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Alternative tree girdling and herbicide treatments for liberation and timber stand improvement in Bolivian tropical forests

Calvin Ohlson-Kiehn [a,b], William Pariona [a,c], Todd S. Fredericksen [a,d,*]

[a] BOLFOR Sustainable Forestry Project, Santa Cruz, Bolivia
[b] Washington State Department of Natural Resources, Sedro-Woolley, WA, United States
[c] Bolivian Forest Research Institute, Santa Cruz, Bolivia
[d] Life Sciences Division, Ferrum College, 212 Garber Hall, Ferrum, VA 24088, United States

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Abstract

Silvicultural treatments that remove non-commercial trees can be very beneficial to the residual stand, but are rarely implemented in tropical forests due to perceptions of high cost. This study evaluated the efficacy and cost of four chainsaw girdling and herbicide treatments in a humid and dry tropical forest of Bolivia. Treatment variables included single-band girdling versus double-band girdling, 50% versus 100% concentration of 2,4-D, and dry versus rainy season application. After 18 months, double-band girdling caused higher mortality of treated trees than single-band girdling (87% versus 76%). There was no difference in the efficacy of different concentrations of 2,4-D. In the humid forest, trees treated in the dry season experienced 97.5% mortality after 18 months, whereas those treated in the rainy season had 90% mortality. In the dry forest, trees treated in the dry season experienced 71.3% mortality after 18 months, whereas those treated in the rainy season had 66.3% mortality. The percentage of trees with callus formation was significantly higher in the humid forest than in the dry forest (22 and 5%, respectively). Differences in the efficacy of treatments for individual tree species were insignificant, with the exception of *Acosmium cardenasii*, which experienced 53% mortality overall after 18 months. Treatment costs ranged from US$ 0.21 to US$ 1.04, with differences due to the high volumes of herbicide required to apply either two girdles, 100% concentrations, or both. The additional cost of more intensive treatments almost certainly outweighs the benefits of increased efficacy in most circumstances, although application of double-band girdles is recommended for resistant species such as *Acosmium*, which had two times higher mortality rates with double-band girdles (72% versus 35%).

Keywords: Silviculture; Girdling; Herbicide; Tropical forest management; Timber stand improvement; Bolivia

1. Introduction

Natural forest management in the tropics is often limited to diameter-limit selection harvesting systems. Harvests tend to concentrate on a relatively small number of species, leading to considerable reductions in populations of commercial species. Post-harvest treatments that remove undesirable non-commercial trees (i.e., liberation and refinement) can improve stand quality, enhance growth and survival of residual commercial trees, and stimulate regeneration (Forget et al., 2001; Smith et al., 1997; Pariona et al., 2003). Studies in secondary forests of Costa Rica (Hutchinson, 1986; Guariguata, 1999), in selectively harvested forests of Costa Rica (Camacho and Finegan, 1997; Finegan et al., 1999; Finegan and Camacho, 1999), Surinam (de Graaf et al., 1999), Indonesia (Kuusipalo et al., 1997), and Bolivia (Pariona and Fredericksen, 2003) have shown that liberation treatments can significantly increase growth rates of released commercial trees. Nonetheless, silvicultural treatments are rarely implemented in tropical forests due to perceptions of high cost, high interest rates, and long returns on investments.

Perhaps the least expensive method to control non-commercial trees is felling. However, felling can have significant impacts on the residual stand by toppling other trees through interconnected lianas or direct contact. In addition, the rapid opening of the canopy exposes released trees to higher temperatures and water stress, often resulting in ‘‘thinning shock’’ which may lead to reduced growth and higher mortality rates (Smith et al., 1997). Girdling treatments give released trees more time to adapt to these environmental

* Corresponding author. Tel.: +1 540 365 2602.
E-mail address: tfredericksen@ferrum.edu (T.S. Fredericksen).

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changes by killing overtopping trees more gradually. Of all methods of girdling, chainsaw girdling is probably the cheapest, fastest, and easiest to implement correctly (Lamprecht, 1990; Pariona et al., 2003). The efficacy of chainsaw girdling can be enhanced when combined with application of herbicide to cut surfaces (Lamprecht, 1990; Wadsworth, 1997; Dawkins and Philip, 1998). However, there is little published literature on the efficacy of different girdling treatments in neotropical forests, with few exceptions (Jonkers and Hendrison, 1986; Pariona et al., 2003).

This study evaluates the efficacy and cost of four girdling treatments in humid and dry tropical forests of eastern Bolivia. Girdling included single or double-banded girdling with different concentrations of the herbicide 2,4-D. Based on another study within the same areas (Pariona et al., 2003), 2,4-D was found to be the most cost-effective and readily-available herbicide to use for this treatment in Bolivia. Due to the high frequencies of callus tissue regrowth across single-band girdles found by Pariona et al. (2003), double-band girdling was included as an additional treatment variable. Treatments were applied to trees in two different forest types (tropical dry forest and tropical humid forest), and at the beginning of each season (dry and rainy) in eastern Bolivia. The evaluation of the efficacy of these treatments will help forest managers decide which treatment is the most cost-effective for liberation and timber stand improvement in humid and dry tropical forests in this region.

2. Methods

2.1. Study sites

This study was carried out at two sites in humid and dry tropical forest types, both within the Department of Santa Cruz, in lowland Bolivia. The humid forest site is located 30 km east of the municipality of Ascensión de Guarayos, within a 100,000 ha forest concession managed by Agroindustria Forestal La Chonta Ltda. Mean annual temperature is 24.5 °C with a mean annual precipitation of 1500 mm. There is a 3-month dry season from June to August. Elevations range between 300 and 400 m. The dry forest is located 45 km east of the municipality of Concepción, within a 30,000 ha forest property owned and managed by INPA Parket. Mean annual temperature is 24.3 °C with a mean annual precipitation of 1100 mm. The dry season is much more pronounced than that of the humid forest, with very little rainfall between April and October, 2001. Elevations range between 400 and 500 m.

Treatments were carried out in areas where timber was harvested 2–3 years prior to this study. Logging was accomplished using chainsaw felling and yarding with rubber-tired skidders. The La Chonta site was located within harvesting compartment 1998-3, where selective harvesting targeted nine species with minimum diameter limits of 50–70 cm, and volumes of 12 m^3 (three to five trees per hectare) were removed. The INPA study site was within compartment 1998-A, where selective harvests removed nine species. Minimum diameter limits were lower at 40 cm, as were volumes (7 m^3/ha), although numbers of trees harvested per hectare were higher (8–10).

2.2. Experimental design and data collection

This study measured the response of non-commercial trees to four different girdling and herbicide treatments (Table 1). One hundred and sixty non-commercial trees (of abundant non-commercial species and having poor form or other defects) were located and tagged within recently harvested in each forest type. Eight groups of 20 trees were selected at each site to obtain relatively homogenous variation in species composition and size. These groups were assigned to two blocks (four groups each). Each of four treatments was randomly assigned to one group in each block. One block was treated at the onset of the dry season, the other at the onset of the rainy season. The experimental unit was considered to be the individual treated tree.

Experimental blocks (4 groups × 20 trees = 80 treated trees in each season × forest block) included:

1. Dry forest, at onset of dry season (July 6–10).
2. Humid forest, at onset of dry season (July 15–20).
3. Dry forest, at onset of rainy season (October 15–20).
4. Humid forest, at onset of rainy season (October 22–26).

All treatments included chainsaw girdling and application of herbicide. Girdling was effected using a Husqvarna 51 model chainsaw. Girdles formed a contiguous ring penetrating the bark and cambium (2–5 cm deep, depending on bark thickness) at approximately 0.5–1.5 m above ground level. An amine formulation of 2,4-D (Herbfluid-720®) herbicide was immediately applied to the cut surfaces of the girdle using a 500 ml plastic squirt bottle. Herbicide was applied to the point of run-off and covered both the upper and lower surface of the girdle.

Each group (20 trees) was randomly assigned one of the following treatments:

Table 1
Experimental design of girdling study

Girdling treatment	Forest types	Treatment seasons	No. of treated trees
Single-tree girdling with 50% aqueous solution of 2,4-D	2	2	40
Double-tree girdling with 50% aqueous solution of 2,4-D	2	2	40
Single-tree girdling with 100% aqueous solution of 2,4-D	2	2	40
Double-tree girdling with 100% aqueous solution of 2,4-D	2	2	40

Ten trees were randomly assigned to one of four girdling treatments, one of two forest types (humid or dry) and one of two seasons (dry or rainy). A total of 160 trees were treated.

1. Single-band girdling with 50% aqueous solution of 2,4-D.
2. Double-band girdling with 50% aqueous solution of 2,4-D.
3. Single-band girdling with 100% solution of 2,4-D.
4. Double-band girdling with 100% solution of 2,4-D.

To determine the relative costs of each treatment, the quantity of gasoline, oil, and herbicide consumed was recorded on a per-tree basis. The time required to complete each treatment was also recorded, and costs were calculated based on local wages for field laborers. Costs for purchase and maintenance of equipment, and for time to travel between trees, were not considered.

Approximately 18 months following treatment applications, treated trees were revisited and the responses to treatments observed using classes of percent crown mortality as indicators of efficacy. Classes included 0–25, 26–50, 51–75, 75–99, and 100% crown mortality. In addition to crown mortality, the presence of resprouts below the girdle and any evidence of callus tissue over girdles was noted on treated trees.

2.3. Data analysis

A Chi-square analysis was used to test for differences in the response of trees to treatments. Differences were considered statistically significant at $P < 0.05$.

3. Results

Relative differences in responses of treated trees, between forest types and treatments, did not change noticeably between the first and second re-measurements (Table 2). After 18 months, double-band girdling caused significantly more crown mortality of treated trees than single-band girdling ($\chi^2 = 6.646$, d.f. = 1, $P < 0.010$, both forests and $\chi^2 = 9.425$, d.f. = 1, $P < 0.002$, dry forest), with 87% versus 76% mortality. It must be noted that these differences were entirely due to the response of one very common dry forest species, *Acosmium cardenasii*, which had two times higher mortality rates (72% versus 35%) with double-band girdling ($\chi^2 = 14.502$, d.f. = 1, $P < 0.0001$). Chi-square analyses run without this species indicated no significant variation between single-band girdling and double-band girdling.

There was no significant difference in the efficacy of 50% versus 100% concentrations of 2,4-D, with dry forest mortality rates of 65.0 and 72.5%, and humid forest mortality rates of 92.5 and 95.0%, respectively.

Season of application had a significant effect on the response of treated trees in the humid forest ($\chi^2 = 3.840$, d.f. = 1, $P = 0.050$). Trees treated at the onset of the dry season experienced 97.5% mortality, whereas those treated at the beginning of the rainy season had 90.0% mortality. There was no significant difference for season of application in the dry forest.

The percentage of trees with callus formation was significantly higher in the humid forest ($\chi^2 = 20.148$, d.f. = 2, $P < 0.001$) than in the dry forest (22 and 5%, respectively). The highest incidence of callus formation was in trees treated at the onset of the rainy season and in the humid forest (Table 3). Differences between treatments were not significant. Resprouting was almost nonexistent: one tree out of 320 treated trees overall resprouted below the girdle (Table 3).

Differences in the efficacy of treatments for individual tree species were insignificant, with the exception of the *A. cardenasii*. Although *Acosmium* had higher mortality with

Table 2
Efficacy of girdling and herbicide treatments by percentage of trees in percent crown mortality classes 18 months after application in a dry and humid tropical forest in Bolivia

Treatment ($n = 20$)	Number of trees and percentage of trees in each of five crown mortality classes				
	0–25%	25–50%	51–75%	76–99%	100% (dead)
Dry forest, dry season					
One girdle, 50% 2,4-D	2 (10%)	4 (20%)	0 (0%)	3 (15%)	11 (55%)
Two girdles, 50% 2,4-D	0 (0%)	1 (5%)	1 (5%)	3 (15%)	15 (75%)
One girdle, 100% 2,4-D	0 (0%)	2 (10%)	1 (5%)	4 (20%)	13 (65%)
Two girdles, 100% 2,4-D	0 (0%)	0 (0%)	1 (5%)	1 (5%)	18 (95%)
Dry forest, rainy season					
One girdle, 50% 2,4-D	1 (5%)	4 (20%)	3 (15%)	2 (10%)	10 (50%)
Two girdles, 50% 2,4-D	0 (0%)	0 (0%)	0 (0%)	4 (20%)	16 (80%)
One girdle, 100% 2,4-D	0 (0%)	2 (10%)	2 (10%)	4 (20%)	12 (60%)
Two girdles, 100% 2,4-D	0 (0%)	1 (5%)	2 (10%)	2 (10%)	15 (75%)
Humid forest, dry season					
One girdle, 50% 2,4-D	0 (0%)	0 (0%)	0 (0%)	0 (0%)	20 (100%)
Two girdles, 50% 2,4-D	0 (0%)	1 (5%)	0 (0%)	0 (0%)	19 (95%)
One girdle, 100% 2,4-D	0 (0%)	0 (0%)	0 (0%)	0 (0%)	20 (100%)
Two girdles, 100% 2,4-D	0 (0%)	1 (5%)	0 (0%)	0 (0%)	19 (95%)
Humid forest, rainy season					
One girdle, 50% 2,4-D	2 (10%)	0 (0%)	0 (0%)	1 (5%)	17 (85%)
Two girdles, 50% 2,4-D	0 (0%)	1 (5%)	0 (0%)	1 (5%)	18 (90%)
One girdle, 100% 2,4-D	1 (5%)	0 (0%)	0 (0%)	1 (5%)	18 (90%)
Two girdles, 100% 2,4-D	0 (0%)	1 (5%)	0 (0%)	0 (0%)	19 (95%)

Table 3
Percent of trees showing callus formation over girdles and resprouting below girdles 18 months following girdling and herbicide treatments in a dry and humid tropical forest in Bolivia

Treatment ($n = 20$)	Percentage of trees with callus formation	Percentage of trees with resprouts
Dry forest, dry season		
One girdle, 50% 2,4-D	15	0
Two girdles, 50% 2,4-D	15	0
One girdle, 100% 2,4-D	5	0
Two girdles, 100% 2,4-D	10	0
Dry forest, rainy season		
One girdle, 50% 2,4-D	0	0
Two girdles, 50% 2,4-D	0	5
One girdle, 100% 2,4-D	0	0
Two girdles, 100% 2,4-D	0	0
Humid forest, dry season		
One girdle, 50% 2,4-D	10	0
Two girdles, 50% 2,4-D	5	0
One girdle, 100% 2,4-D	15	0
Two girdles, 100% 2,4-D	20	0
Humid forest, rainy season		
One girdle, 50% 2,4-D	35	0
Two girdles, 50% 2,4-D	40	0
One girdle, 100% 2,4-D	40	0
Two girdles, 100% 2,4-D	20	0

Table 4
Percentage of common tree species with >75 and 100% crown mortality 18 months following girdling and herbicide treatments in a dry and humid tropical forest in Bolivia

Species (common and scientific names)	N	>75% crown mortality	100% crown mortality
Dry forest			
Cari cari *Acacia polyphylla*	18	100	100
Carne toro *Combretum leprosum*	5	100	100
Mapajo *Ceiba samauma*	3	100	100
Moradillo *Machaerium acutifolium*	3	100	67
Pequi blanco *Eriotheca roseorum*	10	100	100
Pequi *Pseudobombax marginatum*	2	100	100
Tasaa *Acosmium cardenasii*	105	74	53
Toborochi *Chorisia speciosa*	14	100	100
			100
Humid forest			
Ajo *Gallesia integrifolia*	9	100	100
Amarillo *Aspidosperma vargasii*	1	0	0
Blanquillo *Ampelocera ruizii*	56	100	100
Cacha *Cyclolobium blanchetianum*	1	0	0
Cafecillo *Margaritaria nobilis*	5	80	80
Cafecillo blanco Rubiaceae	1	100	0
Cari Cari Colorado *Acacia polyphylla*	4	100	100
Coco *Guazuma ulmifolia*	4	100	100
Coloradillo *Physocalymma scaberrimum*	4	75	100
Isotoubo *Sapindus saponaria*	2	100	100
Leche Leche *Sapium marmieri*	2	100	100
Mani *Sweetia fruticosa*	1	100	100
Momoqui *Caesalpinia pluviosa*	3	100	100
Murure *Batocarpus amazonicum*	1	100	100
Ojoso *Pseudolmedia laevis*	38	97	97
Pacay *Inga* spp.	1	0	0
Pacay Rosario *Inga* spp.	1	0	0
Sirari *Ormosia nobilis*	2	100	100
Tipa *Machaerium acutifolium*	2	100	100
Verdolago *Terminalia oblonga*	20	100	95
Yerboso *Dendropanax arboreus*	2	100	100

N: total number of treated trees.

double-band girdling, there was no significant difference in its response to other treatment variables. Of 29 other species represented in the study, only six had mortality rates lower than 80% after 18 months. Five of these (*Aspidosperma vargasii*, *Cyclolobium blanchetianum*, two different species of *Inga* (‘‘pacay’’ and ‘‘pacay rosario’’), and one species of rubiaceae (‘‘cafecillo blanco’’), were only represented by a single individual, each of which survived. *Ampelocera ruizii* and *Pseudolmedia laevis*, the two most common species treated in the humid forest, had extremely high mortality rates after 18 months (100 and 97%, respectively) (Table 4).

Treatment costs ranged from US$ 0.21 to US$ 1.04. Forest type and season of application had little impact on the relative expense of treatments. The difference was primarily due to the quantity of 2,4-D used: two-band girdling and 100% concentrations each doubled the volume of herbicide applied, resulting in almost four times greater costs (Table 5).

4. Discussion

Efficacy of treatments was very high overall. In the humid forest, 150 of 160 trees (94%) died within 18 months. Mortality rates were lower in the dry forest (110 of 160 trees, or 69%). However, the mortality rate for all other dry forest species, excluding *A. cardenasii*, was 98% after 18 months. Although treatments applied at the onset of the dry season were more effective than those applied in the rainy season in the humid forest, the difference was not great (97.5% versus 90% mortality). This may be explained by the translocation of carbohydrates and other materials towards the roots of many trees during this season (Smith et al., 1997). This finding contradicts the general belief, cited by Lamprecht (1990), that the best time to apply poison-girdling treatments in deciduous humid tropical forests is just before the onset of the rainy season, 2–3 weeks prior to flushing.

Efficacy of treatments in this study was comparable to that of other studies in the neotropics. Jonkers and Hendrison (1986) estimated that poison-girdling (with an unidentified herbicide) led to mortality of 70% of treated trees within 1 year, and nearly 100% within 3 years. Pariona et al. (2003) reported similar results to those found in this study. For example, treatment 1 (one girdle with 50% concentration of 2,4-D), which was applied in both studies, caused high crown mortality in both studies (75–83% in Pariona et al., 2003, 65–95% in this study, for dry and humid forests, respectively). Although this was the least effective of the four treatments applied in this study, crown mortality rates for the other treatments were only 10–15% higher. For treatment 1, there was little difference in rates of callus growth and resprouting between the two studies. The sole

Table 5
Size of trees, time of treatment, volume of herbicide used, and cost per tree of girdling treatments in a dry and humid forest in Bolivia

Treatment	Mean DBH (cm) and range	Mean time (s)	Volume 2,4-D per tree (ml)	Treatment cost per tree (US$)
Dry forest, dry season				
One girdle, 50% 2,4-D	46.9 (30–85)	180	40	0.27
Two girdles, 50% 2,4-D	44.8 (30–87)	317	80	0.53
One girdle, 100% 2,4-D	45.1 (30–74)	173	80	0.49
Two girdles, 100% 2,4-D	45.7 (31–87)	328	160	0.97
Dry forest, rainy season				
One girdle, 50% 2,4-D	46.9 (31–89)	129	28	0.21
Two girdles, 50% 2,4-D	45.7 (32–74)	212	57	0.40
One girdle, 100% 2,4-D	44.5 (32–60)	148	57	0.38
Two girdles, 100% 2,4-D	44.9 (31–77)	208	114	0.73
Humid forest, dry season				
One girdle, 50% 2,4-D	54.7 (30–118)	193	42	0.30
Two girdles, 50% 2,4-D	51.5 (30–83)	226	84	0.54
One girdle, 100% 2,4-D	55.3 (32–168)	215	84	0.54
Two girdles, 100% 2,4-D	51.9 (30–86)	268	168	1.02
Humid forest, rainy season				
One girdle, 50% 2,4-D	50.3 (33–82)	145	44	0.29
Two girdles, 50% 2,4-D	55.3 (34–131)	263	87	0.57
One girdle, 100% 2,4-D	49.1 (30–79)	139	87	0.53
Two girdles, 100% 2,4-D	53.5 (31–87)	224	175	1.04

exception was callus formation in the dry forest, which was much lower in this study (7.5% versus 32%).

Callus formation was not necessarily equated with survivorship in this study. Although rates of callus growth were 400% higher in the humid forest, crown mortality rates were also higher. At the same time, callus growth was lower in the dry forest, but many individuals (particularly *Acosmium*) maintained healthy crowns after 18 months with no visible connection to their roots.

Costs of treatments were as much as 10 times higher in this study than reported in Pariona et al. (2003). As mentioned in the results, the majority of treatment costs were due to the high volumes of herbicide required to apply either two girdles, 100% concentrations, or both. In addition, volumes applied for treatment 1 were 50–100% greater in this study (US$ 0.21–0.30 compared with US$ 0.10–0.23 in Pariona et al., 2003). This may have resulted from more careful application of the herbicide to the cut surfaces of the girdles, one of the recommendations of that study. It may also have been the product of more careful girdling with the chainsaw. Since fewer treated trees had incomplete girdles in this study, it seems likely that in applying the girdles, the operator bore more deeply into the tree. As the person applying the 2,4-D sought to cover the entire cut surface of the girdle, this may partly explain the higher volumes of herbicide applied in this study.

In conclusion, the much higher costs of using two-band girdles and 100% concentrations of herbicide almost certainly outweigh the benefits of increased crown mortality for most species. However, these results demonstrate that for hardy, abundant non-commercial species such as *Acosmium*, application of double-band girdles with 2,4-D significantly improves the efficacy of treatments. Another treatment that should be tested is double-band girdling without herbicide. Although Pariona et al. (2003) found treatments without herbicide to be very ineffective in causing crown mortality of treated trees, double-band girdles were not tested.

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