HERBICIDAL CONTROL OF SELECTED ALIEN PLANT SPECIES IN HAWAII VOLCANOES NATIONAL PARK

Gregory L. Santos, Dina Kageler, Donald E. Gardner, Linda W. Cuddihy, and Charles P. Stone

ABSTRACT

Herbicide tests were conducted between April 1984 and June 1986 on seven species of alien plants classified as threats to native ecosystems within Hawaii Volcanoes National Park. The study was designed to be an initial series of tests to develop effective alien plant treatment techniques and to obtain baseline information on the effects of herbicides on native flora. Highly effective treatments were found for olive (*Olea europaea* subsp. *africana*) (TORDON RTU on cut stumps) and for both species of silk oak (*Grevillea banksii* and *G. robusta*) (2.5% GARLON 4 in diesel oil applied in continuous frill cuts). No hazards to native plants were detected. Treatments for glorybush (*Tibouchina urvilleana*) (20% GARLON 4 in diesel oil on cut stumps) and yellow Himalayan raspberry (*Rubus ellipticus*) (40% GARLON 4 in a foliar drizzle spray and 20% TORDON 22K in water on cut stumps) appeared effective; however, further testing is necessary to refine treatments, verify results, and further assess potential harm to native plant species. Kāhili ginger (*Hedychium gardnerianum*) was effectively controlled with TORDON 10K pellets; however, further testing is warranted for several reasons. A 2% foliar spray of ROUNDUP in water was not completely effective on blackberry (*Rubus argutus*), but it did provide a good measure of control and would be useful in selected situations. Further testing on blackberry is necessary to increase treatment effectiveness and to evaluate other treatments. We recommend continued modest emphasis on herbicide research in Hawai'i's native ecosystems to: increase control effectiveness for invasive alien plant species; evaluate the effects of retreatment regimes; increase knowledge of hazards to native plants and animals; broaden the range of safe chemical tools needed to integrate herbicides with other methods of ecosystem restoration; monitor operational herbicide programs for efficacy and cost effectiveness; increase long-term monitoring of treatment effects in selected areas; and determine and enhance responsible management programs in near-native ecosystems.

INTRODUCTION

Of the approximately 400 alien plant species naturalized in Hawaii Volcanoes National Park, 50 present the greatest threats to native ecosystem processes and have been targeted for control. These 50 species were prioritized by the Park Resources Management Division according to the magnitude of the threat they currently pose, the estimated cost and effort of control, and the potential for successful control methods (Hawaii Volcanoes National Park 1984). The purpose of this paper is to summarize information on herbicidal tests conducted from 1984-1986 on seven species classified as disruptive species.

SPECIES OF CONCERN

Kāhili ginger, *Hedychium gardnerianum*, native to the Himalayas, is considered by horticulturists to be a desirable garden plant in Hawai‘i. It is a cold-tolerant species found in its native habitat at altitudes to 8,200 ft (2,500 m) (Graf 1978). Although somewhat localized within the Park, kāhili ginger is heavily infesting more than 1,235 a (500 ha) and is a serious threat to native rain forests. A very aggressive, shade-tolerant plant, it can invade and establish in intact native rain forest habitat, where it can form dense monotypic stands 6.5 to 10 ft (2-3 m) in height and displace native understory vegetation.

Olive (*Olea europaea* subsp. *africana*), a relatively recent pest in Hawaii Volcanoes National Park, is found on over 14,825 a (6,000 ha) on the former ‘Āinahou Ranch. Its current elevational range in the Park is between 1,640 and 3,280 ft (500-1,000 m) (J.T. Tunison, pers. comm.), and the infestation has expanded rapidly since the removal of cattle (*Bos taurus*) in the early 1970s. Trees 16 ft (5 m) tall have been observed, and it is believed that olive will shade out native species. This olive produces copious fruit, and seedlings beneath a parent tree may exceed 110 individuals/ft^2 (1,200/m^2) (G.L. Santos, unpub. data).

Two species of silk oak (*Grevillea robusta* and *G. banksii*) are currently invading the Park's southwestern boundary. *Grevillea robusta*, a robust, partly deciduous tree native to Australia, was introduced to the State of Hawai‘i for reforestation purposes in 1938 (Skolmen 1979). It is found in a wide variety of habitats and from sea level to over 4,265 ft (1,300 m) elevation. *Grevillea banksii*, also native to Australia, is a small tree to 20 ft (6 m) tall and was officially designated a noxious weed by the Hawaii Department of Agriculture in 1978 (Regulation NW 10, updated by Title 4, Chapter 68 Administrative Rules, 1981).

Both species of *Grevillea* are aggressive, drought-tolerant, have the ability to establish in little or no soil, and may form dense, monotypic stands. If unmanaged, these trees may eventually displace dry forest and shrubland in Hawaii Volcanoes National Park.

Florida blackberry (*Rubus argutus*) was introduced to Hawai'i in 1894 (Haselwood and Motter 1984). By 1962, it had infested 43,405 a (17,565 ha) on O'ahu, Kaua'i, Maui, and Hawai'i at altitudes of 1,970 ft (600 m) or higher. It is well adapted to full sun and grows in submontane forests and woodlands, as well as in montane forests and shrub communities. Florida blackberry is found throughout the Park between 2,270 and 6,560 ft (700-2,000 m) elevation (Smith 1985). Areas that are heavily infested are impenetrable due to the tangling growth habit and the sharp thorns on the branches and leaves. The State of Hawai'i officially classified *R. argutus* a noxious weed.

Yellow Himalayan raspberry (*Rubus ellipticus*) is currently widespread throughout the wet forests near Kīlauea Crater and Volcano Village, especially in areas disturbed by either humans or feral pigs (*Sus scrofa*). Yellow Himalayan raspberry is spread by underground sprouting of roots and by seeds that are probably dispersed by alien and native frugivorous birds (Smith 1985; C.P. Stone, unpub. data). The current elevational range of *R. ellipticus* in Hawai'i is between 2,270 and 5,580 ft (700-1,700 m) (Smith 1985). This species is well adapted to the full sun of open canopy forests or pastures and the deep shade of rain forests. Yellow Himalayan raspberry is a major threat to the 'Ōla'a Forest Tract of the Park (Jacobi and Warshauer 1975).

Glorybush or lasiandra (*Tibouchina urvilleana*), a native of Brazil, is a member of the melastome family. It was introduced to Hawai'i as an ornamental, probably for its large, brillant purple flowers, which are borne either singly or in clusters on branch tips (Neal 1965). Glorybush is currently found in wet habitats on O'ahu, Kaua'i, and Hawai'i between 655 and 5,580 ft (200-1,700 m) elevation. This robust shrub is found in disjunct populations in the Park at approximately 3,940 ft (1,200 m) elevation. However, just outside the Park's eastern boundary, glorybush has invaded native rain forests and formed large, dense monotypic stands to 16 ft (5 m) in height by vigorous vegetative reproduction.

HERBICIDES TESTED

Herbicides used in this series of tests and approved for limited use and testing within Park boundaries included:

AMITROL T: (amitrole + ammonium thiocyanate at 2 lbs active ingredient (ai)/gal). Amitrole is a non-selective systemic herbicide used to control both grasses and broad-leafed species.

GARLON 4: (the ester formulation of triclopyr at 4 lbs acid equivalent (ae)/gal). Triclopyr is a selective, systemic herbicide used for control of woody species.

ROUNDUP: (glyphosate as the amine salt formulation at 3 lbs ae/gal). Roundup is a non-selective systemic herbicide.

TORDON 10K Pellets: (picloram as the potassium salt at 10% ae/lb). Picloram is a persistent, non-selective systemic herbicide used primarily to control broadleafed and woody species.

TORDON 22K: (picloram as the potassium salt at 2 lbs ae/gal).

TORDON RTU: (picloram + 2,4-D as amine salts at 3% and 11.2% ae/gal).

Considerations in the selection of treatment techniques used in tests were practicality of field application, life form of target species, applicator safety, cost and energy efficiency, expected residual activity of herbicide, and presumed toxicity to nontarget native plant species. Techniques will be described for tests of particular chemicals on each target species.

KĀHILI GINGER

Materials and Methods

Sixty clumps of kāhili ginger with rhizome masses ranging in diameter from 2.7 to 10.8 ft^2 (0.25-1 m^2) were chosen from populations in a mixed understory wet ʻōhiʻa *(Metrosideros polymorpha)* forest community. Elevation at test sites was 3,940 ft (1,200 m), with mean annual rainfall and temperature of 130 in. (3,300 mm) and 63 F (17 C).

Treatments tested included undiluted GARLON 4, TORDON 22K, AMITROL T, ROUNDUP, and TORDON RTU injected into the rhizomes via the Maujet Micro-Injection system. Maujet injectors are an effective way of introducing insecticide into the vascular systems of pine trees (Johnson *et al.* 1984). Topical rhizome sprays of GARLON 4, AMITROL T, TORDON 22K, and ROUNDUP in a water carrier at 5% concentration volume/volume (v/v), and TORDON 10K pellets at 1.8 lb (4 kg) ae/ha were also tested. A non-herbicidal treatment consisting of removing all top growth followed by removal of all regrowth at six-week intervals was also evaluated. The purpose of the regrowth removal treatment was to deplete the rhizome colony of its energy reserve by removing the emerging shoots before their photosynthetic capacity exceeded energy needed for growth (P. Motooka, pers. comm.).

All treatments were directed at rhizome clumps, as tests by Gardner (1984) indicated that foliar and basal sprays were either ineffective or effective only at rates injurious to surrounding native vegetation. All top growth was removed from each clump with a cane knife immediately prior to chemical treatment. For the Maujet treatments, four injector capsules, each filled with 0.17 oz (5 ml) of the appropriate herbicide, were inserted into each clump at evenly spaced intervals around the outer edge. Injector tubes were inserted into rhizomes by hand, using a pair of vice-grip pliers to hold the tube at the proper depth while the capsule was inserted onto the tube using a rubber mallet.

In the topical spray treatments, the herbicides were sprayed to wet from 16-oz (500-ml) plastic, trigger spray bottles onto the portion of the rhizomes visible above ground (after removal of the vegetation).

TORDON 10K pellets were used at only one site. Two techniques were tested, one in which the pellets were evenly distributed over the surface of the clump, and one in which pellets were dropped into a 1.2-in. (3-cm) diameter hole that had been augered into the center of the clump to soil depth.

All treatments were applied under partially cloudy but dry conditions on September 26, 1984. Monitoring of the 60 ginger plots was conducted for one year at monthly intervals, when rhizome vigor as well as presence or absence of resprouts was noted. Nontarget native species that occurred within a 3.3-ft (1-m) radius of each treated rhizome colony were observed for possible reactions to the treatments.

Results and Discussion

Among ginger plots treated with undiluted herbicides injected into the rhizomes, only the AMITROL T and TORDON 22K treatments showed significant control of ginger (Table 1). With the TORDON 22K treatments, no resprouts were observed on any of the five clumps during the study period. At one year, rhizomes were decayed and control was 100%. With the AMITROL T treatments, clumps resprouted with severely chlorotic shoots. The shoots gradually declined in vigor, and at one year both shoots and rhizomes were in advanced decay. All visible portions of the rhizomes appeared dead at one year, and control effectiveness was rated at 100%. Treatments with the other injected herbicides showed significantly less control of ginger. While GARLON 4, ROUNDUP, and TORDON RTU suppressed regrowth for up to eight months, clumps were producing apparently healthy regrowth at one year. Results of the far less-effective spray and non-chemical treatments are discussed in Santos *et al.* (1986).

The two methods of applying TORDON pellets (surface and auger) differed in effectiveness, with greater control achieved from pellets broadcast evenly over exposed rhizome surfaces. Decay of the rhizome began within two months and control was 100% at one year. When TORDON pellets were dropped into augered holes in rhizomes, only partial death of clumps was recorded in six months, and resprouting was noted after seven months.

Effects on Nontarget Native Species

Effects on nontarget species varied widely (Table 2), apparently as a result of herbicide used, amount of active ingredient applied per plot, and treatment technique. Proximity of the native plant to actual treatment location and different sensitivities to chemicals may also have affected results.

The injected TORDON 22K treatment was most damaging to native vegetation within a 3.3ft (1-m) radius of treated clumps. All pilo *(Coprosma ochracea)*, wāwae'iole *(Lycopodium cernuum)*, and 'ōhi'a were killed or showed signs of necrosis, stunting, or aberrant growth. The only casualty in the injected AMITROL T treatment was one pa'iniu *(Astelia*

Table 1. Response of kāhili ginger (*Hedychium gardnerianum*) to herbicide treatment and removal of regrowth at 6-week intervals thereafter in Hawaii Volcanoes National Park, 1984-1985. (Numbers in table represent plant response category means of individuals treated in each test.)

Treatment*	OCT** (1 mo)	JAN (4 mo)	MAY (8 mo)	SEP (12 mo)
CONTROL	0	0	0	0
GARLON 4				
100% Maujet	2.8	1.8	2.0	0.8
5% Rhizome	2.8	1.4	0.4	0
TORDON 22K				
100% Maujet	2.8	3.0	4.0	4.0
5% Rhizome	3.0	2.6	3.6	2.4
ROUNDUP				
100% Maujet	3.0	0	0	0
5% Rhizome	3.0	1.0	0.2	0
AMITROL T				
100% Maujet	3.0	2.8	3.8	4.0
5% Rhizome	3.0	2.2	2.6	2.8
TORDON RTU 100% Maujet	3.0	2.2	2.2	0.6
TORDON 10K PELLETS				
4 kg ae/ha Augered	2.2	3.0	2.6	2.0
4 kg ae/ha Surface	2.4	3.0	3.8	4.0
TOP GROWTH REMOVAL	0	0	0	0

*n = 5 clumps/treatment.

**Data for intervening months are available from authors; (months) are post treatment.

Plant response categories:

0 = no effect, healthy resprouting, growth normal.
1 = < 25% rhizome death, resprouts with light abnormalities (chlorosis).
2 = 50% rhizome death, moderate resprouting, abnormalities more severe (deformities).
3 = 75% rhizome death, light resprouting, low vigor, leaf distortions, stunting.
4 = 100% rhizome death, no resprouting.

Table 2. Effects of chemical treatments of kāhili ginger (*Hedychium gardnerianum*) on native vegetation within 1 m of treated clumps (see key).

		Treatment										
		Garlon 4		Roundup		Amitrol T		Tordon 22K		Tordon 10K		Tordon RTU
Species	Control	100%	5%	100%	5%	100%	5%	100%	5%	B'cast	Augured	Maujet
Astelia menziesiana												
(pa'iniu)		0/1			0/2	-/2						0/2
Cheirodendron trigynum												
('ōlapa)									0/1	+/1	0/1	
Cibotium glaucum												
(hāpu'u pulu)				0/1			0/1	0/1	0/1	0/1	0/1	
Clermontia parviflora												
('ōhā)										-/1		
Coprosma ochracea												
(pilo)	0/2	0/5	0/1	+/4	0/2	+/2*	0/1	-/1	0/1	0/7*	0/4*	+/1
Hedyotis centranthoides			0/1									
Ilex anomala												
(kāwa'u)									0/1	+/2*	0/4	
Isachne distichophylla												
('ohe)						0/1				0/1	0/1	
Lycopodium cernuum												
(wāwae'iole)		-/1						-/1				0/1
Machaerina angustifolia												
('uki)									+/1	0/1		
Metrosideros polymorpha												
('ōhi'a)	0/2*	0/5	+/2	0/4	0/2	0/1		-/5	0/4	+/4	+/6	+/4
Myrsine lessertiana												
(kōlea)				0/1			+/2			0/1	-/1	

Table 2, continued.

Table 2, continued.

		Treatment										
		Garlon 4		Roundup		Amitrol T		Tordon 22K		Tordon 10K		Tordon RTU
Species	Control	100%	5%	100%	5%	100%	5%	100%	5%	B'cast	Augured	Maujet
Sadleria pallida												
('ama'uma'u)	+/1				0/1		0/1	0/1		+/1	-/4	+2
Vaccinium spp.												
('ōhelo)	0/2	0/2				0/1					0/1*	

Key:

vigor rating/no. individuals (* = seedlings):
+ = increase in vigor from pretreatment condition.
0 = no change from pretreatment condition.
- = decrease in vigor from pretreatment condition.

menziesiana) individual growing on top of a treated clump. This plant exhibited the typical AMITROL T-induced symptoms of severe chlorosis prior to death.

TORDON 10K pellets caused vigor decline and death within four months in one *Clermontia parviflora* shrub growing 24 in. (60 cm) downslope from a broadcast-treated ginger clump. Similarly, an individual kōlea *(Myrsine lessertiana)* sapling (28 in. (70 cm) tall), located 24 in. (60 cm) from an augered-pellet plot, declined from excellent to poor vigor at 12 months. One kōlea seedling 35 in. (90 cm) from a broadcast-pellet plot remained in good vigor during the study period. Except for the decline in vigor of one wāwae'iole in the 100% GARLON 4 treatment, no adverse effects were observed on nontarget native species associated with any of the remaining treatments for ginger.

Management and Research Recommendations

While injected TORDON 22K treatment effectively controlled kāhili ginger, it cannot be recommended because of the heavy impact it had on native plants. The injected AMITROL T treatment was also very effective, with only minor effects on nontarget plant species; however, the high cost of this treatment (equipment and labor) may preclude its use on a widescale basis. Broadcasted TORDON 10K pellets were an effective and relatively economical treatment and, in general, had only minor effects on the native flora in this test. However, picloram, the active ingredient in TORDON, is a persistent chemical that was shown (in this test) to be lethal to native species when present in sufficient concentrations. Tests in temperate climates have shown that picloram retains soil residual activity (herbicidal concentrations) for at least one year (4 kg ae/ha rate), with sub-herbicidal residues present for at least 2.5 years (1 and 4 lb kg/ha rate) (Anderson 1983). High rainfall, high organic matter in the soil, and microbial activity in the areas where kāhili ginger is found are likely to decrease the residual activity of picloram (P. Motooka, pers. comm.); however, the degree of reduced activity is unknown. High rainfall may also increase the potential threat to native species, as picloram is water soluble and readily transported to other areas in surface runoff and/or in soil solution. A small-scale test in 'Ōla'a Tract indicated that several common native tree and shrub species are very sensitive to TORDON 10K (Hawaii Volcanoes National Park Resources Management Division, unpub. data). Further research is required to address concerns about persistence and mobility.

We recommend that TORDON 10K pellets not be used where water runoff is a problem and where rare plant species are present, until the degree of threat of this chemical to native species has been better established. Tests with increased plot and sample sizes and lower ginger densities are necessary to determine treatment effectiveness and impacts on native species under these conditions. Monitoring should be long term, for target as well as nontarget species, as picloram may persist in the soil for years, and more slowly-growing woody components of native forest systems ('ōhi'a, pilo, etc.) may not show symptoms for a year or more. The effects of picloram on the native microfauna are at present unknown, and that situation should be addressed; however, the cost may be prohibitive.

AMITROL T also appeared promising as a control for kāhili ginger, although it was not completely effective when applied to rhizomes in a 5% solution. Since additional testing of this herbicide and others that are less threatening to native ecosystems than TORDON was warranted, a subsequent test was conducted using a 20% concentration of AMITROL applied as a topical rhizome spray. This treatment resulted in the death of 90% of a sample of 20 kāhili ginger. Two of three additional herbicides tested were also effective against ginger (Santos *et al.* 1986).

OLIVE

Cut-Stump Treatment

Materials and Methods. Three hundred fifty olive shrubs of different size classes were chosen for cut-stump treatment from a healthy population in a dry, very scattered ʻōhiʻa community at 2,740 ft (835 m) elevation with mean annual rainfall and temperature of 77 in. (1,955 mm) and 66 F (19 C).

The 14 treatments tested in this study included an untreated stump control; diesel oil only; TORDON RTU undiluted; TORDON 22K undiluted and as 20% and 5% dilutions in water; ROUNDUP undiluted and as 20% and 5% dilutions in water; and GARLON 4 undiluted and as 20%, 10%, 5% and 2% concentrations in diesel oil. Each treatment was applied to 25 stumps in May 1984, during dry weather punctuated by one brief light rain.

Each shrub was cut with a chain saw as close to the ground as possible (usually less than 6 in. or 15 cm). Treatments were immediately applied to all cut surfaces so that the negative pressure in the xylem could facilitate the deep penetration of herbicides into the stump (Hay 1956).

Stumps were monitored for resprouting, cambium death, and vigor of resprouts. Although herbicides were not directly applied to any native species, nontarget vegetation within a 3.3-ft (1-m) radius was monitored for possible reactions to the treatments.

Results and Discussion. TORDON RTU and undiluted GARLON 4 were the most effective cut-stump control treatments for olive (Table 3). Of the 25 stumps treated with GARLON 4, one had resprouted by the fourth month. This stump produced seven unhealthy shoots, which grew to an average height of 4 in. (10 cm), declined in vigor, and died within a year. A cambium vigor check at one year confirmed that no stumps were alive. Of the stumps treated with TORDON RTU, only one produced a single unhealthy shoot by the fifth month, and this soon died. No viable cambium remained on any of the TORDON RTU-treated stumps at six months. Control effectiveness did not vary among the five size classes of olive for these two treatments or other treatments.

The undiluted TORDON 22K, ROUNDUP, and the 20% GARLON 4 treatments showed good control effectiveness, with only 12% to 20% of the stumps resprouting after one year. In addition, there were few new shoots from those stumps that did resprout. When compared with the stumps in the

Table 3. Response of olive (*Olea europaea* subsp. *africana*) to cut stump control treatments (% plants resprouted) in Hawaii Volcanoes National Park, 1984-1985.

Treatment*	JUN** (1 mo)	SEP (4 mo)	JAN (8 mo)	MAY (12 mo)
CONTROL	36	92	100	100
DIESEL	24	100	100	100
TORDON RTU	0	0	0	0
TORDON 22K				
100%	0	8	16	12
20%	4	40	48	52
5%	0	76	96	96
ROUNDUP				
100%	0	12	8	12
20%	0	28	32	48
5%	0	80	100	96
GARLON 4				
100%	0	4	4	0
20%	0	4	20	20
10%	8	12	28	36
5%	8	20	48	52
2%	8	32	56	60

*n = 25 plants in each treatment.
**Data for intervening months are available from authors; (months) are post treatment.

control group, all of the other nine treatments were relatively ineffective; discussion of these results can be found in Santos *et al.* (1986).

Effects on Nontarget Native Species. Monthly observations of nontarget native vegetation within 3.3 ft (1 m) of treated stumps showed no adverse effects on ʻōhiʻa, ʻaʻaliʻi *(Dodonaea viscosa)*, and māmane *(Sophora chrysophylla)*. This does not imply that the herbicides tested have no effect on these species; few mamane were exposed, for example. The herbicides applied on the olive stumps apparently remained very localized on the target species and did not volatilize into the atmosphere or leach into the surrounding soil in sufficient concentrations to harm native species in the area.

Foliar Application

Materials and Methods. Sixty healthy olive shrubs ranging in height from 34 to 65 in. (85-165 cm) were selected for foliar treatment. The foliar treatments tested were: 5% aqueous solutions of ROUNDUP, GARLON 4, and TORDON 22K. Each treatment was applied to 15 shrubs.

Plants were sprayed to wet, using hand-pump pressurized sprayers with even, flat-fan nozzles. Pressure was regulated at 20 psi. All treatments were applied on June 18, 1984, under sunny skies with winds estimated at 13 mph (8 km/hr). No rain fell for at least six hours after treatment. Individuals were monitored monthly for a period of one year, although plant responses had peaked by eight months.

No native vegetation was directly sprayed except that growing among the test plants. Monitoring included observations of these native plants as well as natives within a 6.6-ft (2-m) radius that could have been exposed to incidental spraying or drift.

Results and Discussion. The most effective herbicide tested as a foliar spray on olive was the 5% concentration of GARLON 4 in water (Table 4). One month after treatment, 87% of the treated individuals exhibited severely desiccated foliage, which remained attached to branches for several months. Cambium vigor evaluations at eight months and one year indicated complete death of all shrubs.

Effects on Nontarget Native Species. Incidental herbicide drift affected some nontarget plants growing within 3.3 ft (1 m) of target olive shrubs. Most ‘a‘ali‘i receiving herbicide drift of 5% GARLON 4 reacted with rapid leaf desiccation or total defoliation but subsequently recovered. Two ‘a‘ali‘i died; these had received a spray dose equal to that for the target species. ‘A‘ali‘i branches heavily hit with GARLON 4 defoliated and declined to apparent death, while untreated branches on the same shrub remained healthy. This suggests minimal translocation. Pūkiawe *(Styphelia tameiaemeiae)* exhibited localized leaf desiccation with subsequent recovery when exposed to all herbicides tested. ‘Ūlei *(Osteomeles anthyllidifolia)* received only very light, incidental drift from all three herbicides and seemed unaffected.

Treatment of Seedlings

Materials and Methods. Fifty-four 0.25 m^2 plots were chosen under mature olive trees in Hawaii Volcanoes National Park. Prior to treatment, olive seedlings within each plot were counted and height range was recorded for each plot. Six plots were selected for each treatment. Nontarget native plant species growing within the plots were identified and monitored for possible reactions to the treatments. Pretreatment vigor was recorded for both target and nontarget species.

Treatments tested included 1% and 5% concentrations of: ROUNDUP, TORDON 22K, GARLON 4, and AMITROL T. Herbicides were applied with 16-oz (500-ml) trigger spray bottles set for a coarse spray. Treatments were applied at a rate of 63 gal/a of spray solution (600 l/ha) on July 20, 1984, under partially cloudy skies with a 13 mph (8 km/hr) breeze. No rain

Table 4. Plant response to foliar spray tests on olive (*Olea europaea* subsp. *africana*) in Hawaii Volcanoes National Park, 1984-1985. (Numbers in table represent response category means for each test.)

Treatment*	JUL** (1 mo)	OCT (4 mo)	FEB (8 mo)	JUN (12 mo)
CONTROL	1.0	1.0	1.0	1.0
ROUNDUP 5%	4.3	4.4	4.9	4.7
GARLON 4, 5%	4.7	5.7	6.0	6.0
TORDON 22K, 5%	2.1	1.7	1.7	1.6

*n = 15 plants/treatment.

**Data for intervening months are available from authors; (months) are post treatment.

Olive plant response categories:
- 1 = unaffected, healthy, normal.
- 2 = < 50% leaves chlorotic.
- 3 = > 50% leaves chlorotic.
- 4 = < 50% leaves desiccated/defoliated, cambium viable.
- 5 = > 50% leaves desiccated/defoliated, cambium viable.
- 6 = 100% foliar desiccation, cambium dead.

fell for at least six hours after spraying. Observations of all vegetation for changes in vigor and any other reactions were conducted at monthly intervals for six months.

Results and Discussion. Responses of olive seedlings to the treatments peaked between the fourth and sixth month (Table 5). Resprouting had occurred by the sixth month.

Five percent GARLON 4 produced 100% control of olive seedlings by the fourth month. Treated seedlings were defoliated and desiccated, with no viable tissue. No resprouting was observed during the test.

A range of 50 to 90% seedling mortality was achieved with the 5% ROUNDUP, 5% AMITROL T, and 1% GARLON 4 treatments. Within this group the 1% GARLON 4 treatment produced the most consistent results, with 75-90% control in all six plots by the fourth month.

Heavy rains that fell in November 1984 apparently initiated the germination of olive seeds in the test area. Concentration of seeds in the soil was assumed to be the same both inside and immediately outside test

Table 5. Results of herbicide spray trials on olive (*Olea europaea* subsp. *africana*) seedlings, Hawaii Volcanoes National Park, 1984-85. (Numbers in table represent response category means for each test.)

Treatment	AUG* (1 mo)	SEP (2 mo)	NOV (4 mo)	JAN (6 mo)
CONTROL (n = 689)	0.5	0.0	0.0	0.2
GARLON 4				
5% (n = 671)	2.2	3.5	4.0	4.0
1% (n = 671)	1.7	2.3	2.5	3.0
TORDON 22K				
5% (n = 691)	1.2	1.2	1.3	1.0
1% (n = 685)	0.7	0.2	0.0	0.3
ROUNDUP				
5% (n = 683)	1.3	1.5	1.2	2.0
1% (n = 691)	0.7	0.7	0.8	0.8
AMITROL T				
5% (n = 671)	1.0	1.2	1.8	2.3
1% (n = 668)	0.8	0.8	0.8	1.0

*Data for intervening months are available from authors; (months) are post treatment.

Olive seedling response categories:
- 0 = normal, healthy.
- 1 = chlorosis, < 25% death.
- 2 = foliar desiccation, 25-50% death.
- 3 = 50-75% death, defoliation.
- 4 = 100% cambium death.

plots. General observations indicated no residual activity with any of the treatments by this time, as seedlings appeared within all plots with the same apparent frequency as outside.

Effects on Nontarget Native Species. All results are based on chance occurrences of native species within plots and do not represent a designed test for effects on natives (Table 6). Species evaluated were directly sprayed during treatments, as they were growing within test plots. The only native plants treated with 5% GARLON 4, one ʻūlei and one ʻaʻaliʻi seedling, died. Another ʻaʻaliʻi seedling treated with 5% TORDON 22K also died. No other adverse effects were observed in this test, although very low numbers of these plants were exposed to treatments.

Table 6. Effects of herbicide treatments for control of olive (*Olea europaea* subsp. *africana*) seedlings on nontarget native species within 0.25 m^2 treated plots.*

		Treatment								
	Life	Roundup		Tordon 22K		Garlon 4		Amitrol T		Total No.
Species	Stage**	5%	1%	5%	1%	5%	1%	5%	1%	Plants Treated
Carex wahuensis	M		N/1***	N/1					N/2	4
Coprosma ochracea (pilo)	S								N/1	1
Dodonaea viscosa ('a'ali'i)	S		N/1	H/1		H/1		N/1		4
Osteomeles anthyllidifolia ('ūlei)	S					H/1		N/1		2
Sophora chrysophylla (māmane)	S									1
Styphelia tameiameiae (pūkiawe)	S			N/1	N/1					2

*Plant response categories:
H = Heavy
M = Moderate
L = Light
N = No effect
Blank = Not exposed to treatment.

**Life stage: S = Seedling; M = Mature, capable of sexual reproduction.

***Number of plants exposed in each test.

Management and Research Recommendations

TORDON RTU or undiluted GARLON 4 are effective treatments when applied to cut olive stumps. TORDON RTU is less expensive on a per use basis and presents a lower hazard to the applicator. The oral LD_{50} (the dose that is lethal to 50% of rats tested) of triclopyr (the active ingredient in GARLON 4) is 630 mg of chemical/kg of body weight, and that of picloram is 8,200 mg/kg (the lower the number the higher the toxicity) (Berg 1985). Both herbicides are easy to apply, and residual activity and nontarget hazards do not appear to be a problem. Therefore, TORDON RTU is the preferred treatment on cut stumps of olive. No further research is necessary to improve control techniques for mature olive shrubs. However, it would be desirable to monitor nontarget plants in greater numbers if large-scale management begins.

Although 5% GARLON 4 in water as a foliar spray was found to be an effective control for olive, the potential hazards of this treatment may preclude its use for widescale control efforts. Spraying shrubs greater than 3.3 ft (1 m) in height presents a high probability of exposure by drift to nontarget species as well as to the applicator. Therefore, this treatment is recommended only in situations where olive shrubs are less than 1 m tall and where native plants are not in close proximity. Further research is needed to find the lowest effective concentration of GARLON 4 to minimize cost and possible hazards to the native vegetation and the applicator. In the process of determining efficacy, more data on nontarget responses of native species can be obtained.

GARLON 4 appears to be the most effective herbicide for olive seedlings, with the lowest effective rate somewhere between the two tested rates (1% and 5%). Further testing should be conducted to find the lowest effective rate. More information on hazards to nontarget native plants could be obtained in the process.

The three control methods developed for olive could be combined as part of an overall olive removal strategy. One suggestion would involve a crew of three people using the cut-stump method to eliminate all olive plants taller than 3.3 ft (1 m), followed by a crew of two concentrating on seedlings and saplings, with either the foliar treatments or manual removal, depending on the proximity of native species. Follow-up treatments on seedlings could be scheduled one to two months after a rainy period, to allow time for seed germination, and would continue periodically until the soil seed bank is exhausted. Studies on seed viability in the soil would be needed to determine the length of time necessary to exhaust the seed bank. Studies of the fate of untreated seedlings could shed some light on the importance of seedling treatment as a part of control strategy.

SILK OAK

The purpose of this test was to determine the sensitivity of two species of silk oak (*Grevillea robusta* and *G. banksii*) to a variety of herbicides when applied via basal, continuous frill cuts.

Materials and Methods

One hundred twenty trees of each species were chosen from healthy populations in a dry, scattered ʻōhiʻa community with native shrubs and alien grasses that had been partially converted to pasture. For each of eight treatments, 15 trees of each species were selected; each treatment included members of four diameter classes to parallel size distribution determined by a belt transect in the study area.

Identical treatments were used on both species: GARLON 4 diluted in diesel oil at 2.5%, 5%, and 10% concentrations; TORDON 22K diluted in water at 5%, 10%, and 20% concentrations; and control treatments of diesel oil only and water only. Overlapping rather than spaced frill cuts were used because tests by Leonard (1957) showed them to be more effective. The frill cuts were made with a hatchet around the entire circumference of each trunk less than 6 in. (15 cm) from the ground and deep enough to sever the cambium. A single, solid stream of the appropriate herbicide was squirted from a plastic squeeze bottle into the trough created by the frill cuts. The application dates were August 20, 1984, for *G. banksii* and August 29, 1984, for *G. robusta*. Weather on both days was overcast but dry. Treatments were monitored at monthly intervals for one year.

Results and Discussion

G. banksii. All of the GARLON 4 treatments (2.5%, 5%, and 10% in diesel oil) and two of the TORDON 22K treatments (5% and 20% in water) resulted in 100% mortality of treated individuals within 11 months (Table 7). Slightly less effective was 10% TORDON 22K in water, which killed 87% (13) of the treated trees by the seventh month, with the remaining two trees exhibiting severe leaf desiccation, moderate cambium vigor, and basal resprouting by the ninth month. A characteristic progression of symptoms was apparent in all TORDON 22K and GARLON 4 treatments. Trees demonstrated leaf chlorosis over 50-75% of the canopy within one month, followed by increased leaf desiccation and simultaneous decline of cambium vigor both above and below the frill cut. The highest concentration of both GARLON 4 and TORDON 22K resulted in an accelerated plant reaction and more rapid death of treated individuals. The interval between treatment and death was 5-6 months for the highest concentrations, compared with 11 months for the lower concentrations. It is notable that lower concentrations of GARLON 4 were sufficient to eventually achieve a success rate comparable to higher concentrations of TORDON 22K (*e.g.*, GARLON 4 at 2.5% was as effective as TORDON 22K at 5%). Younger trees (1-3 in. or 3-8 cm basal diameters) were generally more susceptible to all of the herbicides and declined more rapidly than the larger trees.

G. robusta. The three concentrations of GARLON 4 (2.5%, 5% and 10% in diesel oil) produced 100% control of *G. robusta* within eight months. In all three treatments, foliage rapidly desiccated but did not abscise for several months. Decline of cambium vigor both above and below the frill cut was gradual. TORDON 22K, at 20% in water, was slightly less effective, with 93% control of treated individuals at one year.

Table 7. Mean response ratings for *Grevillea banksii* and *G. robusta* subjected to herbicide treatments. (Numbers in table represent response category means for each test.)*

Species and Treatment	OCT** (1 mo)	JAN (4 mo)	MAY (8 mo)	SEP (12 mo)
Grevillea banksii				
DIESEL OIL ONLY	1.0	0.7	1.9	1.6
GARLON 4				
10%	3.3	4.8	5.0	5.0
5%	2.5	4.5	5.0	5.0
2.5%	2.5	4.2	4.7	5.0
TORDON 22K				
20%	3.8	4.7	5.0	5.0
10%	3.4	4.3	4.7	4.7
5%	3.5	4.3	4.8	5.0
WATER	0.6	0.3	0.1	0.2
Grevillea robusta				
DIESEL OIL ONLY	0	0	0.3	0.5
GARLON 4				
10%	2.9	4.9	5.0	5.0
5%	2.4	4.9	5.0	5.0
2.5%	2.4	4.0	5.0	5.0
TORDON 22K				
20%	2.9	4.5	4.9	4.9
10%	2.5	4.1	4.4	4.4
5%	2.0	2.9	3.5	3.6
WATER	0.5	0	0.1	0

*(n = 15 trees/test).

**Data for intervening months are available from authors; (months) are post treatment.

Plant response categories:

0 = no effect, normal healthy growth.
1 = <25% defoliation, cambium alive.
2 = 50% defoliation, cambium alive.
3 = 75% defoliation, cambium alive.
4 = 100% defoliation, cambium alive.
5 = 100% defoliation, cambium dead.

Effects on Nontarget Native Species

Native species within a 3.3-ft (1-m) radius of treated trees included 'ōhi'a, 'ākia (*Wikstroemia* sp.), and 'a'ali'i. No adverse effects were noted for any of these species.

Management and Research Recommendations

Results indicated that 2.5% GARLON 4 in diesel oil was the lowest concentration of herbicide effective in controlling both species of *Grevillea*. The basal frill application of 2.5% GARLON 4 in diesel oil is therefore recommended. No future research on the control of silk oak is anticipated, and it is recommended that implementation of silk oak control begin as soon as possible.

FLORIDA BLACKBERRY

Materials and Methods

Seventy 32-ft^2 (3-m^2) plots were selected for treatment from a *Rubus argutus* population in a closed canopy, mesic 'ōhi'a/koa/mānele *(Metrosideros/Acacia/Sapindus)* forest, with mixed native shrubs and alien grasses in the understory. The study site was located at 4,200 ft (1,280 m) elevation, and mean annual rainfall and temperature were 75 in. (1,890 mm) and 59 F (15 C). Untreated buffer zones at least 10 ft (3 m) wide were included around all plots to prevent any overlap of treatments.

Two foliar spray techniques were tested: conventional sprays and drizzle sprays. The drizzle or "magic wand" method developed by Uyeda and described by Motooka *et al.* (1983) is a high-concentration, low-volume, non-atomizing technique using pressure-regulated sprayers fitted with an orifice disk instead of a conventional nozzle tip. The orifice disk produces a single, thin stream of liquid rather than a spray. The conventional sprays included 0.5% and 2% concentrations v/v of GARLON 4, TORDON 22K, ROUNDUP, and AMITROL T. These were applied with water as the carrier at a volume of 20 gal/a (190 l/ha). Pressure was regulated at 30 psi with a spray volume of 1 gal/a (9.5 l/ha) for the drizzle sprays. A No. 20 orifice disk was used, with water as the carrier. A spreader-sticker, TRITON B1956 (Ortho), was added to the conventional sprays at 0.5% v/v and to the drizzle sprays at 1% v/v.

Nontarget species located within the test plots were identified on a presence/absence basis, and vigor was evaluated prior to and one year after treatment. All herbicide treatments were applied sequentially as suitable plots were encountered in the field on October 29, 1984, under partially cloudy skies. A very light rain fell briefly during application, but no rain fell for at least four hours after application.

Results and Discussion

Although no treatment was shown to be totally effective in the control of *Rubus argutus*, the most successful was a conventional spray of 2% ROUNDUP in water (Tables 8 and 9). Plants on all five of the blackberry plots subjected to this treatment reacted with a gradual decline in vigor until the sixth month, when response stabilized. Plants on two of the

Table 8. Response of blackberry (*Rubus argutus*) to foliar herbicide treatments, Hawaii Volcanoes National Park, 1984-85. (Numbers in table represent response category means of individuals treated in each test.)

Treatment*	NOV** (1 mo)	APR (6 mo)	OCT (12 mo)	PRETREATMENT
CONTROL	0.7	0.8	1.0	1.4
GARLON 4				
40% drizzle	4.0	4.4	1.2	1.8
2% conventional	4.0	3.8	1.0	1.4
0.5% conventional	4.0	3.2	1.0	1.2
TORDON 22K				
20% drizzle	3.2	2.6	1.0	1.2
2% conventional	4.0	3.2	1.0	1.0
0.5% conventional	3.4	2.0	1.0	1.2
ROUNDUP				
20% drizzle	2.6	3.8	2.2	1.4
2% conventional	2.4	4.6	4.4	1.6
0.5% conventional	2.6	3.4	1.4	1.6
AMITROL T				
40% drizzle	2.4	1.2	1.0	1.4
2% conventional	2.0	0.8	1.0	1.2
0.5% conventional	2.4	1.2	1.2	1.4

*n = 5 plants/treatment.

**Data for intervening months are available from authors; (months) are post treatment.

Plant response categories:

0 = >90% stems and foliage alive, excellent vigor.
1 = 75-90% stems and foliage alive, excellent vigor.
2 = 50-75% stems and foliage alive, moderate vigor.
3 = 10-50% stems and foliage alive, moderate vigor.
4 = < 10% stems and foliage alive, poor vigor.
5 = 100% death, no resprouts.

Table 9. Cover change of blackberry (*Rubus argutus*) within 3 m^2 plots one year after treatment.*

Plot	AMITROL T 40%	AMITROL T 2.0%	AMITROL T 0.5%	GARLON 4 40%	GARLON 4 2.0%	GARLON 4 0.5%	ROUNDUP 20%	ROUNDUP 2.0%	ROUNDUP 0.5%	TORDON 22K 20%	TORDON 22K 2.0%	TORDON 22K 0.5%	UNTREATED CONTROL	UNTREATED CONTROL
1														
Pretreatment	80	90	80	100	80	90	80	70	80	90	90	90	70	80
Post treatment*	30	70	20	90	30	90	5	10	5	90	50	90	90	90
2														
Pretreatment	90	90	60	90	100	60	90	90	90	100	100	70	80	80
Post treatment	90	90	90	25	70	100	80	0	90	80	80	90	80	80
3														
Pretreatment	80	90	70	80	50	80	90	50	80	90	80	90	80	100
Post treatment	75	80	90	90	10	70	10	0	20	90	70	100	80	100
4														
Pretreatment	90	70	80	80	80	80	100	70	80	80	90	95	90	80
Post treatment	100	70	80	10	80	90	60	<1	80	50	80	100	80	60
5														
Pretreatment	90	100	60	90	90	70	80	100	60	80	60	90	100	80
Post treatment	90	100	30	75	70	50	75	40	5	50	10	90	100	100

*Visual estimates one year post treatment. n = 5 plots/treatment, except 10 plots for control.

five plots exhibited 100% mortality with no resprouting after one year. In a third plot, all sprayed *Rubus* plants were dead, but healthy root sprouts were observed. Plants on the remaining two plots exhibited greater than 90% foliar and stem mortality and a great reduction in blackberry cover. Several stems that survived the herbicide treatment remained dormant for up to 10 months before producing stunted and severely deformed resprouts in tight clusters at the nodes. While these initial resprouts remained stunted, resprouts that appeared during the eleventh month appeared healthy.

Effects on Nontarget Native Species

Plant species monitored for possible reactions to the herbicide treatments included the species listed in Table 10. All nontarget species did not occur within each herbicide treatment plot; therefore, the information presented reflects plant responses to specific herbicides in incidental spray situations. Data are presented to assist in gauging incidental impacts and do not reflect broad-scale, systematic testing of nontarget species. Evaluations were made one year after treatment.

The results in Table 10 indicate that ROUNDUP is more detrimental to native species when applied as low-concentration, high-volume sprays, than with high-concentration, drizzle-spray application. One likely explanation is that high-concentration ROUNDUP physically burns plant tissue to the extent that systemic translocation is not possible. Another possibility is that high-concentration coverage was poor, a drawback to low-volume spray applications in general. It is possible that the poor coverage inherent in drizzle sprays resulted in untreated areas within treated plots. High-volume sprays resulted in uniform coverage, increasing the probability that all vegetation within a plot was treated.

Management and Research Recommendations

Although no treatment was found that provided total control of blackberry, the conventional foliar spray of 2% ROUNDUP in water would be useful in certain applications. This treatment, because of its effectiveness in greatly reducing the shade cover of blackberry for an extended period of time, could be used to assist in the regeneration of native tree species in areas where blackberry may be preventing this. ROUNDUP should not deter the germination of native species, as it is rapidly inactivated in soils (Sprankel *et al.* 1975). The treatment is within labeled application rates when used as prescribed. Post-treatment monitoring would be necessary, as resprouting of blackberry is likely. Large stands may need to be treated in stages, as it may not be possible to reach the central portions of some thickets with the spray. Applicators must be aware of changing wind patterns when spraying blackberry stands taller than 3.3 ft (1 m), to avoid spray drift, which can be hazardous to both the applicator and to surrounding nontarget species. Another critical factor involved in the treatment of blackberry deals with informing the general public where and when this activity is being conducted, to protect berry pickers from any contamination. Blackberries are commonly used as food in Hawai'i.

Table 10. Responses of nontarget native and introduced plants to herbicide treatments to control blackberry (*Rubus argutus*).

Species	Treatment* GARLON 4 40%	GARLON 4 2%	GARLON 4 0.5%	ROUNDUP 20%	ROUNDUP 2%	ROUNDUP 0.5%	AMITROL T 40%	AMITROL T 2%	AMITROL T 0.5%	TORDON 22K 20%	TORDON 22K 2%	TORDON 22K 0.5%
Endemic and Indigenous Species												
Acacia koa (Koa)		+	+	+	+		+	+		+	+	+
Asplenium sp.								+				
Coprosma ochracea (Pilo)					+		+			+		+
Ipomoea congesta (Morning glory)	L-H**	+	+	L**	L-H**	L-H**	H**	+	+	+	+	+
Lythrum maritimum (Pūkāmole)	+	+	+	+	+	H	+	+	+	+	+	+
Microlepia strigosa (Palapalai)					H							
Myoporum sandwicense (Naio)											+	
Pipturus albidus (Māmaki)	+			+								+
Pteridium aquilinum var. *decompositum* (Kīlau)	+	+	+	+	+	+	+	+	+	+	+	+
Sadleria cyatheoides ('Ama'uma'u)				+								
Sapindus saponaria (Mānele)				H			H**			H		
Sophora chrysophylla (Māmane)								M				
Introduced Species												
Commelina diffusa (Honohono)					+			+			H	
Crocosmia crocosmiiflora (Montbretia)	+											

Table 10, continued.

Table 10, continued.

Species	Treatment* GARLON 4 40%	2%	0.5%	ROUNDUP 20%	2%	0.5%	AMITROL T 40%	2%	0.5%	TORDON 22K 20%	2%	0.5%
Cynodon dactylon (Bermuda grass)		+			H		+	+	+		+	+
Ehrharta stipoides (Meadow ricegrass)		+	+	+		H					+	+
Fragaria vesca (Wild strawberry)	+			+	+		+			+		
Holcus lanatus (Velvet grass)		+		+	H	H		+				
Paspalum dilatatum (Dallis grass)	+	+	+	+	H	+	+	+	+	+	+	H**
Pennisetum clandestinum (Kikuyu grass)	+		+			+	+		+	+		+
Setaria gracilis (Foxtail grass)			+						+			
Solanum pseudocapsicum (Jerusalem cherry)	L-H		L-H	+	+	L-H	+			+		L-H
Stenotaphrum secundatum (St. Augustine grass)								L				
Verbena litoralis (Weed verbena)		H										
Veronica plebeia (Common speedwell)		+			+			+	+		+	

Key:

+ = exposed to treatment, no adverse effects
blank = not present in plot, therefore not exposed to treatment
H = heavily impacted (death)
M = moderately impacted (defoliation/desiccation, severely chlorotic plants partially recovered)
L = light effects (light chlorosis, some defoliation, some plants unaffected, full recovery).

*Drizzle for highest concentrations, spray for middle and lowest concentrations

**Comments:

40% Garlon 4	Four *Ipomoea* vines were treated. Two of these of moderate to poor pretreatment vigor died, while the remaining two, in excellent pretreatment vigor, were unaffected.
20% Roundup	Three *Ipomoea* vines were treated. One declined from good to very poor vigor, while the remaining two, in excellent vigor, were unaffected.
2% Roundup	Three *Ipomoea* vines were exposed. One in good vigor died, one declined from excellent to moderate vigor, and one increased from good to excellent vigor.
0.5% Roundup	Three *Ipomoea* vines in good vigor were treated. One died, one declined to poor vigor, and one increased to excellent vigor.
40% Amitrol T	Three *Ipomoea* vines were treated. One, in poor vigor, died; one, in good vigor died, while the last vine, in excellent vigor, was unaffected. *Sapindus* seedlings in one plot were not found after treatment and are presumed to have died.
2% Amitrol T	One *Sophora chrysophylla* individual reacted to treatment with partial defoliation; however, subsequent resprouts were healthy and vigorous.
20% Tordon 22K	A cluster of *Sapindus* seedlings was not found and is presumed to have died.
0.5% Tordon 22K	One *Paspalum* clump in excellent vigor died, while the others were unaffected.

Further research is definitely needed to improve the methods already tested and to explore new treatments (perhaps combinations of herbicides and/or repeated treatment annually). Larger plot and sample sizes (including treating entire stands) would yield more accurate information about treatment effectiveness. Repeat treatment testing is necessary to determine the number of treatments required to complete control. In a subsequent test of five herbicides applied as a foliar spray, conducted to increase sample size and test additional herbicides, ROUNDUP (2% v/v in water) was more effective at killing and defoliating small individual blackberry plants than GARLON 4, ARSENAL, ESCORT, OR CROSSBOW. As in the test described here, ROUNDUP completely killed only 40% of treated blackberry plants (G.L. Santos, unpub. data). Monitoring of areas where blackberry has been eliminated could yield valuable information about what is likely to colonize these areas. More information is needed about the effects of 2% ROUNDUP on native species, as this treatment is not target specific.

YELLOW HIMALAYAN RASPBERRY

Materials and Methods

Three foliar sprays, four soil applications, and 10 cut-stump treatments were tested on yellow Himalayan raspberry. Each treatment was applied to five plots. For the three foliar and four soil treatments, 35, 32-ft^2 (3-m^2) plots were selected from a *Rubus ellipticus* population in open canopy tall ʻōhiʻa rain forest with hāpuʻu (*Cibotium* spp.) and native shrubs in the understory. Elevation was 3,900 ft (1,190 m), with mean annual rainfall of 98 in. (2,494 mm). Mean monthly maximum temperatures ranged between 66 and 72 F (19-22 C).

Foliar sprays were applied via the drizzle or "magic wand" method in a water carrier at a spray volume of 2.25 gal/a (21 l/ha). The three treatments tested were: 50% concentrations of GARLON 4 and of ROUNDUP, and a 25% concentration of TORDON 22K. Hand-pressurized sprayers fitted with No. 20 orifice disks were used. Pressure was regulated at 30 psi. Triton 1956B (Ortho) was added as a spreader-sticker at 1% v/v.

Four soil applications of TORDON 10K pellets were tested: topical broadcast treatments at 0.08 and 0.15 oz/ft^2 (0.2-0.4 gm ae/m^2), and spot treatments at 0.08 and 0.15 oz/ft^2 (0.2-0.4 gm ae/m^2). The spot treatments involved depositing all pellets in one spot in the center of the 32-ft^2 (3-m^2) plot.

The nine treatments tested on cut stumps included: TORDON RTU; undiluted ROUNDUP, GARLON 4, and TORDON 22K; 5% and 20% dilutions of GARLON 4 in diesel oil; TORDON 22K in water; diesel oil only; and an untreated control. Trunks were severed at a height of <4 in. (<10 cm) either with a hand pruning saw or with pruning shears, depending upon stem size. Treatments were applied immediately to the freshly cut surface with 16-oz (500-ml) plastic squeeze bottles.

All treatments were applied under partially cloudy skies but dry weather with winds estimated at 5 mph (3 km/hr). Treatment application dates were May 5, 1985 for the foliar and soil treatments and July 22, 1985 for the cut-stump tests. No rain fell for at least four hours after treatment. Monitoring was conducted at monthly intervals for one year.

Results and Discussion

Foliar and Soil Treatments. Of the three foliar and four soil treatments tested, only the 50% GARLON 4 drizzle application proved to be effective in controlling yellow Himalayan raspberry (Table 11). After one month, four of the five plots exhibited leaf and stem desiccation on greater than 50% of the treated plants. The remaining plot showed only light chlorosis on a few scattered leaves and recovered by the fifth month. This plot, through an error in application technique, probably received less than the prescribed dose of GARLON 4. Overall reactions to the GARLON 4 treatment peaked by the fourth month after treatment, with greater than 90% defoliation and stem desiccation and no resprouting observed in three of four plots. Plant death in the fourth plot was 75-90%, with one healthy root resprout. No additional resprouting was observed in any of the GARLON 4-treated plots at one year.

Cut Stump Treatments. The most effective of the cut-stump treatments on yellow Himalayan raspberry was the 20% concentration of TORDON 22K in water (Table 12). This resulted in an 80% mortality rate (four of five stumps died with no shoot or root resprouting) at one year. Cambium vigor evaluations at seven months indicated complete mortality of all five stumps. In addition, no resprouting was observed on any of the decaying stumps during the next five months. By the twelfth month, however, resprouting was observed 6 in. (15 cm) from one stump from roots, which had apparently survived the treatment. Leaves that appeared on the two resprouts were deformed, with leaf margins curling upward towards the midrib. In addition, the upper leaf surface was bronze in color, and the shoots appeared stunted. It is not known at this time if these deformities are permanent or if the stump will subsequently produce healthy growth. Data obtained from herbicide tests on another *Rubus* species (*R. argutus* in this report) suggest that the longer the resprouts survive, the greater the likelihood of a resumption of normal growth.

Effects on Nontarget Native Species

Cut Stump Treatments. No adverse effects on any native plant species were observed within a 3.3-ft (1-m) radius of any of the test stumps. Nontarget species included ʻōhiʻa, hāpuʻu pulu (*Cibotium glaucum*), ʻamaʻu (*Sadleria pallida* and *S. cyatheoides*), and ʻōlapa (*Cheirodendron trigynum*). Since it is unlikely that any of the species were exposed to the treatments, no conclusions can be drawn as to sensitivity to the herbicides.

Foliar Treatments. Two ʻōhiʻa trees and one hāpuʻu, each 7 to 10 ft (2-3 m) in height, were exposed to the 50% GARLON 4 spray. The hāpuʻu was growing within 3.3 ft (1 m) of one of the test plots, with a single frond hanging within the plot. This frond died within three months of treatment; however, the untreated fronds remained healthy, and new fronds that

Table 11. Response of yellow Himalayan raspberry (*Rubus ellipticus*) to foliar and soil herbicide treatments, Hawaii Volcanoes National Park, 1985-86. (Numbers in table represent mean values for response categories.)

Treatment*	JUN** (1 mo)	SEP (4 mo)	JAN (8 mo)	MAY (12 mo)
ROUNDUP 50%	1.2	1.6	0.6	1.8
GARLON 4, 50%	3.4	4.8	4.4	5.2
TORDON 22K, 25%	1.8	1.4	0.6	0
TORDON 10K PELLETS BROADCAST				
0.4 gm	1.0	1.4	1.0	0.2
0.2 gm	1.0	1.0	0	0
TORDON 10K PELLETS SPOTTED				
0.4 gm	0.2	1.2	1.2	0.4
0.2 gm	1.0	1.0	0.2	0

*n = 5 plants/test.

**Data for intervening months are available from authors; (months) are post treatment.

Plant response category:
- 0 = healthy, no effect.
- 1 = light effects, chlorosis < 50% of plant.
- 2 = chlorosis > 50% of plant.
- 3 = moderate effects, > 50% leaf desiccation/defoliation.
- 4 = 50-75% leaf desiccation/defoliation.
- 5 = 75-90% plant death (cambium, stem desiccation).
- 6 = 90-100% plant death.

Table 12. Response of yellow Himalayan raspberry (*Rubus ellipticus*) to cut-stump treatments, Hawaii Volcanoes National Park, 1985-86. (Numbers in table represent mean response categories.)

Treatment*	AUG** (1 mo)	NOV (4 mo)	MAR (8 mo)	JUL (10 mo)	% DEAD STUMPS***
UNTREATED	4.4	0	0	0	0
TORDON RTU	5.0	4.6	3.6	3.0	60
ROUNDUP 100%	5.0	3.4	2.8	3.0	40
GARLON 4					
100%	5.0	5.0	5.0	3.6	60
20%	5.0	4.0	3.6	3.4	60
5%	5.0	5.0	4.8	2.6	20
TORDON 22K					
100%	5.0	3.0	3.2	3.0	60
20%	5.0	4.6	5.0	4.4	80
5%	5.0	4.2	0.8	1.4	20
DIESEL OIL	5.0	3.2	1.8	1.4	20

*n = 5 plants/test.

**Data for intervening months are available from authors; (months) are post treatment.

***at one year post treatment.

Plant response category:

0 = healthy, normal, resprouts.
1 = healthy resprouts w/ light abnormalities (chlorosis).
2 = moderate resprouts w/ abnormalities.
3 = light resprouts, w/ abnormalities.
4 = no resprouts, cambium alive.
5 = no resprouts, cambium dead.

appeared after treatment were healthy and normal. The two ʻōhiʻa trees were growing within two of the GARLON 4 plots and were directly treated. Although the surrounding raspberry was heavily affected, both ʻōhiʻa trees remained healthy and normal and were apparently unaffected by the treatment.

Management and Research Recommendations

Both the cut stump treatment of 20% TORDON 22K in water and the 50% GARLON 4 drizzle spray treatment were moderately effective in controlling *R. ellipticus*. The cut stump treatment is more target-specific than the drizzle spray, but it may involve clearing away considerable amounts of bramble in order to expose the stump for treatment. The difficulty of accessibility to the stem and the presence of native species in close association with yellow Himalayan raspberry are the two major factors in determining treatment feasibility.

Because of the less than satisfactory effectiveness of herbicides used in the cut-stump test, further research was warranted. In a second test, TORDON 22K and five other herbicides were evaluated as cut-stump treatments on a larger sample of yellow Himalayan raspberry plants, and effects on native species were studied systematically. After two years of monitoring, several herbicides were found to be more effective than TORDON 22K for use against yellow Himalayan raspberry (Santos *et al.* 1991).

TIBOUCHINA

Materials and Methods

Two hundred twenty shoots of glorybush with basal diameters ranging from <0.5 to 5 in. (1-13.5 cm) were selected from a population in a wet 'ōhi'a forest at 4,035 ft (1,230 m) elevation. Mean annual rainfall is 98 in. (2,494 mm), and mean monthly maximum temperatures ranged between 66 and 72 F (19-22 C), with the highest and lowest temperatures in August and February.

Lateral runners, which grow above and below ground on glorybush, made it necessary to trace each stem back to its primary root. Stems were then tagged, diameters measured, and plants were treated. Treatments consisted of severing the stems with a chain saw at a maximum height of 6 in. (15 cm) and applying the herbicide immediately to ensure maximum uptake and translocation throughout the root system. On plants with basal branching, all stems were cut, treated, and monitored, but only the largest stem was measured.

The 11 treatments tested included: 5% and 20% solutions of GARLON 4 in diesel oil; TORDON RTU undiluted; 5% and 20% solutions of ROUNDUP, TORDON 22K, and AMITROL T in water; diesel oil only; and an untreated control. Treatments were applied on the fresh cut so as to cover the entire surface, especially the cambium. The treatment surface was cut as level as possible to reduce runoff prior to absorption of chemical by the stump. The distance between treated areas was as great as practical (usually 10 ft or >3 m) to reduce the chances of cross contamination among connected glorybush roots. Treatments were applied to plants on January 10 and 11, 1985, under sunny and dry weather conditions. No rain fell for at least four hours after treatment on either date. Monitoring, conducted at monthly intervals for one year, consisted of visual observations of resprouting buds.

Results and Discussion

GARLON 4 in a 20% dilution with diesel oil was the most effective treatment tested, with 85% control of glorybush after one year (Table 13). A cambium vigor evaluation of the non-resprouting stumps at one year indicated complete death of all stumps. Resprouting on the surviving stumps was suppressed until the seventh month, when resprouts were etiolated with chlorotic leaves. The deformities were short-lived, and by one year post treatment the resprouts appeared normal.

Table 13. Percentages of glorybush (*Tibouchina urvilleana*) that resprouted after cut-stump treatment at Hawaii Volcanoes National Park, 1985-86.

Treatment*	FEB** (1 mo)	MAY (4 mo)	SEP (8 Mo)	JAN (12 mo)
DIESEL OIL	10	30	40	60
GARLON 4				
20%	0	0	5	15
5%	0	0	25	45
ROUNDUP				
20%	0	45	95	95
5%	5	90	100	95
TORDON 22K				
20%	0	5	10	25
5%	0	0	35	55
TORDON RTU	0	0	5	25
AMITROL T				
20%	10	80	95	95
5%	15	85	85	95
UNTREATED	15	95	95	95

*n = 20 stumps/treatment.

**Data for intervening months are available from authors; (months) are post treatment.

Effects on Nontarget Native Species

None of the native species present within a 3.3-ft (1-m) radius of treated stumps exhibited any adverse reactions to the herbicides. However, during treatment application no nontarget species were directly treated either accidentally or incidentally. Species monitored were: pūkiawe, ʻōhelo or kau-laʻai *(Vaccinium reticulatum)*, ʻōhiʻa, wāwaeʻiole, uluhe *(Dicranopteris emarginata)*, and ʻuki *(Machaerina angustifolia)*.

Management and Research Recommendations

Cut stump treatment is a practical, cost-effective, highly specific treatment method that is well suited for both the growth habit of glorybush and for the forest type in which it is currently found. GARLON 4 at 20% in diesel oil produced a high mortality rate with no adverse effects on native species. Retreatment is strongly recommended to achieve eventual eradication, and follow-up monitoring is necessary. Because glorybush readily reproduces vegetatively, any treatment program will need to include complete removal or spraying of cut branches and slash. Further testing of higher concentrations of both GARLON 4 and TORDON 22K might result in a more effective treatment for glorybush, and therefore require less follow-up monitoring.

CONCLUSIONS

The current restrictions on operational use of TORDON in Hawaiʻi, and the possibility of withdrawal from the market of all TORDON products by Dow Chemical Company in the near future, make it necessary to reevaluate the status of knowledge about control of alien plants considered in this study. For example, without TORDON, effective treatments for kāhili ginger and yellow Himalayan raspberry are compromised wholly or in part. Continual testing of a wide variety of chemicals seems a necessity to ensure availability of safe and effective chemicals. Chemicals that are less persistent than TORDON are known to be available. Determination of retreatment intervals and effective concentrations (and even sequences) of newly available, less persistent chemicals to be used in retreatment also seems desirable. More information on hazards to native species is needed for some application techniques in certain areas, for many chemicals used for many species of alien plants. Especially important is the thorough testing of current and newly available herbicides in near-native systems such as the Special Ecological Areas in Hawaii Volcanoes National Park. Most tests to date have been conducted in areas with heavy concentrations of alien plants. Obviously, less herbicide per unit area is necessary in more pristine areas, but risks to more native individuals and species also increase in these areas.

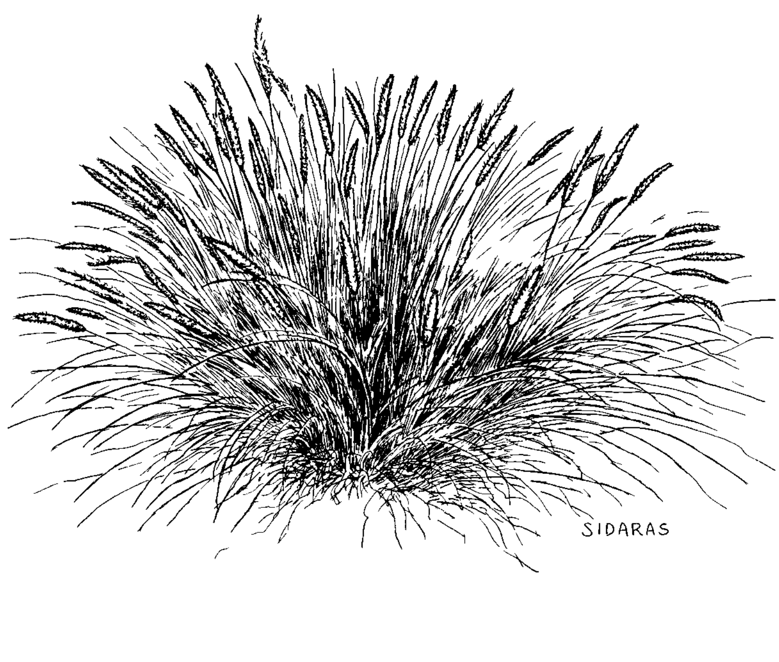
The use of herbicides on additional alien plant species that threaten the intactness of native ecosystems should be carefully studied. A few examples of such species are banana poka (*Passiflora mollissima*), *Paspalum* spp., pearl flower (*Heterocentron subtriplinervium*), molasses grass (*Melinis minutiflora*), Jerusalem cherry (*Solanum pseudocapsicum*), and meadow ricegrass (*Ehrharta stipoides*). Testing of the effects of herbicide treatment for some of these species and on native plants is needed, and some reports are now (1991) in preparation.

Better data on the persistence of herbicides in soils, the colonization of treated areas by alien and native plants, and the costs of herbicide applications by different techniques in different situations are also needed. Information on the effects of herbicide treatments on invertebrates and birds, in particular, is necessary in more intact ecosystems. Close monitoring of operational usage of chemicals in native systems should be a key element in a management-oriented herbicide research program in a public agency. Long-term monitoring, especially for alien tree or shrub species, is very important in determining effectiveness of chemical treatments.

We believe that herbicides are an effective and essential tool in the restoration of Hawaiian ecosystems. However, much more remains to be learned, and continual research is necessary. A modest investment in research on and monitoring of herbicide use should ensure responsible integration of safe and effective herbicidal control with other approaches used in ecosystem restoration programs.

ACKNOWLEDGMENTS

We would like to thank many individuals who assisted in this project, including Dan Taylor, Tim Tunison, and Chris Zimmer for their encouragement and advice. Thanks also to Casey Baldwin, Kevin McGough, Nelson Ho, and Lou Whiteaker for field assistance. We are very grateful to Paul Higashino and Lani Stemmermann for their help with plant identification. Sincere thanks to Philip Motooka for advice and technical assistance, and to Steve Anderson for help with plant identification and computer technology. Cliff Smith, Dan Taylor, and Tim Tunison provided critical review and comments, and Danielle Stone typed and helped edit the manuscript.



Literature Cited

Anderson, W.P. 1983. *Weed science: principles*, 2nd ed. New York: West Pub. Co.

Berg, G.L., ed. 1985. *Farm chemicals handbook '85.* Willoughby, Ohio: Meister Pub. Co.

Gardner, D.E. 1984. Tests for the control of kahili ginger (*Hedychium gardnerianum*) with GARLON 4 foliar spray and basal applications. Unpub. rep. Files, Hawaii Volcanoes Natl. Park and Coop. Natl. Park Resour. Stud. Unit, Honolulu.

Graf, A.B. 1978. *Tropica, color cyclopedia of exotic plants and trees from the tropics and subtropics.* East Rutherford, N.J.: Roehrs Co.

Haselwood, E.L., and G.G. Motter, eds. 1984. *Handbook of Hawaiian Weeds,* 2nd ed., revised and expanded by R.T. Hirano. Harold L. Lyon Arboretum. Honolulu: Univ. Hawaii Pr.

Hawaii Volcanoes National Park. 1984. Natural resources management management program, November, 1984 update: An addendum to the Natural Resources Management Plan. Div. Resour. Manage. Files, Resources Management Div., Hawaii Volcanoes Natl. Park.

Jacobi, J.D., and F.R. Warshauer. 1975. A preliminary bioecological study of the Ola'a Tract, Hawaii Volcanoes National Park. Prep. for Hawaii Natural Hist. Assn. Hawaii Volcanoes National Park. Univ. Hawaii Dep. Botany, Honolulu. Library, Hawaii Volcanoes Natl. Park. Typewritten.

Johnson, D.R., G.P. Markin, R.C. Reardan, and W.K. Randall. 1984. Injecting Metasystox-R at three spacing intervals to improve seed yield in Douglas fir. *J. Econ. Entomol.* 77:1320-1322.

Leonard, O.A. 1957. Effect of phenoxy herbicide concentrates applied to cuts of sprouting tree species. *Weeds* 5(4):291-303.

Motooka, P., G. Nagai, and L. Ching. 1983. The Uyeda "magic wand" method of herbicide application. *Proc. Asian Pac. Weed Sci. Soc. Conf.*, Suppl. Vol. II, Manila, Philippines, Nov. 28-Dec. 2, 1983, 550-553.

Neal, M.C. 1965. *In gardens of Hawaii.* B.P. Bishop Mus. Spec. Pub. 50. Honolulu: Bishop Mus. Pr.

Santos, G.L., L.W. Cuddihy, and C.P. Stone. 1991. *Control of yellow Himalayan raspberry (*Rubus ellipticus *Sm.) with cut-stump herbicide treatments in Hawai'i.* Tech. Rep. 80, Univ. Hawaii Coop. Natl. Resour. Stud. Unit. Honolulu.

Santos, G.L., D. Kageler, D.E. Gardner, and C.P. Stone. 1986. *Herbicidal control of selected alien plant species in Hawaii Volcanoes National Park: a preliminary report.* Tech. Rep. 60, Univ. Hawaii Coop. Natl. Park Resour. Stud. Unit. Honolulu.

Skolmen, R.G. 1979. *Plantings on the forest reserves of Hawaii 1910-1960.* Inst. Pac. Islands For., Pac. SW For. Range Exp. Sta., U.S. For. Serv., Honolulu.

Smith, C.W. 1985. Impact of alien plants on Hawai'i's native biota. In *Hawai'i's terrestrial ecosystems: preservation and management*, ed. C.P. Stone and J.M. Scott, 180-250. Univ. Hawaii Coop. Natl. Park Resour. Stud. Unit. Honolulu: Univ. Hawaii Pr.

Sprankle, P., W.F. Meggitt, and E. Penner. 1975. Rapid inactivation of glyphosate in the soil. *Weed Sci.* 23(3):224-228.