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CONTROL OF YELLOW HIMALAYAN RASPBERRY (*Rubus ellipticus* Sm.) WITH CUT STUMP HERBICIDE TREATMENTS IN HAWAII VOLCANOES NATIONAL PARK

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ABSTRACT

Yellow Himalayan raspberry (*Rubus ellipticus* Sm.), introduced to Hawai'i Island approximately 30 years ago, has become a serious pest in the 'Ōla'a Tract of Hawaii Volcanoes National Park. This shade-tolerant raspberry forms dense thickets, which replace native understory vegetation.

Four herbicides were effective cut-stump treatments for yellow raspberry: imazapyr (Arsenal, 50% in water), triclopyr triethyl amine salt (Garlon 3A, 50% in water), triclopyr butoxyethyl ester (Garlon 4, 50% in diesel oil), and metsulfuron methyl (Escort, 28 gm/liter water). Ninety-five to one hundred percent of raspberry plants treated with these chemicals died within 24 months. With each of the four treatments, 10-15% of raspberry plants resprouted from the roots, but at least half of the resprouts later died. Two other herbicides tested were much less effective at killing raspberry. Picloram potassium salt (Tordon 22K, 20% in water) killed only 65% of treated plants, and a commercial mix of 2,4-D and triclopyr (Crossbow, 50% in diesel oil) caused the death of 75% of treated raspberry.

Fifteen common native plant species and 10 others of sporadic occurrence were monitored for a year in plots surrounding treated raspberry plants. No statistically significant changes in number were observed for any native species in any herbicide treatment. In general, the number of individuals taller than 0.1 m counted in herbicide plots increased over the year for six common native fern species, one sedge, and one herb. Results were more variable for seven native woody species common in study plots, with increases in numbers in some treatments and small decreases in others. Both picloram and imazapyr plots displayed losses in a larger variety of native woody species than were observed in the other treatments. Saplings of one native tree, olomea (*Perrottetia sandwicensis*) appeared to be particularly sensitive to both picloram and imazapyr applied to nearby raspberry stumps.

INTRODUCTION

Yellow Himalayan raspberry or yellow raspberry (*Rubus ellipticus* Sm.), native to tropical and subtropical India, was first collected in Hawai'i in 1961 (Wagner *et al.* 1990). The plant was probably intentionally introduced as an ornamental or for its insipid yellow fruit. Currently restricted to the island of Hawai'i, yellow raspberry is found in wet habitats between 700 and 1,700 m (2,300-5,575 ft) elevation, but the most serious infestation is in the Volcano area (Smith 1985).

A robust shrub, yellow raspberry can attain heights greater than 5 m (15 ft) and may climb on other plants. Leaves are palmately compound with three broad, roundish (obcordate) leaflets, which are quite hairy on the undersides. Small white flowers are borne at branch tips and are succeeded by aggregate yellow fruit. The most conspicuous characteristics of the yellow raspberry are the strong curved prickles and fine straight ones that densely clothe stems and are also found on leaves and inflorescences.

Yellow raspberry is a problem in rain forests of Hawaii Volcanoes National Park because of its ability to thrive in deep shade and take advantage of natural openings, where it may form dense thickets, replacing all other herbaceous vegetation. Seeds of this species are spread by alien (and possibly native) birds, so plants may be seen in forests far from roads or trails.

This raspberry has spread most of the Park's ʻŌlaʻa Tract since its introduction 30 years ago, and in the last 15 years the plant has greatly intensified in numbers and cover, particularly in areas disturbed by feral pigs (*Sus scrofa*) (Jacobi and Warshauer 1975; S.J. Anderson, unpub. data). In 1988, yellow raspberry was distributed over more than 2,500 ha (6,175 a) of the 3,770-ha (9,312-a) Tract (S.J. Anderson, unpub. data). Yellow raspberry is not limited to ʻŌlaʻa but may also be found occasionally in the forests of Kīlauea's Crater Rim. Current control strategy in the Park is to kill yellow raspberry in two rain forest Special Ecological Areas (SEAs) (Thurston and Small Tract ʻŌlaʻa) from which both feral pig and other alien plants have been removed (Tunison and Stone, in press). At Thurston, yellow raspberry (and three other alien plant species) have been removed from more than 50 ha (118 a); within ʻŌlaʻa Tract alien plant control is ongoing in portions (142 ha or 351 a and 25 ha or 62 a) of two fenced pig control units.

Mechanical control of yellow raspberry is not possible for any but the smallest plants. Past atttempts to mechanically remove raspberry from limited areas of the Park failed (Gardner and Davis 1982), and a previous small-scale test indicated that uprooting was ineffective and impractical (Hawaii Volcanoes National Park 1985). Enormous thickets in which basal stem diameters exceed 5 cm (2 in.) are not uncommon in the dense rain forest of ʻŌlaʻa. Even smaller plants are difficult to uproot without leaving some of the root system, which is often capable of producing new shoots. Park Resources Management personnel control yellow raspberry by cutting the stem at its base and applying Tordon RTU or a solution of Tordon 22K (J.T. Tunison, pers. comm.). Neither chemical has been found to be as effective as desired for a large-scale assault on raspberry in a newly fenced 810-ha (2,000-a) pig exclosure of ʻŌlaʻa Tract. The research reported here was undertaken to find an effective herbicide against yellow Himalayan raspberry. A secondary goal was to evaluate the impact of tested herbicides on native plant species of the rain forest.

National Park Service pesticide guidelines specify that biocontrol or mechanical control methods for a pest be considered before chemical means may be used (Gardner 1990, in press). Hawaii Volcanoes National Park personnel recognize that biological control may be required to permanently reduce weed density and prevent the spread of a number of alien plant species that are already too widespread to tackle by other means. However, biocontrol agents are not available for most alien plants that have invaded the Park.

Biocontrol research has been undertaken for one alien *Rubus* species, prickly blackberry (*R. argutus*). Five insect species (four moths and a sawfly) have been introduced to Hawai'i as potential biocontrol agents for blackberry; three have become established (Markin *et al.*, in press). Despite the apparent range extension and activity of two of these introduced blackberry-attacking insects (Clausen 1978), all five of these potential biocontrol agents are now considered ineffective (Markin *et al.*, in press). Furthermore, one of the introduced blackberry biocontrol agents, a leaf-rolling moth, has been observed feeding on the endemic Hawaiian raspberry, 'ākala (*Rubus hawaiiensis*) (Gagné 1972). Potential harm to native plants is of particular concern with *Rubus*, since an endemic raspberry species (*R. macraei*) is a candidate for endangered species status (Markin and Yoshioka, in press). More promising biological control agents for *Rubus* species are several plant rust fungi. One rust (*Koehneola uredinis*), native to the southeastern U.S., is already present in Hawai'i, where it attacks the leaves of blackberry (*R. argutus*) (Gardner, in press). Another, possibly more virulent, systemic pathogen (*Gymnoconia nitens*) is the focus of current biocontrol research. While effective against *R. argutus*, this rust did not infect three other non-native *Rubus* species, which received inoculation in greenhouse experiments at North Carolina State University (Gardner 1988, in press). Yellow Himalayan raspberry was among those species tested.

Because of the uncertainty of success in finding effective biocontrol agents without negative impact on native *Rubus* species and the length of time required to search for, propagate, and test insects and pathogens (Markin and Yoshioka, in press), the Park cannot at present base a yellow raspberry control program on biocontrol. Mechanical and chemical control methods now available for use must be the immediate focus.

THE STUDY AREA

The area selected for testing herbicides on yellow Himalayan raspberry is in the southwestern corner of the Park's 3,770-ha (9,310-a) 'Ōla'a Tract at 1,160 m (3,800 ft) elevation (Fig. 1). The study site is bounded on one side by Wright Road (Highway 148) in Volcano Village, and on another by a fenced pasture. The site contains an abundance of medium-sized raspberry plants and is representative of Park forests where control of raspberry is planned.

The vegetation of the study site is a multi-layered montane rain forest dominated by native trees and tree ferns. The uppermost canopy is composed of very scattered, tall 'ōhi'a (*Metrosideros polymorpha*). Below this is an open understory of mixed native tree species, in which 'ōlapa (*Cheirodendron trigynum*) and kāwa'u (*Ilex anomala*) are dominant. Other common native tree species are kōlea lau nui (*Myrsine*

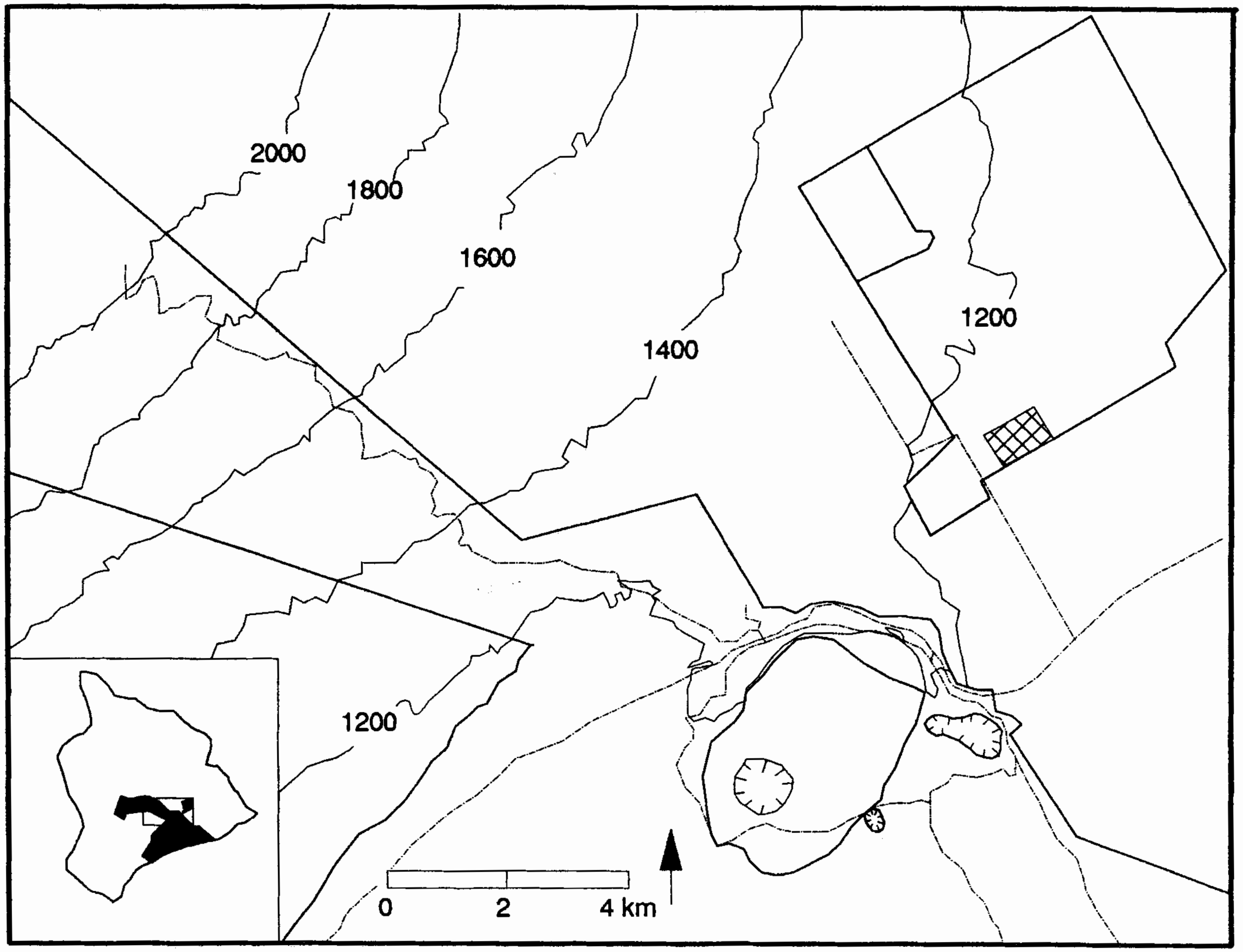

Figure 1. ʻŌlaʻa Tract and a portion of Hawaii Volcanoes National Park, with location of yellow Himalayan raspberry herbicide test indicated by cross-hatching.

lessertiana), olomea (*Perrottetia sandwicensis*), pilo (*Coprosma ochracea, C. rhynchocarpa*), and alani (*Melicope* spp.). The third layer of the forest is composed of tall tree ferns (*Cibotium* spp.); these ferns generally provide deep shade below their overlapping fronds. Where undisturbed, the forest floor is covered with native ferns, particularly hō'i'o (*Diplazium sandwichianum*), hō'i'o-kula (*Pneumatopteris sandwicensis*), and 'ākōlea (*Athyrium microphyllum*). A few native shrubs and herbs are also common, such as pū'ahanui (*Broussaisia arguta*), 'ōhelo (*Vaccinium calycinum*), *Cyrtandra platyphylla*, and 'ala'ala wai nui (*Peperomia* spp.). Where feral pigs have rooted and trampled the forest floor, soil is exposed and the native cover is often replaced by alien herbaceous plants.

The substrate of the 'Ōla'a study site is deep silt loam of the Puaulu Soil Series, formed primarily from layers of volcanic ash (Sato *et al.* 1973). Soils are deep with very few exposed rocks; the 'Ōla'a forest substrate is approximately 4,000 years old (Lockwood *et al.* 1988). The climate of the 'Ōla'a Tract is wet and cool. Rainfall is distributed over most of the year and annually averages more than 2,540 mm (100 in.); mean annual temperature is approximately 15.6 C (60 F) (Hawaii Divison of Water and Land Development 1970).

METHODS

In October 1987, 160 yellow raspberry plants were selected from a population in the southwestern corner of the Park's 'Ōla'a forest. The herbicide treatments tested were: metsulfuron methyl (Escort, 60% dry flowable, 28 gm product/liter of water); triclopyr triethyl amine salt (Garlon 3A, 3 lb a.e./gal, 50% in water); triclopyr butoxyethyl ester (Garlon 4, 4 lb a.e./gal, 50% in diesel); imazapyr (Arsenal, 2 lb a.e./gal, 50% in water); picloram, potassium salt (Tordon 22K, 2 lb a.e./gal, 20% in water); a commercial mix of 2,4-D + triclopyr, butoxyethyl esters (Crossbow: 2,4-D 2 lb/gal + triclopyr 1 lb/gal, 50% in diesel).* Diesel and water were used as controls. Pertinent information on the chemicals used is described in the Appendix.

Plants to be treated were found on parallel transects perpendicular to a fence at the Park's southeastern boundary with pasture of a privately owned ranch. The location of the first transect was chosen at random, with subsequent transects spaced at regular intervals (50 m) from the first. Raspberry plants of at least 1 cm basal diameter and good to excellent vigor were selected. All yellow raspberry plants along the transects that met the minimum size and vigor qualifications were used except when rare native plants were within 1 m of the trunk base. This exception protected those species from chemical or mechanical damage during the test. Sample size was 20 raspberry plants per treatment.

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*Reference to commercial products does not imply endorsement by the National Park Service.

Prior to treatment application, data collected on each yellow raspberry plant included basal diameter (cm), height class (<0.1, 0.1-0.5, >0.5-1, >1-2, >2-3, >3-5 m), vigor (excellent or good), location (terrestrial or epiphytic), phenology, and whether the plant was single or multiple trunked.

Application

One of the eight treatments, chosen at random, was applied to the cut stumps of 20 consecutive plants along the transect. When application of one treatment was finished, a second treatment was chosen and applied to the next 20 plants. Three transects contained two treatments each, and two transects contained one treatment each, for a total of five transects. The purpose of using the same treatment on consecutive trees was to preclude the possibility of cross contamination of plots or target plants. This was a concern, as imazapyr, triclopyr, picloram, and metsulfuron methyl can be absorbed through roots. These herbicides have low to high adsorption to soil clay and organic matter, making them available to plants. In addition, picloram can be released into the soil in an active form from decomposing plant tissue (V. Carrithers, pers. comm.; Santos *et al.* 1986).

The treatment protocol was to sever the raspberry trunk with either pruning shears or a hand saw, as close to the ground as possible. The treatment was then immediately (within 1 minute) applied to the entire surface of the stump using a hand trigger spray bottle. Immediate application of the treatment is necessary as the xylem is under negative pressure. This negative pressure causes the sap to recede when the trunk is cut, drawing the herbicide deeper into the stump (Hay 1956).

Monitoring

Treatments were evaluated at 1, 3, 6, 9, 12, 18, and 24 months post treatment. Data collected for each stump included: resprout number class, expressed as either zero (0), "light" (1-9), "moderate" (10-50), or "heavy" (>50); height of the tallest resprout (in cm); cambium color (green, yellow, or brown), in descending order of estimated vigor; and resprout vigor, estimated as either excellent -- leaves darker green, robust and normal looking, full turgidity in stem and leaves, no chlorosis; good -- leaves green and normal looking, full turgidity in leaves and stem, some chlorosis (<10% leaf area); fair -- leaves light green with some stunting or abnormalities, flaccidity in stem and leaves, chlorosis more pronounced and widespread (10-50% of leaf area), with some necrosis; poor -- leaves and stem stunted, deformed, severely chlorotic and partially to fully flaccid, necrosis more pronounced; and dead -- leaves and stem fully necrotic. Mean monthly resprout growth rate was calculated from the change in height of the tallest resprout on each stump, divided by the number of resprouting trees and the interval duration (months).

Native plants were monitored for nontarget effects of the herbicide treatment in a circular plot 1 m in radius, centered on the treated raspberry. All native plants within this circle were counted in height classes and had their vigor evaluated before the treatment and at intervals of 3, 6, and 12 months following it. Height classes for native plants were

<0.1 m, 0.1-0.5 m, >0.5-1 m, >1-2 m, >2-3 m, >3-5 m, >5-10 m, and >10 m. Vigor of native plants was rated excellent if they looked exceptionally dark green, healthy, and vigorous; good if their appearance was normal for the species without obvious disease or damage; fair if there was some sign of discoloration, wilting, or deformity; poor if such signs were pronounced; and dead if plants were brown, dry, completely defoliated, and discolored.

Data Analysis

Data collected on the number of raspberry resprouts (resprout class mid-point) and resprout heights were analyzed using the Statistical Analysis System (SAS), microcomputer version 6.03 (Statistical Analysis Systems 1985). As the raspberry sample sizes were equal, resprout numbers were compared with an analysis of variance procedure and further analyzed with Duncan's multiple range test and the Waller-Duncan K-ratio t test. The sample sizes of resprout heights were not equal in the different treatments. Because not all raspberry stumps resprouted, differences among the herbicides and controls were analyzed using the General Linear Models procedure and Tukey's studentized range test.

Native plant data on the change in number of individuals in raspberry plots over the year of monitoring were also analyzed with the General Linear Models procedure and Tukey's test. These tests were carried out for 15 native plant species, all with representatives in at least seven of the eight different treatments.

RESULTS

Treatment Efficacy

Numbers of resprouts observed in the six herbicide treatments and two controls differed significantly ($F = 20.31$, $p = 0.0001$). The Waller-Duncan K-Ratio t test indicated four significantly different groups among the treatments ($p = 0.05$), with the water and diesel controls isolated in two separate groups (Table 1). All herbicide treatments were significantly better ($p = 0.05$) at inhibiting resprout initiation than either the water or the diesel control. Imazapyr, metsulfuron, triclopyr amine, and triclopyr ester were significantly more effective at preventing resprouts than the picloram and the 2,4-D + triclopyr treatments. No significant difference was found among the imazapyr, metsulfuron, triclopyr amine, and triclopyr ester treatments, which were grouped together in the Waller-Duncan mean separation test. No significant difference in resprout height was found among the eight treatments ($F = 2.22$, $p = 0.06$). The imazapyr treatment, which had no resprouts, was not included in this test.

Imazapyr/Water. The imazapyr/water treatments resulted in 100% kill (20) of yellow Himalayan raspberry stumps 12 months after treatment, with no additional resprouting for the remainder of the test (Table 2). Imazapyr was most effective at inhibiting bud initiation and development, with the fewest resprouting stumps (two) and the lowest mean resprout height (3 cm). The resprouts, which appeared after one month and were few in number, were dead within three months, with no subsequent resprouting.

Table 1. Mean number of resprouts in *Rubus ellipticus* treatment groups compared with the Waller-Duncan K-ratio t test.

Treatment	Mean # resprouts	Waller-Duncan group*
Water	4.5	A
Diesel	3.5	B
Picloram	1.8	C
2,4-D + Triclopyr	1.3	C
Triclopyr ester	0.3	D
Triclopyr amine	0.3	D
Metsulfuron	0.3	D
Imazapyr	0	D

*Treatments with different letters are significantly different at the 95% confidence level.

Resprout vigor appeared good at first, with green, normal-looking leaves. Cambium color changed sharply at three months post treatment, followed by a gradual decline to 20 stumps with brown cambium by 12 months.

Triclopyr Amine/Water. The triclopyr amine/water treatment produced 95% (19) kill of yellow raspberry stumps within 18 months after treatment. Bud initiation and development were severely retarded, with only three stumps ultimately resprouting, and resprouting was delayed until nine months post treatment. Resprouting intensity was light (1-9 per stump) on the three stumps, with resprouts dying on two stumps by 12 months after reaching heights of 8 and 40 cm. The typical deformations observed were foliar chlorosis, stunting, and involute leaf edges. Resprout growth rate ranged between 1.7 and 10 cm per month. All resprouts in this treatment emanated not from the stump, but from surviving underground roots. Resprouts on the surviving stump were in good vigor and appeared normal, with early, rapid growth followed by very slow growth. Cambium color showed a steady decline from yellow to brown on all stumps by 12 months after treatment.

Triclopyr Ester/Diesel. The triclopyr ester/diesel treatment resulted in 95% (19) kill of yellow raspberry stumps within 24 months. Only two stumps resprouted during the test; resprouts did not appear until six months post treatment and were of light intensity (1-9 per stump). As with the imazapyr and triclopyr amine treatments, resprouts originated from underground roots and not the stumps, which were dead. Resprouts on one stump, although appearing healthy at first, were dead by 24 months, and resprouts on the surviving stump varied from good to fair vigor, with chlorosis and stunting observed at 24 months. With the slow growth rate and abnormalities observed on these resprouts, their survival was doubtful. For both resprouting stumps, the growth rate ranged from a loss of 1.1 cm per month to a gain of 7.3 cm. Cambium color sharply deteriorated by three months, with 16 stumps brown, then gradually declined to 20 stumps brown at 18 months post treatment.

Table 2. Effects of herbicide treatments on cut stumps of yellow Himalayan raspberry (*Rubus ellipticus*) in Hawaii Volcanoes National Park, 1987-1989.

Treatment	Time Since Treatment (mos)	No. Killed (n = 20)	No. Live Resprouts*	Mean Resprout Height in cm	(n)	Resprout Vigor	(n)	Cambium Color	Live Resprout Growth Rate in cm/mo	(n)
Imazapyr/ Water	1	0	0[a]	3	(2)	Good	(2)	Green	3	(2)
	3	13	0	n/a	(0)	Dead	(2)	Brown[b]	(n/a)	(0)
	6	15	0	n/a	(0)	Dead	(2)	Brown[b]	(n/a)	(0)
	9	19	0	n/a	(0)	Dead	(2)	Brown[b]	(n/a)	(0)
	12	20	0	n/a	(0)	Dead	(2)	Brown	(n/a)	(0)
	18	20	0	n/a	(0)	Dead	(2)	Brown	(n/a)	(0)
	24	20	0	n/a	(0)	Dead	(2)	Brown	(n/a)	(0)
Metsulfuron/ Water	1	1	0[a]	1	(1)	Good	(1)	Green	1	(1)
	3	7	0	n/a	(0)	Dead	(1)	Yellow	n/a	(0)
	6	15	0[a]	63	(1)	Fair	(2)	Brown[b]	21	(1)
	9	19	0[a]	83	(1)	Fair	(2)	Brown	6.7	(1)
	12	19	0[a]	95	(1)	Fair	(2)	Brown	4	(1)
	18	19	0[a]	140	(1)	Fair	(2)	Brown	7.5	(1)
	24	19	0[a]	210	(1)	Fair	(2)	Brown	11.7	(1)
Triclopyr amine/Water	1	1	0	n/a	(0)	n/a	(0)	Yellow	n/a	(0)
	3	11	0	n/a	(0)	n/a	(0)	Yellow	n/a	(0)
	6	17	0	n/a	(0)	n/a	(0)	Brown[b]	n/a	(0)
	9	18	0[a]	8	(1)	Poor	(1)	Brown[b]	2.7	(1)
	12	18	0[a]	30	(2)	Fair	(3)	Brown	10	(2)
	18	19	0[a]	20	(1)	Poor	(3)	Brown	0	(1)
	24	19	0[a]	30	(1)	Poor	(3)	Brown	1.7	(1)

Table 2, continued.

Treatment	Time Since Treatment (mos)	No. Killed (n = 20)	No. Live Resprouts*	Mean Resprout Height in cm	(n)	Resprout Vigor	(n)	Cambium Color	Live Resprout Growth Rate in cm/mo	(n)
Triclopyr ester/Diesel	1	0	0	n/a	(0)	n/a	(0)	Yellow	n/a	(0)
	3	16	0	n/a	(0)	n/a	(0)	Brown[b]	n/a	(0)
	6	17	0[a]	22	(2)	Good	(2)	Brown[b]	7.3	(2)
	9	17	0[a]	27.5	(2)	Good	(2)	Brown[b]	1.8	(2)
	12	17	0[a]	32.5	(2)	Good	(2)	Brown[b]	1.7	(2)
	18	18	0[a]	26	(2)	Good	(2)	Brown	-1.1	(2)
	24	19	0[a]	55	(1)	Poor	(2)	Brown	3.2	(1)
2,4-D + triclopyr ester/Diesel	1	5	0[a]	1	(1)	Fair	(1)	Yellow	1	(1)
	3	18	0[a]	20	(1)	Fair	(1)	Brown[b]	10	(1)
	6	16	0[a]	23.3	(3)	Good	(4)	Brown[b]	7.8	(3)
	9	13	0[a]	48.3	(7)	Good	(7)	Brown[b]	12.8	(7)
	12	14	0[a]	66	(5)	Fair	(7)	Brown[b]	5.3	(5)
	18	15	0[a]	96	(5)	Fair	(7)	Brown[b]	5.7	(5)
	24	15	0[a]	142	(5)	Fair	(7)	Brown[b]	7.7	(5)
Picloram/ Water	1	1	0	n/a	(0)	n/a	(0)	Yellow	n/a	(0)
	3	5	0[a]	17.8	(4)	Excellent	(4)	Yellow	8.9	(4)
	6	8	0[a]	36.2	(6)	Good	(7)	Brown[b]	8.2	(6)
	9	10	0[a]	47	(6)	Fair	(7)	Brown[b]	3.6	(6)
	12	12	0[a]	55.3	(7)	Fair	(9)	Brown[b]	6.7	(7)
	18	13	0[a]	163.6	(7)	Fair	(10)	Brown[b]	18.5	(7)
	24	13	0[a]	287.9	(7)	Fair	(10)	Brown[b]	20.7	(7)

Table 2, continued.

Treatment	Time Since Treatment (mos)	No. Killed (n = 20)	No. Live Resprouts*	Mean Resprout Height in cm	(n)	Resprout Vigor	(n)	Cambium Color	Live Resprout Growth Rate in cm/mo	(n)
Diesel	1	1	0[a]	3.5	(6)	Good	(6)	Green	3.5	(6)
	3	7	1-9	23.4	(10)	Good	(11)	Yellow	10.7	(10)
	6	4	1-9	67.6	(16)	Good	(18)	Yellow	17.9	(16)
	9	7	1-9	101.2	(13)	Fair	(18)	Brown[b]	8.2	(13)
	12	6	1-9	117.2	(14)	Good	(18)	Brown[b]	7.7	(14)
	18	7	1-9	129.2	(13)	Fair	(18)	Brown[b]	1.3	(13)
	24	6	1-9	145.4	(14)	Fair	(18)	Yellow	8.5	(14)
Water	1	0	1-9	4.3	(13)	Good	(13)	Green	4.3	(13)
	3	0	1-9	23.6	(18)	Good	(18)	Yellow	10.6	(18)
	6	0	1-9	64	(20)	Good	(20)	Green	14.2	(20)
	9	0	1-9	110.4	(18)	Good	(20)	Yellow	13.4	(18)
	12	1	1-9	129.5	(18)	Good	(20)	Green	6.4	(18)
	18	2	1-9	156.9	(18)	Good	(20)	Green	4.6	(18)
	24	2	1-9	213.6	(18)	Good	(20)	Green	9.4	(18)

*Categories: 0, 1-9, 10-50, >50.
[a]= <0.5, so rounded to 0.
[b]= some viability detected, but insufficient to alter overall rating.

Metsulfuron/Water. Metsulfuron in water gave 95% kill (19) by nine months post treatment. Bud initiation was severely inhibited, with only two stumps resprouting during the test. Resprouts, which first appeared on one stump after one month, were dead by three months after growing to only 1 cm in height. No further resprouting occurred on that stump during the test. Resprouts on the second plant, which appeared at six months, were healthy and normal. These resprouts, which originated from roots, grew rapidly at first, followed by a more moderate rate for the duration of the test. Cambium color showed a steady decline until 20 stumps were brown nine months after treatment.

2,4-D + Triclopyr/Diesel. The 2,4-D + triclopyr in diesel treatment killed 75% (15) of yellow raspberry stumps within 18 months after treatment. A total of seven stumps resprouted during the test, but resprouts died on two stumps after growing to 20-26 cm in height. Three stumps exhibited a pattern of resprouting followed by the death of those resprouts and subsequent new regrowth. On one of these stumps, death of the subsequent resprouts also occurred, casting doubt on the viability of that plant. Resprouts on six of the seven resprouting stumps originated from underground roots near the treated stump. Resprout vigor was generally good, with some stunting and involute leaf edges, predominately in those resprouts that did not survive. Resprouts on the five surviving stumps appeared healthy and were growing at rates comparable with resprouts on the diesel control stumps. Cambium color rapidly declined after the first month, with 19 brown stumps by three months.

Picloram/Water. The picloram/water treatment resulted in 65% kill (13) of yellow raspberry stumps within 18 months after treatment. Ten stumps resprouted during the test, with the first observed at three months and the last at 18 months. Resprouts on three of the stumps died after reaching heights of 1 to 35 cm. Resprout vigor was generally good, except for those that eventually died, which were stunted and chlorotic. Resprouts grew at a steady, moderate rate for the first 12 months and increased rapidly during the next 12 months. Regrowth was from underground roots on 9 of the 10 resprouting plants. Cambium color showed a steady decline to 19 brown stumps by 18 months.

Diesel Control. Diesel killed 30% (6 of 20) of the yellow raspberry stumps by 24 months post treatment. Eighteen stumps resprouted during the test, with resprouts dying on four stumps after growing to heights between 1 and 60 cm. Resprouts on 10 plants originated from underground roots and not the stump. Surviving resprouts were generally of good vigor and had a steady growth rate. Chlorosis, which was observed on resprouts early in the test, was not evident after 12 months. Cambium color on the treated stumps gradually declined until 15 stumps were brown by 18 months.

Water Control. All 20 stumps in the water control resprouted during the test, with resprouts dying on two stumps after growing to 2 and 11 cm in height. Resprouts were of good vigor but light intensity, with rapid initial growth rates followed by moderate growth. Resprouts came primarily from the stumps in this treatment. Cambium color varied from yellow to green on all control stumps during the test.

Effects on Native Plants

Approximately 25 different native plant species were monitored in the plots around treated raspberry stumps, and 15 of these were widespread enough to allow statistical analysis. Three-quarters of these species showed minor losses of individual plants in one or more treatments. For the tree and shrub species, none of the losses were significantly greater than what was generally observed in the herbicide and control plots alike. Although not statistically significant, a pattern did emerge, with picloram treatment plots showing small losses in eight shrub and tree species monitored (Table 3). Most species of ferns increased in number in most treatments over the year of monitoring. For six fern species, slight decreases in numbers were observed in a few plots of all treatments except imazapyr and the water control.

Trees and Shrubs. Olomea was the most abundant tree in ʻŌlaʻa raspberry plots. Most olomea were saplings 0.1 to 1 m in height, but young trees 1-3 m tall were also well represented. No net losses were recorded in over a year of monitoring in any of the treatments except picloram, and this very small decrease was not significant in an analysis of variance among treatments ($F = 1.04$, $p = 0.41$) (Table 4). The disappearance of five olomea in the picloram treatment was not statistically significant when compared with the water control (chi square = 1.88, $p > 0.1$).

Deaths of five other olomea saplings between 0.1 and 1 m in height were noted in the imazapyr treatment, but the overall number of olomea increased due to recruitment from the seedling class. When compared with the water control, the olomea sapling deaths in the imazapyr treatment were not statistically significant (chi square = 1.74, $p > 0.1$). In addition to the olomea that died or disappeared in imazapyr plots, more than 15 saplings, nearly half those followed in plots, showed markedly reduced vigor during the year of monitoring. In the water control, only one olomea showed reduced vigor over the year.

The second-most numerous tree species in plots was ʻōhiʻa. ʻŌhiʻa saplings 0.1-1 m tall were the best represented size class in the raspberry test plots. The loss of only two ʻōhiʻa >0.1 m tall was noted over the course of a year, one individual in both the metsulfuron and picloram treatments. ʻŌhiʻa seedlings increased in numbers over the year in all treatments except picloram and triclopyr ester, which showed a very slight loss.

Two other tree species were found in a few plots of all treatments: pilo in 33% of the plots and ʻōlapa in 23%. Over the year of monitoring, the number of pilo individuals >0.1 m in height showed a very small decrease in four treatments (metsulfuron, triclopyr ester, imazapyr, and picloram). One individual was lost from both the water and diesel controls, but pilo seedling growth resulted in an increase over the year in both sets of plots. These differences among treatments were not significant ($F = 0.93$, $p = 0.50$). Like pilo, the number of ʻōlapa decreased over time in plots of four treatments (triclopyr ester, picloram, diesel control, and the water control). Three small ʻōlapa disappeared from two 2,4-D + triclopyr plots and another was lost from an imazapyr

Table 3. Observed death or disappearance of native woody plants (>0.1 m tall) in yellow Himalayan raspberry (*Rubus ellipticus*) herbicide test plots, ʻŌlaʻa Tract, Hawaii Volcanoes National Park, 1987-1989.

Treatment	Species	Size Class (m)	No. Died	No. Disappeared	Original No. in Treatment >0.1 m
Imazapyr	*Cheirodendron trigynum* (ʻōlapa)	0.5-1		1	3
	Clermontia parviflora (ʻōhā)	0.1-0.5		1	3
	Coprosma spp. (pilo)	1-2		1	6
	Myrsine lessertiana (kōlea lau nui)	0.1-0.5		3	3
	Perrottetia sandwicensis (olomea)	0.1-0.5	1	1	39
	Perrottetia sandwicensis	0.5-1	3		39
Metsulfuron	*Clermontia parviflora* (ʻōhā)	0.1-0.5		1	3
	Clermontia parviflora	1-2		1	3
	Coprosma spp. (pilo)	1-2	1		6
	Metrosideros polymorpha (ʻōhiʻa)	0.1-0.5	1		23
Picloram	*Cheirodendron trigynum* (ʻōlapa)	1-2	1	1	8
	Clermontia parviflora (ʻōhā)	0.5-1	1		3
	Coprosma spp. (pilo)	1-2	1		9
	Cyrtandra spp.	0.1-0.5	1		4
	Ilex anomala (kāwaʻu)	0.5-1		1	3
	Metrosideros polymorpha (ʻōhiʻa)	1-2	1		12
	Perrotettia sandwicensis (olomea)	0.1-0.5		2	35
	Perrottetia sandwicensis	1-2		3	35
	Vaccinium calycinum (ʻōhelo)	0.1-0.5		1	4
Triclopyr amine	*Perrottetia sandwicensis* (olomea)	0.5-1		1	18
	Pipturus albidus (māmaki)	1-2		1	1

Table 3, continued.

Treatment	Species	Size Class (m)	No. Died	No. Disappeared	Original No. in Treatment >0.1 m
Triclopyr ester	*Cheirodendron trigynum* (‘ōlapa)	0.1-0.5		2	12
	Coprosma spp. (pilo)	0.1-0.5		2	9
	Coprosma spp.	2-3	1		9
	Cyrtandra spp.	0.1-0.5		1	4
	Vaccinium calycinum (‘ōhelo)	0.1-0.5	1		6
2,4-D + Triclopyr	*Cheirodendron trigynum* (‘ōlapa)	0.1-0.5		2	9
	Cheirodendron trigynum	0.5-1		1	9
	Clermontia parviflora (‘ōha)	0.1-0.5		2	12
	Cyrtandra spp.	1-2	1		6
Diesel Control	*Cheirodendron trigynum* (‘ōlapa)	0.1-0.5		2	7
	Coprosma spp. (pilo)	2-3	1		8
	Perrottetia sandwicensis (olomea)	0.5-1		1	12
	Perrottetia sandwicensis	1-2		1	12
Water Control	*Broussaisia arguta* (pū‘ahanui)	0.1-0.5	1		1
	Cheirodendron trigynum (‘ōlapa)	0.1-0.5		1	10
	Cheirodendron trigynum	1-2		2	10
	Coprosma spp. (pilo)	0.5-1		1	12

Table 4. Analysis of variance among eight treatments for change in number of individuals of 15 plant species in yellow Himalayan raspberry (*Rubus ellipticus*) test plots at ʻŌlaʻa Tract, Hawaii Volcanoes National Park.

Species	Life form	No. Treatments Containing Species	N	F	p*
Asplenium spp. (spleenwort)	fern	8	68	0.05	0.9998
Athyrium microphyllum (ʻākōlea)	fern	8	62	1.00	0.4387
Cheirodendron trigynum (ʻōlapa)	tree	8	33	0.93	0.4978
Cibotium glaucum (hāpuʻu)	fern	8	106	1.36	0.2331
Clermontia parviflora (ʻōhā)	shrub	8	23	1.55	0.2255
Coprosma spp. (pilo)	tree	8	52	1.06	0.4079
Cyrtandra spp.	shrub	8	29	1.30	0.2968
Diplazium sandwichianum (hōʻiʻo)	fern	8	75	1.22	0.3035
Dryopteris spp.	fern	8	19	0.93	0.5197
Metrosideros polymorpha (ʻōhiʻa)	tree	7	53	1.57	0.1769
Peperomia spp. (ʻalaʻala wai nui)	herb	8	43	0.50	0.8264
Perrottetia sandwicensis (olomea)	tree	8	75	1.04	0.4117
Pneumatopteris sandwicensis (hōʻiʻo kula)	fern	7	40	1.31	0.2803
Uncinia uncinata	sedge	8	22	0.79	0.6048
Vaccinium calycinum (ʻōhelo)	shrub	7	22	0.94	0.4963

*No comparisons are significantly different at the 95% level of confidence.

plot, but overall number of individuals still increased in these treatments. These differences among treatments were not statistically significant (F = 0.93, p = 0.50) (Table 4).

The three most common native shrubs in study site plots were ʻōhā *(Clermontia parviflora), Cyrtandra* spp. (including *C. platyphylla, C. lysiosepala,* and a possible hybrid), and ʻōhelo. *Cyrtandra* and ʻōhelo showed increases over a year's time in plots of most treatments but declined by an individual plant in both triclopyr ester and picloram treatments. In the 2,4-D + triclopyr treatment, one *Cyrtandra* died, but two others appeared during the year. All decreases were in the 0.1-0.5 and 0.5-1 m size classes. One or two ʻōhā, primarily in the 0.1-0.5-m size class, died or disappeared in each of the metsulfuron, 2,4-D + triclopyr, imazapyr, and picloram treatments. Species losses were insignificant when differences among treatments were compared (*Clermontia*: F = 1.55, p = 0.23; *Cyrtandra*: F = 1.30, p = 0.30; *Vaccinium*: F = 0.94, p = 0.50).

Other tree and shrub species were unevenly distributed in the study area. Four that were seen occasionally in about half of the treatments were pūʻahanui, māmaki (*Pipturus albidus*), ʻākala (*Rubus hawaiiensis*), and kāwaʻu. Pūʻahanui showed a loss of one plant in a control plot over the year of monitoring, and one mamaki disappeared from a triclopyr amine plot. Kāwaʻu or Hawaiian holly decreased by only one sapling (0.1-1 m tall) in a plot of the picloram treatment.

Ferns. Five widespread fern species (or species groups) were sampled in each of the eight treatments. The most abundant of these was the tree fern or hāpuʻu-pulu (*Cibotium glaucum*), which occurred in 66% of all raspberry plots. The number of tree ferns >0.1 m tall increased in all treatments except triclopyr amine, triclopyr ester, and 2,4-D + triclopyr, all three of which showed an overall loss of one individual during the year. These losses were not significant when treatments were compared (F = 1.36, p = 0.23) (Table 4).

Two large terrestrial ferns occurred in almost half of all raspberry plots. Hōʻiʻo numbers rose during the year in all treatments except the diesel control, in which the loss of one individual was recorded. Not surprisingly, the small differences among treatments were not significant (F = 1.22, p = 0.30). Similarly, the number of ʻākōlea increased very slightly or stayed the same in all treatments except triclopyr ester. The minute changes in numbers among the treatments were not significant (F = 1.00, p = 0.44). These two species of ferns showed the only obvious herbicidal effects noted on any living, non-target plant. Hōʻiʻo exhibited frond deformities in one imazapyr plot and several picloram plots. ʻĀkōlea had frond tip deformation in picloram plots.

Another common group of ferns, the spleenworts or *Asplenium (A. lobulatum, A. polyodon)* showed an almost identical increase in numbers in all treatments, and differences among the six herbicides and two controls were not significant (F = 0.05, p = 0.99). Somewhat less abundant were members of the genus *Dryopteris (D. wallichiana, D. glabra,* and *D.*

fusco-atra). Over the course of a year, the number of these terrestrial ferns rose or remained constant in all treatments, and the small variability among treatments was not significant (F = 0.93, p = 0.52) (Table 4). One other fern species was found in only seven treatments; no hōʻiʻo-kula (*Pneumatopteris sandwicensis*), a large terrestrial fern, occurred in plots of the imazapyr treatment. This fern increased in number or stayed the same in all other treatments except metsulfuron and picloram, in which the loss of one individual was noted. These differences among treatments were not significant (F = 1.31, p = 0.28).

Three other species of ferns and a fern ally were found sporadically in plots of five to six treatments. Meu (*Cibotium hawaiiense*), a tree fern less common than hāpuʻu, and pauoa (*Ctenitis rubiginosa*) showed no losses in any treatment. Palapalai (*Microlepia strigosa*) numbers increased over time in four of the treatments and decreased slightly in only the triclopyr amine plots. The number of whisk ferns (*Psilotum complanatum*) increased or stayed constant in all except one plot of both the triclopyr ester and imazapyr treatments, where two of these diminutive fern-like plants disappeared.

Herbs. Native herbaceous plants (other than ferns) were not abundant in the pig-inhabited study area. Two that did frequently occur were ʻalaʻala wai nui (*Peperomia* spp., primarily *P. hypoleuca*) and the indigenous sedge *Uncinia uncinata*. Over the year of monitoring, the number of *Peperomia* >0.1 m tall increased in plots of all treatments except diesel and metsulfuron, where these herbs remained constant. Differences among the eight treatments and controls were not significant (F = 0.50, p = 0.83). The number of young *Peperomia* (<0.1 m tall) fluctuated over the year, but a trend of rising numbers was noted in most treatments. *Uncinia* numbers rose in half of the treatments and decreased an insignificant amount in the diesel treatment (F = 0.79, p = 0.60). The only other native herb seen in the raspberry plots was paʻiniu (*Astelia menziesiana*), which occurred quite infrequently in only five treatments and was not observed in the water control plots. The loss of a single paʻiniu was noted in three treatments: triclopyr amine, triclopyr ester, and 2,4-D + triclopyr.

DISCUSSION

Four of the chemicals evaluated in this test were very effective when applied to cut stumps of yellow Himalayan raspberry: imazapyr (Arsenal), metsulfuron (Escort), triclopyr amine (Garlon 3A), and triclopyr ester (Garlon 4). In all four treatments 10-15% of treated raspberry plants resprouted from root stocks rather than stumps. Resprouting occurred within six months in the imazapyr-, metsulfuron-, and triclopyr ester-treated plants but was delayed to 9-12 months in the triclopyr amine treatment. All resprouts in the imazapyr-treated plants and most in the two triclopyr treatments later died. Resprouts on the two surviving plants in the triclopyr treatments were quite stunted when compared with those of the controls, and the few resprouts observed on triclopyr ester-treated plants displayed abnormalities. Even though they survived for two years, these triclopyr-treated plants were in very poor condition at the end of the study and may eventually have succumbed. Resprouts on the one surviving metsulfuron-treated raspberry were tall and healthy compared with those of the triclopyr treatments. While differences in these four treatments were not significant, metsulfuron regrowth appeared likely to survive, and the chemical is more expensive than the three other effective herbicides. In other tests, some difficulty in keeping metsulfuron in suspension has been experienced (N.G. Zimmer, pers. comm. 1990).

In a previous test of herbicides applied to cut stumps of yellow raspberry, triclopyr ester killed only 60% of treated plants (Santos *et al.* 1986), but the concentrations used differed from that tested here. The 50% dilution of Garlon 4 (triclopyr ester) used in the present study appears to be a distinct improvement in raspberry control over undiluted or 20% Garlon 4. Garlon 4 (50%) was effective against raspberry when applied as a foliar spray (Santos *et al.* 1986), but this treatment method is inappropriate in a dense rain forest, where many nontarget native plants would be hit by overspray or would receive some herbicide from the treatment of large, overhanging raspberry plants.

The other two chemicals tested in the current test (picloram and 2,4-D + triclopyr) were far less effective at killing raspberry plants and inhibiting resprouting. The 65% death rated achieved in this study is considerably less than the 80% kill reported by Santos *et al.* 1986, who used a smaller sample of raspberry and followed treated plants for only one year. In both tests, picloram was applied as a 20% solution of Tordon 22K. In the current test, all picloram-treated raspberry plants that resprouted did so within a year. Picloram mixed with 2,4-D (Tordon RTU) killed 60% of raspberry stumps in the 1986 study (Santos *et al.* 1986). In another small-scale test, Tordon RTU was completely ineffective in suppressing raspberrry resprouting (Hawaii Volcanoes National Park 1985).

No great losses of native plants were observed in any of the treatments tested. A few individuals of 18 species disappeared from plots during the year of monitoring. Most of these plants were in the 0.1 to 1 m size class, and their loss may have been partly due to low levels of feral pigs or to trampling during treatment and monitoring. In general, the abundant ferns in the study area increased in number throughout the year. Deformities in frond development were noted for two fern species in the picloram treatment and one fern in an imazapyr plot; all these affected ferns survived. Picloram mixed with 2,4-D (Tordon 101) has been shown to cause twisting and epinasty in treeferns when sprayed directly on understory foliage (Carpenter 1966).

Each treatment showed some loss of native trees and shrubs in small size classes; most of the observed deaths and disappearances of woody plants occurred in the picloram or imazapyr treatments. Picloram, in particular, appeared to affect a larger number of woody plant species than did the other chemicals tested. Within three months after treatment, the deaths of two ʻōlapa and one individual of ʻōhā, Cyrtandra, and ʻōhiʻa were noted in the picloram treatment. Additionally, three olomea in the 1-2 m size class and two smaller saplings disappeared during the year of monitoring.

Olomea was affected negatively by picloram mixed with 2,4-D (as Tordon RTU) applied to raspberry stumps in an earlier small-sample test, but although wilted and chlorotic, small trees near treated raspberry recovered (Hawaii Volcanoes National Park 1985). Picloram, a relatively persistent herbicide (Humburg *et al.* 1989), can leach out of roots or decaying stumps of target plants (V. Carrithers, pers. comm.). This treatment is not as effective as others tested, and its negative impacts would make it a poor choice of herbicide to use in rain forest dominated by native plants.

Woody plants of five species disappeared from imazapyr treatment plots. Imazapyr appeared to mainly affect olomea, with four deaths observed within three months of treatment and a reduction in vigor of nearly half of all individuals in these plots. This endemic tree seems to be particularly sensitive to herbicides. More than three times as many olomea plants occurred in imazapyr plots as in the control plots; some or all of the losses in the imazapyr treatment may have been due to natural causes. Further tests with imazapyr and an increased sample size of native woody plants would be useful to determine if native plant death or decline are actually caused by the herbicide treatment of raspberry.

Based on the density of yellow raspberry (101/ha or 249/a) found in a 25-ha (62-a) experimental management block in ʻŌlaʻa and the average amount of solution required to treat each plant (3 ml or 0.09 oz) (J.T. Tunison, pers. comm 1991), both imazapyr (Arsenal) and triclopyr amine (Garlon 3A) treatments fall well within the rates specified on the herbicide labels. While the amount of triclopyr ester (Garlon 4) used per hectare in this test does not exceed the labeled rate, the Garlon 4 label specifies a 30% solution as the maximum allowable concentration, except in California and the Pacific Northwest. The rate of metsulfuron (Escort) used in this study slightly exceeds the labeled rate and cannot be recommended for use by the National Park Service.

Although imazapyr was marginally more effective than other chemicals in this test, triclopyr amine might be a better choice for immediate use in native-dominated rain forests. This chemical is effective on raspberry, does not seem to harm nontarget native plants (when used as a stump treatment), and can also be used in the Park's rain forest against other targeted alien plants, such as banana poka (*Passiflora mollissima*) and strawberry guava (*Psidium cattleianum*) (Santos *et al.* 1991; Cuddihy *et al.*, in press).

APPENDIX*

Imazapyr

Chemical name:
(±)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl-5-oxo-1H-imidazol-2-yl]-3-pyridinecarboxylic acid

Chemical formulation used: ARSENAL (2 lb/gal). American Cyanamid.

Herbicidal use: Imazapyr is effective on a wide range of annual and perennial weeds, deciduous trees, vines, and brambles in non-cropland situations. ARSENAL is formulated for cut-stump, basal bark, and frilling use.

Mode of action: Imazapyr is readily absorbed through the roots and foliage of plants and is translocated in the xylem and phloem to the meristematic regions, where it accumulates. It kills plants through the inhibition of an enzyme common to the biosynthetic pathways of three amino acids (valine, leucine, and isoleucine).

Leaching: Imazapyr is strongly adsorbed and does not leach downward in the soil.

Degradation: Primarily through photodecomposition.

Toxicity: When used according to the label, imazapyr provides no hazard to mammals, fish, or birds. It is excreted rapidly before any accumulation in the tissues or blood can occur.

Information source: American Cyanamid.

Triclopyr

Chemical name: [(3,5,6-trichloro-2-pyridyl)oxy]acetic acid

Chemical formulation used: GARLON 3A (3 lb/gal) as triethylamine salt, and GARLON 4 (4 lb/gal) as butoxyethyl ester. Dow Chemical.

Herbicidal use: Triclopyr is an auxin type selective herbicide for control of many woody plants and broadleaf weeds. Most grasses are tolerant.

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*Reference to commercial products does not imply endorsement by the National Park Service.

Mode of action: Triclopyr is readily absorbed by both foliage and roots, where it translocates both up and down in plants, accumulating in meristematic tissue. The exact mechanism of action is unknown but appears to be similar to that of phenoxy herbicides.

Leaching: Triclopyr is not strongly adsorbed, with leaching potential dependent on soil organic matter content and pH. Some leaching may occur in light soils under high rainfall conditions; however, in most soils rapid breakdown precludes offsite movement.

Degradation: Rapid via microbial action and photodecomposition.

Toxicity: Triclopyr has a low order of toxicity to wildlife. GARLON 4 is toxic to fish. It is rapidly excreted and does not accumulate in blood or tissues.

Triclopyr as GARLON 4 is absorbed through the skin. Triclopyr as GARLON 3A causes irritation to the skin and eye damage.

Information source: Dow Chemical.

Metsulfuron (metsulfuron methyl)

Chemical name: [[[[4-methoxy-6-methyl-1,2,5-triazin-2-yl)amino] carbonyl]amino]sulfonyl]benzoic acid.

Chemical formulation used: ALLY, 60% dry flowable as the methyl ester. ESCORT is the old name for the same formulation. DuPont.

Herbicidal use: Metsulfuron has activity on many broadleaf weeds, some annual grasses, and certain brush species.

Mode of action: Metsulfuron is rapidly absorbed by foliage and roots and translocated throughout the plant. The primary mechanism of action is the inhibition of valine and isoleucine biosynthesis, which inhibits cell division.

Leaching: Potential for leaching is higher in soils low in organic matter and pH 6.0 or higher, with high rainfall.

Degradation: Chemical hydrolysis is the major form of degradation, increasing with high soil temperature, low pH, and the presence of moisture. Following initial deactivation through hydrolysis, complete metabolism occurs through normal soil microbial processes. Breakdown products are nontoxic and nonherbicidal.

Toxicity: Metsulfuron has a low order of toxicity to wildlife and fish.

Information source: DuPont

Picloram

Chemical name: 4-amino-3,5,6-trichloro-2-pyridinecarboxylic acid

Chemical formulation used: TORDON 22K (20% in water). Dow Chemical.

Herbicidal use: Picloram is effective on most annual and perennial broadleaf weeds and woody plants, although most grasses are resistant at labeled rates.

Mode of action: Picloram is rapidly absorbed by both tops and roots and is translocated to the meristematic regions, where it accumulates.

Leaching: Sorption of Picloram by organic matter and certain clays has been demonstrated. Picloram salt formulations are water soluble, and leaching may occur in sandy soils low in organic matter.

Degradation: Primarily through photodecomposition.

Toxicity: Picloram has a low order of toxicity to wildlife and fish.

Information source: Dow Chemical.

2,4-D + Triclopyr

Chemical name: (2,4-dichlorophenoxy)acetic acid
+ 3,5,6-trichloro-2-pyridinyloxyacetic acid

Chemical formulation used: CROSSBOW [triclopyr (1 lb/gal)
+ 2,4-D (2 lb/gal)].

Herbicidal use: CROSSBOW is recommended for the control of most species of unwanted woody plants, as well as annual and perennial broadleaf weeds. 2,4-D is a systemic herbicide used for control of broadleaf weeds. Triclopyr previously discussed.

Mode of action: 2,4-D causes abnormal growth response and affects respiration, food reserves, and cell division, although the primary mode of action has not been clearly established. 2,4-D is absorbed by foliage and roots and translocates within the phloem and xylem; it accumulates at the meristematic regions of shoots and roots. (Triclopyr previously discussed.)

Leaching: Degree of sorption is low; dependent upon soil organic matter content and acidity.

Degradation: Degrades in soil in less than 8 weeks, depending on soil and climatic conditions.

Toxicity: Some formulations of 2,4-D are relatively toxic to fish.

Information source: Dow Chemical.

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