future management actions will be an education and training campaign for the GNP workers to show them how to use this method to reduce costs.

The potential of red quinine tree as an invader elsewhere has been recognized but perhaps not given the attention warranted. Red quinine tree may still be sufficiently restricted in distribution on some islands in the state of Hawaii or on St. Helena and Tahiti to eradicate it (Meyer 2000; F. Starr, personal communication). Certainly, the feasibility of eradication should be seriously examined because it is an easily identifiable tree that stands out amongst other vegetation, and there is a period of 2 to 3 yr between germination and reproduction (J. L. Renteria, personal observation). Wherever it occurs on tropical islands with humid environments, the effective manual or chemical methods described in this study should be used to control or eradicate this troublesome species.

ACKNOWLEDGMENTS

This is a contribution (1003) to the Charles Darwin Foundation. A number of volunteers and staff at the Botany Department of Charles Darwin Research Station have been involved in the collection of data during the years that the latest study has been run. Their help has been invaluable. The late Hamish Saunders helped with the analysis of the satellite image in Figure 1. The GNP Introduced Plants group currently managed by Carlos Carvajal has done an amazing job in recent years controlling large areas of red quinine tree as described in Figure 2. Thanks to the GNP for access to archives for the review of historical control efforts. Funding provided by the United Nations Foundation, Monsanto, and the Global Environment Facility invasive species project through UNDP-ECU/00/G31 is gratefully acknowledged.

LITERATURE CITED

Cronk, Q.C.B. and J. L. Fuller. 1995. Plant Invaders. The Threat to Natural Ecosystems. London: Chapman and Hall. 147 p.

Hamann, O. 1974. Contributions to the flora and vegetation of the Galapagos Islands. 5 new floristic records. Bot. Not. 127:309-316.

Jager, H. 1999. Impact of the Introduced Tree *Cinchona pubescens* Vahl. On the Native Flora of the Highlands of Santa Cruz Island (Galapagos Islands). Oldenburg, Germany: University of Oldenburg. Pp. 1-102.

Kastdalen, A. 1982. Changes in the biology of Santa Cruz 1935-1965. Not. Galapagos 35:7-12.

Macdonald, I.A.W., L. Ortiz, J. E. Lawesson, and J. B. Nowak. 1988. The invasion of highlands in Galapagos by the red quinine-tree *Cinchona succirubra.* Environ. Conserv. 15:215-220.

Meyer, J.-Y. 2000. Preliminary review of the invasive plants in the Pacific islands (SPREP Member Countries). *In* G. Sherley, ed. Invasive Species in the Pacific: A Technical Review and Draft Regional Strategy. Apia, Samoa: South Pacific Regional Environment Programme. Pp. 85-114.

Renteria, J. L. 2002. Ecología y manejo de la cascarilla *(Cinchona pubescens* Vahl), en Santa Cruz, Galapagos. Área Agropecuaria y de Recursos Naturales Renovables. Loja, Ecuador: Universidad Nacional de Loja. Pp. 1-89.

Tuoc, L. T. 1983. Some thoughts on the control of introduced plants. Not. Galapagos 37:25-26.

Wiggins, I. L. and D. M. Porter. 1971. Flora of the Galapagos Islands. Stanford, CA: Stanford University Press. Pp. 16-30, 695-697.

2004

Invasive Weed Symposium

A Journal of the Weed Science Society of America

Table of Contents

•Peer reviewed papers.

Cover

Awareness of invasive weeds, such as Kudzu *(Pueraria montana)* has increased in recent years. This image was taken by Dr. Shawn Askew, Department of Plant Pathology and Weed Science at Virginia Polytechnic and State University, Blacksburg, Virginia 24061.