THE COST OF QUININE *CINCHONA PUBESCENS* CONTROL ON SANTA CRUZ ISLAND, GALAPAGOS

By: Chris Buddenhagen & Patricio Yáñez

Charles Darwin Research Station, Santa Cruz, Galapagos, Ecuador <chrisb@fcdarwin.org.ec>

SUMMARY

We analyse the cost of controlling the invasive quinine tree *Cinchona pubescens* Vahl in the highlands of Santa Cruz Island, Galapagos. Control costs in ten 400 m² plots formed the basis for estimating the cost of control over the whole island. In the plots, densities were 2100–24,000 stems/ha (stems >150 cm tall) and 55,000–138,000 stems/ha (all size classes combined). Control involved uprooting small plants, and applying of a mix of metsulfuron methyl and picloram to cut stumps or to machete cuts in the bark of larger trees. These methods are presently used by Galapagos National Park field crews to control quinine. Costs (in man hours, herbicide and US$) were related to stem density; the density of stems summed across four height classes was a better predictor of costs than density of any one size class. Regressions (on all size classes combined) formed the basis for predictive models of costs. Costs ranged from $14 to $2225 per ha depending on stem density. The amount of herbicide (active ingredient/ha) that must be applied to high density stands of quinine is higher than typical rates of application in an agricultural setting. The cost of treating all existing plants once across quinine’s known range on Santa Cruz Island (c. 11,000 ha) was estimated at c. US$1.65 million.

RESUMEN

Analizamos el costo de controlar quinina *Cinchona pubescens* Vahl, en la zona alta de la Isla Santa Cruz, Galápagos. El costo de efectuar el control en diez parcelas de 400 m² formó la base de una estimación de los costos de controlarlo en toda la isla. En las parcelas la densidad fue de 2100–24.000 tallos/ha (tallos con altura >150 cm) y de 55.000–138.000 tallos/ha (todas las clases de tamaño combinadas). El control consistió en arrancar de raíz juveniles, y aplicar herbicida (mezcla de metsulfuron metil y picloram) a tocones o a cortes de machete en la corteza de tallos mayores. Estos métodos son los utilizados actualmente para combatir esta especie por las cuadrillas del Parque Nacional Galápagos. Los costos (en horas-hombre, herbicida y US$) fueron relacionados con la densidad de tallos (todas las clases de tamaño combinadas); la densidad de tallos total (todas las clases de tamaño combinadas) fue el mejor factor determinante del incremento de los costos de control, más que la densidad de los tallos en alguna de las categorías de tamaño en particular. La regresión (usando todas las clases de tamaño combinadas) fue utilizada para crear modelos predictivos de los costos de control. Los costos variaron entre $14 a $2225 por ha, dependiendo de la densidad de los tallos. La cantidad de herbicida (kg de ingrediente activo/ha) que debe ser aplicada a rodales densos de quinina es más alta que la típica para controlar malezas en campos agrícolas. El costo para controlar todas las plantas de esta maleza en su rango actual conocido en la isla Santa Cruz (c. 11,000 ha) sería de c. US$1.65 millones.

INTRODUCTION

Since its introduction to Galapagos in 1946 (Hamman 1974), quinine *Cinchona pubescens* Vahl has spread to more than 11,000 ha on Santa Cruz Island, heavily impacting agricultural land and native plant communities, including those dominated by the endemic shrub *Miconia robinsoniana* Cogn. (Jäger 1999, Rentería 2002). Quinine forms dense stands (Fig. 1), and was first recognized as a threat to the Galapagos National Park (GNP) in the 1970s, when it probably occupied c. 2000 ha. A satellite image taken in 2001 was used to determine the areas of arbitrarily defined densities: 376 ha were densely infested and 1366 ha had medium density (Buddenhagen et al. 2004). Currently the total infested area is probably c. 11,000 ha (Rentería 2002). GNP controlled 110 ha between 1998 and 2003 (Buddenhagen et al. 2004); since then even more area has been controlled but probably still < 2% of the total infested area.

Quinine is difficult to control; an effective labor-intensive manual method requires trees to be pulled (small ones) or dug out of the ground. Such treatment of large trees causes severe disturbance to the soil and nearby plants. Control can be complicated because many trees have multiple stems connected by a network of roots, individual trees sucker when cut and pulled stems left in contact with the ground may set root. Apart from the high costs of labor, at high densities the impact of a purely manual method on native plants is considered unacceptable. An effective control method using herbicides, which leads to slow death of standing trees, is preferred and cheaper, mainly due to lower labor cost. In practice, a combined manual-chemical method is most effective, with small plants hand-pulled and larger ones treated with herbicide. Amongst dozens of herbicides and application methods that have been tested over almost 25 years, only one herbicide combination was found to be
≥ 80% effective: the application by “hack and squirt” of a mix of metsulfuron-methyl and picloram to connecting machete cuts around the trunk (Buddenhagen et al. 2004). The GNP has used this method with 1g metsulfuron and 60 g picloram per liter of water, since 2001. In this paper we investigate the cost of controlling quinine using the methods currently employed by the GNP.

METHODS

Study area
Santa Cruz is one of the largest islands in the Galapagos archipelago. It has an estimated maximum age of 3.6 million years, with shallow soils (Geist 1996). It reaches an altitude of 860 m above sea level. Quinine occupies a range from 180 m asl to the top of the island but is particularly dense in the area above 400 m, in the Miconia and Fern-Sedge Zones (sensu Wiggins & Porter 1971) both of which are now dominated by quinine. Our study was undertaken in the Miconia Zone and in the transition zone between Miconia and Fern-Sedge Zones, in areas with quinine density levels “medium” and “high” as identified by Buddenhagen et al. (2004) (Fig. 1).

Quinine densities in the experimental plots
We wanted to measure costs of controlling quinine at high density (worst case) and medium density, in the area that currently forms the focus of control by the GNP. Five 20 × 20 m plots were marked out in the medium density area and five more in the dense area. The plots were placed systematically at 20-m intervals along trail sides. We were only interested in the relationship between density or basal area of quinine and the effort required to control it, so random placement of plots was not considered necessary. The plots were sub-sampled using ten 2 × 2 m plots arranged from corner to corner (Fig. 2) to estimate the density of stems of quinine in four height classes, 0–20 cm, 21–100 cm, 101–150 cm, and >150 cm, as used by Jäger (1999). Diameter at breast height (dbh) was measured for all stems >150 cm tall. The proportion of stems >150 cm tall was compared between high and medium density areas.

Control methods
All the quinine in the plots was controlled using a combination of three methods: (1) for stems >150 cm tall and with dbh > 8 cm, the hack and squirt method described by Buddenhagen et al. (2004) was applied using a mix of metsulfuron 1g/l and picloram 60g/l of water; (2) stems >150 cm tall with dbh < 8 cm were cut through and the same herbicide mix applied immediately to the cut stump; (3) stems <150 cm tall were uprooted manually. Control was carried out by a team of 4–7 field staff from the GNP and the Charles Darwin Research Station (CDRS).

Relationships of costs with stem density
Several regressions were tried to find the best model for the relationships between stem density and man hours, herbicide, and cost in US$. A curved quadratic function was considered, as this is likely to be a better empirical description of some of these relationships than a linear function, since there are diminishing returns with progressively lower stem densities, i.e. more time is needed to find each stem at lower densities.

For man-hours, regressions were made using a quadratic function available in Sigma Plot 2000, with the y intercept restricted to 4 h, which is the average time required for searching and controlling 1 ha, with the average of several different terrains and densities of non-target vegetation) for plants at very low densities, using systematic search methods employed by CDRS (unpubl. data). For herbicide use, a linear regression with the y intercept restricted to 0 (the amount of herbicide needed to control zero stems) seemed logically appropriate, assuming that size structure is uniform in different density areas. However, a quadratic function was also tested and found not to be a better predictor than a linear function.
Monetary cost estimates were based on a labor rate of $3.50 per h (the current standard rate for field staff in Galapagos) and the cost of the herbicide product (Combo®) in mainland Ecuador at the time of writing ($33.70 per l of mixture). Combo is distributed as 1 l of a liquid component containing 240 g of active ingredient picloram, plus 15 g of an emulsifiable powder of metsulfuron that is mixed at the time of use with the liquid component, before dilution with water to application concentration. Each liter of undiluted herbicide was mixed with 13.98 l of water.

We noted additional factors (apart from stem density) that contribute to the cost of control, including time to reach the control sites and distance to nearest water sources.

Density and total cost estimates
Buddenhagen et al. (2004) estimated the spatial extent of “high”, “medium” and “low” density quinine on Santa Cruz Island at 376 ha, 1366 ha and 9258 ha respectively. Our plots were situated in the same high and medium density areas visible in the satellite images that were used to estimate these areas. We assumed the average stem density (all size classes) in the relatively small high density area to be the same as that in our plots there (138,000 stems/ha). However, we are less confident of the representativeness of our five plots in the medium-density area, due to localised previous manual control operations that may have resulted in unrepresentatively high stem densities in our plots. Because of this, we calculated an average density for the medium density area based on both our plots and five 20×20 m randomly located plots near to ours (H. Jäger unpubl. data). The remaining area we classified as low density. In this area, H. Jäger (unpubl. data from eight 20×20 m plots randomly located in the Fern-Sedge Zone) recorded an average of 728 stems per ha, which we used to calculate the cost of a complete control pass through the area. Regression equations derived for costs on stem density in the plots were used to determine costs of controlling all stems once, in the three density-level areas.

RESULTS

Control costs and stem density
Effort (man-hours) required to control an area was closely related to both density of all stems (all size classes summed) \( r^2 = 0.96 \) and stems >150 cm tall \( r^2 = 0.89 \) in the plots (Fig. 3). Since density of all stems was a slightly better predictor, this was used for the calculation of total costs in Table 1. This was also true for liters of herbicide (all stems \( r^2 = 0.87; \) stems >150 cm tall \( r^2 = 0.76 \) ) (Fig. 4) despite a significant difference in the size class distribution between medium and high density plots (stems >150 cm in height made up 20% of all stems in medium density plots and 17% in high density plots; \( \chi^2 = 200.752, P < 0.001 \) ). Basal area of stems >150 cm tall varied between 3 and 27 m²·ha⁻¹ in different plots. Despite this, basal area of stems >150 cm tall was a poor predictor of herbicide use \( r^2 = 0.62 \) compared with stem densities (Fig. 4).

US$ costs were therefore graphed using a quadratic function of the density of all stems (Fig. 6) since the cost estimate is based on herbicide and effort combined and should reflect diminishing returns of search effort at lower densities.

Water for mixing with the herbicide (13.98 l per l of herbicide product) was carried from sources 0–250 m from each plot. The effect of distance to water source on costs (the time required) is included in the total time measured for the control of each plot.

**Figure 3.** Man-hours per ha (by a team of four) to search for and control *Cinchona pubescens* at a given density of stems >150 cm tall per ha (circles, \( r^2 = 0.89, y = 4 + 0.013162x + 3.26 \times 10^{-5}x^2 \)) or in all size classes (triangles, \( r^2 = 0.96, y = 4 + 0.00190373x + 1.45 \times 10^{-7}x^2 \)).

**Figure 4.** Liters of herbicide (before dilution) required to control *Cinchona pubescens* at a given density of stems >150 cm tall (circles, \( r^2 = 0.76, y = 0.00162441x \)) or of stems in all size classes (triangles, \( r^2 = 0.87, y = 0.000295077x \)).
Partial cost estimate of controlling known infestations

The cost of control over the estimated range of densities found in the infested areas on Santa Cruz ranged from $21 to $2255 per ha (Table 1). However, based on the average cost of systematic searching (unpubl. data), costs could be as low as $14 (4 man-h) per ha in areas where few or no quinine stems are found. The overall cost of controlling (one pass through) the known infested areas (no overheads, no travel costs, 2004 rates) is estimated at just over US$1.1 million (Table 1).

In the high density area, herbicide application rate was equivalent to 9.7 kg active ingredient per ha of picloram and 0.61 kg a.i. per ha of metsulfuron methyl.

DISCUSSION

Costs not accounted for in the models

Our estimates of costs are restricted to the cost of control work at the control site. These provide a partial estimate of the costs of a practical control program. Additional, so far unestimated, direct (transport etc.) and indirect costs (overheads) would have to be estimated to obtain the total cost of a control program. Such factors include time taken to hike to and from the nearby parking area to the plots, which varied between 17 and 37 min., and could be longer, and transport costs from town (a 20-min. drive each way). Costs associated with getting to and from the infestations depend on a number of interacting factors such as weather, distance, terrain, availability of access points and trails, all of which affect the time available for control in a given day. In this study, transport from Puerto Ayora to a convenient access point and the subsequent hike to each work site, together took up to 2 h per day (25% of a working day), and could vary from 1–4 h per day, depending on the distance to work sites. Herbicide costs are based on the cost in mainland Ecuador; cost of importation to Galapagos has not been included. All these costs are difficult to predict, but should be considered in a more complete cost analysis.

Total cost of controlling known infestations

In 2004, GNP paid $800 per ha to contractors to control quinine (F. Correa pers. comm.). According to our calculations, this would be a reasonable price at infestation levels up to about 60,000 stems/ha but inadequate in the densest areas, where costs are likely to exceed $2000 per ha (Table 1). However, it would be generous in the lowest density areas where costs could be little higher than $14

Table 1. Costs to control the estimated area of infestation of *Cinchona pubescens* (one pass through the entire area). Costs were estimated using the equations given for the regressions from Figs 3–5.

<table>
<thead>
<tr>
<th>Density level</th>
<th>Average density (stems per ha all size classes)</th>
<th>Number of ha</th>
<th>Man-hours</th>
<th>Undiluted herbicide (l)</th>
<th>Total cost (US$)</th>
<th>Water (l)</th>
<th>Cost per ha (US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>728(^1)</td>
<td>9258</td>
<td>49,901</td>
<td>1296</td>
<td>189,882</td>
<td>18,120</td>
<td>21</td>
</tr>
<tr>
<td>Medium</td>
<td>6352(^2)</td>
<td>1366</td>
<td>22,785</td>
<td>1721</td>
<td>99,281</td>
<td>24,062</td>
<td>73</td>
</tr>
<tr>
<td>High</td>
<td>138,000(^3)</td>
<td>376</td>
<td>203,807</td>
<td>13,995</td>
<td>848,008</td>
<td>195,646</td>
<td>2255</td>
</tr>
<tr>
<td>Total</td>
<td>48,362</td>
<td>11,000</td>
<td>276,493</td>
<td>17,012</td>
<td>1,137,170</td>
<td>237,828</td>
<td>103</td>
</tr>
</tbody>
</table>

\(^1\) Based on unpubl. data from H. Jäger. \(^2\) Based on unpubl. data from H. Jäger combined with our data. \(^3\) Based on counts in our study plots.
per ha. Of course contractors would have to cover overheads that are not accounted for here.

Table 1 provides a first estimate of the total cost of controlling the known infested areas on Santa Cruz. Our estimates of the density and extent of quinine over the island are approximate, but represent the best information at hand; more detailed and accurate information would permit refining the cost estimate. The model from this study could contribute to a detailed management plan for quinine, be that a large-scale control program or the first phase of a complete eradication attempt. According to our estimates, the cost of field work, i.e. searching for and controlling quinine, in the first phase of an eradication program would exceed US $1.1 million (Table 1). Adding indirect and unaccounted costs mentioned above might take the actual cost to 1.5 times our estimate, or $1.65 million. It takes approximately two years for quinine trees to reach maturity (J. Rentería pers. comm.), so the first control pass should ideally be completed in <2 yr, and repeated every year thereafter, to prevent seeding of trees. It is not clear how long an eradication program would need to continue, perhaps 10–20 years. In planning such a project, other costs, such as travel time and a logistical-administrative overhead, obviously still need to be estimated in more detail.

The number of work hours per person per year is c. 1700. Our estimate of man-hours required for a first control pass is therefore equivalent to >150 man-years of work. A staff of at least 75 (preferably up to 200) field operatives would therefore be needed to complete the control pass with confidence within two years.

The application rates at the highest stem densities, equivalent to 9.7 kg active ingredient per ha of picloram and 0.61 kg a.i. per ha of metsulfuron methyl, are many times higher than label rates recommended for use in agriculture, i.e. 0.14–1.8 kg per ha (picloram) and 0.014–0.17 kg per ha (metsulfuron). This may be surprising considering that the application method is targeted to cuts in the trunk and volumes of mixture applied to individual trees are small, but may be explained by the high concentrations needed to control large trees, and the high stem densities encountered, as compared with herbaceous weed control typical of agricultural situations.

**ACKNOWLEDGMENTS**

This work was accomplished with the support of Project ECU/00/G31 “Control of Invasive Species in the Galapagos Archipelago”, a donation from the Global Environment Facility to the Ecuadorian Government. Opinions expressed herein belong to the authors. Carlos Carvajal, head of the GNP introduced plants program kindly allowed his field team to advise and carry out the control work. GNP staff Kiman Valle, Francisco Correa and Vicente Orellana, and CDRS staff Félix Burgos, Manuel Orellana, Manuel Montalván, Guilber Valle and Kléber Román did the control work, and Marianne Lindhardt and Ruth Llumiquinga helped collect data. Alan Tye provided detailed comments on the manuscript. This is contribution 1013 of the Charles Darwin Foundation for the Galapagos Islands.

**LITERATURE CITED**


Jäger, H. 1999. *Impact of the introduced tree Cinchona pubescens Vahl on the native flora of the highlands of Santa Cruz Island (Galapagos Islands)*. Diplomarbeit, University of Oldenburg, Germany.
