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RESEARCH PAPER

Control of the invasive liana, *Hiptage benghalensis*

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The liana, hiptage (*Hiptage benghalensis*), is currently invading the wet tropics of northern Queensland and remnant bushland in south-eastern Queensland, Australia. Trials using seven herbicides and three application methods (foliar, basal bark, and cut stump) were undertaken at a site in north Queensland (158 700 hiptage plants ha^{-1}). The foliar-applied herbicides were only effective in controlling the hiptage seedlings. Of the foliar herbicides trialed, dicamba, fluroxypyr, and triclopyr/picloram controlled >75% of the treated seedlings. On the larger plants, the cut stump applications were more effective than the basal bark treatments. Kills of >95% were obtained when the plants were cut close to ground level (5 cm) and treated with herbicides that were mixed with diesel (fluroxypyr and triclopyr/picloram), with water (glyphosate), or were applied neat (picloram). The costings for the cut stump treatment of a hiptage infestation (85 000 plants ha^{-1}), excluding labor, would be \$A14 324 ha^{-1} using picloram and \$A5294 ha^{-1} and \$A2676 ha^{-1}, respectively, using glyphosate and fluroxypyr. Foliar application using dicamba for seedling control would cost \$A1830 ha^{-1}. The costs range from 2–17 cents per plant depending on the treatment. A lack of hiptage seeds below the soil surface, a high germinability (>98%) of the viable seeds, a low viability (0%) of 2 year old, laboratory-stored fruit, and a seedling density of 0.1 seedlings m^{-2} 12 months after a control program indicate that hiptage might have a short-term seed bank. Protracted recolonization from the seed bank would therefore be unlikely after established seed-producing plants have been controlled.

Keywords: forest management, herbicides, vine.

Hiptage (*Hiptage benghalensis* [L.] Kurz), a member of the Malpighiaceae family, is a vine-like plant native to temperate (south China and Taiwan) and tropical Asia (India [Kadavul & Parthasarathy 1999; Chittibabu & Parthasarathy 2001], Indochina, Indonesia, Cambodia, Malaysia, Myanmar, the Philippines, Sri Lanka, Thailand, and Vietnam [PIER 2002; Starr *et al*. 2003]). Hiptage has been cultivated in the tropics as an ornamental plant and is now naturalized on the Hawaiian islands of Kauai (Starr *et al*. 2003) and Oahu (Carr 2001), Broward County of Florida (Wunderlin & Hansen 2000; FLEPPC 2001), and the Mascarene Archipelago islands of La Reunion (Baret *et al*. 2006; Tassin *et al*. 2006) and Mauritius (Lorence & Sussman 1988). In Australia, hiptage has been found in the Far North, Wide Bay Burnett, Sunshine Coast, Morton, and Gold Coast regions of Queensland (HERBRECS 2007).

Hiptage grows as a high-climbing (50–60 m), twining liana when adjacent to trees or forms a large shrub to 4 m when trees are absent. The stems are covered with small, white or yellowish hairs (Bailey & Bailey 1976). The young stems are grayish-green with many white lenticels; older stems are gray and can become woody and twisted into long, thick vines. The hiptage leaves are leathery, with a smooth glossy upper surface, and the new foliage is red in appearance. The simple leaves are usually lanceolate to ovate-lanceolate, grow 6–20 cm in length

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in opposite pairs along the stem, and are elongated with pointed tips (Whistler 2000).

The peak flowering period in Australia is during spring and summer (September to February), though hiptage flowers intermittently throughout the year. The sweetly perfumed flowers grow in clusters of 10–30 at the base of the upper leaves and have five rounded petals, 1–2 cm long, with fringed margins. The petals are white to pink with one yellow petal in the center (Bailey & Bailey 1976). The flowers develop into distinctive brown samaras, each with three papery wings that are 2–5 cm long, allowing the fruit to fall in a helicopter-like fashion (Whistler 2000; Starr *et al.* 2003). Each samara contains one seed that can exhibit polyembryony, with two gametophytes in the same ovule (Bacchi 1940). The samaras are mainly dispersed by wind but also by water (PIER 2002; Cooperative Research Centre for Australian Weed Management 2005). Hiptage also can be propagated by cuttings (Ellison 1995; PIER 2002) and is often cultivated in the tropics for its attractive and fragrant flowers. The hiptage seed oil is rich in ricinoleic acid (Siddiqi & Osman 1969) and is used for medicinal purposes in India for scabies (leaves), chronic rheumatism and asthma (plant), biliousness, coughing, a burning sensation, and thirst and inflammation (leaf and bark) (Bailey & Bailey 1976; Agharkar 1991; IMPGC 2007).

Pacific Island Ecosystems at Risk has rated hiptage as a high-risk plant for the Pacific islands and, with a risk score of 8 (plants receiving scores >6 are rejected for import), advises the prohibition of its import into Australia (PIER 2002). The Global Invasive Species Database (GISD 2000) lists hiptage as one of the 100 worst invasive species (Lowe *et al.* 2000) and states that, on Mauritius and La Reunion Island, hiptage is extremely invasive, thriving in drier lowland forest, forming impenetrable thickets, smothering native vegetation, and choking large trees. Hiptage was first recorded on La Reunion Island in 1967 (Baret *et al.* 2006) and is now listed as having the highest invasive capacity and the greatest impact on succession and the utilization of resources in natural areas of La Reunion Island of 26 non-indigenous woody species selected for ranking (Tassin *et al.* 2006). It preferentially invades disturbed sites, such as gaps, landslides, and river banks (Baret *et al.* 2006). Baret *et al.* (2006) found hiptage to have invaded lowland, open woodlands, lowland rainforests, semidry forests, windward submountain rainforests, and submountain mesic forest habitats of La Reunion Island, forming dense thickets capable of smothering native vegetation and choking trees.

Several studies have reported on the negative impact of climbing plants, such as hiptage, on tree seedlings and saplings (Dillenburg *et al.* 1995; Perez-Salicrup & Barker 2000; Schnitzer & Bongers 2002; Schnitzer *et al.* 2005). Climbing plants, particularly lianas (woody, climbing vines), reduce tree growth by competing with trees for light and below-ground resources, such as water and nutrients (Perez-Salicrup & Barker 2000; Schnitzer *et al.* 2005). Climbers can assign more resources to height growth and to leaf production than to supporting tissue, allowing lianas to overgrow tree saplings and consequently suppress their growth (Caballe 1993, 1998; Schnitzer & Bongers 2002; Toledo-Aceves & Swaine 2007). Lianas also have exceedingly deep root systems, transport water very effectively, and grow and maintain their leaves for longer and under drier conditions than trees (Longino 1986; Perez-Salicrup & Barker 2000; Gerwing 2001). In hiptage's native habitat of the Eastern Ghats of southern India, stem diameters of ≤15.3 cm at breast height (130 cm) have been recorded (Chittibabu & Parthasarathy 2001). As lianas grow very rapidly in length, they can remain on top of the canopies for several decades or more, resulting in tree death and impedance of tree recruitment (Putz 1995). As a result of the intertangling of vines and branches, the fall of liana-laden trees causes more significant damage to the surrounding trees, creates larger canopy gaps, and leads to slower regeneration within the gaps than the fall of liana-free trees (Appanah & Putz 1984; Vidal *et al.* 1997). Vidal *et al.* (1997) found lianas connected each tree to another three-to-nine large trees in an eastern Brazilian Amazon forest. For every individual tree felled, an average of 7.2 neighboring trees were pulled down in the Pahang Sungei Tekam Forest Reserve, Malaysia (Appanah & Putz 1984). Cutting the lianas prior (9 months) to felling reduced the number of neighboring trees that were damaged to four (Appanah & Putz 1984).

Hiptage is on the list of potential environmental weeds in Australia (Csurhes & Edwards 1998), is ranked 92 on the list of invasive naturalized plants in south-eastern Queensland (Batianoff & Butler 2002), and is on the list of exotic plants that have naturalized within the Queensland Wet Tropics Bioregion (Wet Tropics World Heritage Area, WTWHA). In Australia, hiptage is broadly distributed over 60 ha of mesophyll rainforest and remnant gallery forests within Queensland. It was first recorded in Queensland growing at the Brisbane Botanic Gardens in October 1932 and was described at the time as a vigorously growing vine (HERBRECS 2007). Naturalized pockets of hiptage were recorded in 1980, growing on the sandy loam soils along the banks of the Burnett River (24°55′S, 152°15′E), and in 1987, along

the banks of the Mossman River (16°27′30″S, 145°22′30″E) among a complex mesophyll rainforest on Krasnozem soils derived from basalt, while in 1999, it was found growing in Manaton Park Fig Tree Pocket, Brisbane (27°30′S, 152°57′E) (HERBRECS 2007). Anecdotal evidence suggests that the infestation in Mossman dates back to the late 1940s, when a keen plant collector introduced the plant to the region (Logan P., 2007, personal communication).

Hiptage is capable of smothering vegetation 50–60 m above the ground and, with the weight of the vine and foliage, snapping branches (Clarkson J., 2007, personal communication). Many of the native trees and shrubs in areas heavily infested by hiptage are visibly deformed from having developed while carrying large hiptage vines. A blanket of hiptage seedlings, with an absence of native tree seedlings or saplings, is often observed growing under the canopy of a dense hiptage infestation. Hiptage is placing habitats of high conservation value, such as complex mesophyll rainforest systems within the WTWHA of far north Queensland, under threat.

There are no chemicals currently registered in Australia for control of hiptage. In Hawaii, on the island of Oahu, hiptage has been targeted for eradication by the Oahu Invasive Species Committee (GISD 2000), with three sites containing >40 plants controlled (DLNR 2001) by the basal bark and cut stump application of triclopyr (9600 g 100 L^{-1}) (GISD 2000; CTAHR 2003). This paper reports on the population structure of a hiptage infestation in north Queensland, identifies the effective chemicals that can be applied to control the seedlings and mature hiptage plants in Australia, and discusses the management of hiptage infestations.

MATERIALS AND METHODS

The field experiments were initiated in December 2005 to determine the effect of basal bark-, cut stump-, and foliar-applied herbicides on hiptage plants and on the viability of the hiptage soil seed bank growing in the wet tropics of north Queensland. The wet season is from November to April, with 88% of the annual rainfall falling during this period (BOM 2007). All the treatments were applied to individual plants that were actively growing and ranging in height from 0.2–40 m.

Study site

Trials were conducted 2 km south-east of Mossman, Queensland, along the South Mossman River (16°28′S, 145°23′E), where hiptage infests 3.5 km of riparian land between the South Mossman Bridge and the Mossman Sugar Mill. This intact riparian corridor of gallery rainforest, a simple-complex mesophyll-to-notophyll vine forest, is on the very wet and wet lowlands on fertile riverine alluvia, with a conservation status of "endangered" to "of concern" under the Queensland Vegetation Management Act 1999 (QVMA 2007). The tree species include *Archontophoenix alexandrae* (F. Muell.) H.Wendl. & Drude (feather palm), *Blepharocarya involucrigera* F. Muell. (rose butternut), *Acacia celsa* Tindale (brown salwood), *Flindersia bourjotiana* F. Muell. (silver ash), *Syzygium angophoroides* (F.Muell.) B.Hyland (Yarrabah satinash), *Syzygium kuranda* (F.M.Bailey) B.Hyland (Kuranda satinash), *Dillenia alata* A. DC. (red beech), *Grevillea baileyana* McGill. (Findlay's silky oak), *Calophyllum sil* Lauterb. (blush toriga), *Backhousia hughesii* C.T. White (stonewood), and *Acronychia acronychioides* (F.Muell.) T.G.Hartley (white aspen). The tree density within the trial site averaged 2680 (standard error of the mean [SEM]: 340) plants ha^{-1} and the density of the vines (excluding hiptage) was 2680 (SEM: 1130) plants ha^{-1}. The width of the riparian vegetation varied from 20–180 m and was bordered by sugar cane on both sides of the river.

Trial site measurements

Five plots of 10 m × 10 m (total area of 500 m^2) were randomly selected within the trial site. Plants were included in a plot if the stem's last rooting point was within the plot before ascending into the canopy (Gerwing *et al.* 2006). All plants with diameters at breast height (or 130 cm above the main rooting point for hiptage and other vines; Gerwing *et al.* 2006; Schnitzer *et al.* 2006) of ≥0.1 cm were recorded as trees, shrubs, vines, or the targeted weed, hiptage. The hiptage saplings (non-climbing) that met the minimum diameter limit (0.1 cm) were recorded as freestanding. Hiptage plants were also recorded as ascending trees, intertwining in the crown of trees, or freestanding in the study area. Seedlings also were recorded in each plot by randomly selecting four 1 m × 1 m quadrats (total sample area of 20 m^2) and recording all the plants <1.3 m in height. In each of the 20 quadrats, the hiptage seeds on the soil surface were counted and two soil core samples, each consisting of five pooled 40 mm-diameter × 10 cm-deep cores, were taken to determine the hiptage soil seed bank. All the soil was sieved and the hiptage seeds were counted.

Germination/viability measurements

Germination tests were undertaken on both fresh hiptage fruit retrieved from the field and from 2 year old fruit stored at 25°C in dry paper bags in the laboratory. The fresh hiptage fruits were either left as intact fruit (IS)

or had their seeds removed from the samara (SO). The older fruits were left intact (IS2). Four replicates of 25 randomly selected fruit or seeds from each group were placed on moist filter paper in Petri dishes. The dishes were placed in a growth cabinet set at 28°C/18°C (12/12 h thermoperiod) and a 12/12 h day (600 lux at seed level)/night photoperiod. The germination was monitored every 48 h for 17 days. Additional deionized water was added as required. The seeds were counted as germinated when the radicle was visible. On day 17, the remaining ungerminated seeds were tested for viability using tetrazolium. The ungerminated seeds were placed in Petri dishes containing a 1% aqueous solution of 2,4,5,-triphenyl tetrazolium chloride (pH = 7.0) (tetrazolium) for 48 h in darkness at 25°C. Following the soaking period, the seeds with a red-stained embryo were classed as viable.

Treatment information and spray application equipment

The experiment evaluated a total of seven herbicides at various concentrations (Table 1). The rates that were selected were based on the label recommendations for the control of other woody vine species. All plant diameters that were 130 cm above ground level were measured prior to the treatment. The mean diameter of the treated hiptage plants that were 130 cm above

Table 1. Herbicides and dose rates tested on hiptage

Method of application	Herbicide (active ingredient)	Trade name (manufacturer)	Rates applied (g active ingredient per 100 L spray solution)	Cost ($A) per 100 L spray solution
Foliar†	Dicamba	Nufarm Kamba 500 (Jiangsu Institute of Ecomones, Jiangsu, China)	100	10.65
	Fluroxypyr	Starane 200 Herbicide (DowAgrosciences, Drusenheim, France)	100	15.23
	Metsulfuron	Dupont Brush-Off Brush Controller (DuPont Agricultural Chemicals Ltd., Shanghai, China)	12	6.15
	Triclopyr/picloram	Grazon DS Herbicide (DowAgrosciences, Michigan, USA)	100/33.3	14.31
Basal bark‡	Fluroxypyr	Starane 200 Herbicide (DowAgrosciences, Drusenheim, France)	667	202.70
	Triclopyr/picloram	Access Herbicide (DowAgrosciences, Michigan, USA)	400/200	233.88
	No herbicide		Neat diesel	124.30
Cut stump·	Fluroxypyr	Starane 200 Herbicide (DowAgrosciences, Drusenheim, France)	667	202.70
	Glyphosate	Roundup Herbicide By Monsanto (Monsanto Company, Louisiana, USA)§	18 000	401.10
	Metsulfuron	Dupont Brush-Off Brush Controller (DuPont Agricultural Chemicals Ltd., Shanghai, China)§	60	19.35
	Picloram	Vigilant Herbicide Gel (The Horticulture & Food Research Institute of New Zealand, Hamilton, New Zealand)	4300	81.40 kg^{-1}
	Triclopyr/picloram	Access Herbicide (DowAgrosciences, Michigan, USA)	400/200	233.88
	No herbicide		Neat diesel	124.30

Herbicide costing per 100 L of spray solution is based on retail prices for November 2007. † Foliar-applied herbicides were diluted with water; ‡ the basal bark-/cut stump-applied herbicides were diluted with diesel (the cost of diesel was based on $A1.24 L^{-1}); § glyphosate and metsulfuron were diluted with water.

ground level was 31.97 mm (SEM: 0.95). The plants were treated with herbicides by foliar, basal bark, and cut stump application. Each treatment contained 20 plants and was replicated three times in a complete randomized block design. The temperatures at the treatment application ranged from 30–34°C and the relative humidity ranged from 75–80%. There was a slight easterly wind of 0–1.5 m s^{-1} and no cloud cover. The mean annual rainfall at the site during the study period (2005–2006) was 2032 mm $year^{-1}$. The number of rainy days per year was 102. At the final assessment (269 days after treatment), the main stem and taproot of the plants recorded as dead were cut to ensure no live tissue remained.

Foliar application

A 20 L, 12 volt electric-powered backpack spray unit (R&D Sprayers Inc., Opelaousas LA, USA) with an adjustable solid cone nozzle and operating pressure of 200 kPa was used to apply the herbicides for the foliar treatments in the experiments. Each plant was sprayed to the point where the spray mixture dripped from the foliage. For the seedlings, the spray volume was ~2500 L ha^{-1} and for the mature plants, it was ~4000 L ha^{-1}. All the solutions contained 0.2% (v/v) BS1000 (100 g L^{-1} alcohol alkoxylate, Crop Care Australasia, Pinkenba Queensland, Australia).

Basal bark application

An 8 L hand-held pneumatic sprayer (Silvan Australia Pty Ltd., Dandenong Victoria, Australia) with a 0.6 m wand, an adjustable full-cone nozzle, and an operating pressure of 70 kPa was used to deliver the herbicide spray mix to the entire circumference of the lower 40 cm of each plant stem.

Cut stump application

All the plants were cut to a height of 5 cm above ground level. An 8 L hand-held pneumatic sprayer (operating pressure of 70 kPa) with a 0.6 m wand and variable full-cone nozzle was used to deliver the herbicide spray mix to the freshly cut stumps. The herbicide spray mix was applied to the entire freshly cut surface of each stem within 15–30 s of the stem being cut. The picloram treatment involved applying a 3 mm layer of the neat picloram gel mix to the entire freshly cut stem surface.

Treatment costs

To assist in determining the costs of treating hiptage-infested areas with various control techniques, the basal diameters of all the hiptage plants were measured within the trial site and substituted into the exponential equation, $Y = 0.00248\ BD \ln(BD)$ for foliar spraying, and the power equation, $Y = 0.00189\ BD^{0.6688}$, for cut stump spraying (Vitelli *et al.* 2008). The regression equations allow the volume of herbicide required to treat an individual plant to be determined based on the plant's basal diameter, where Y equals the volume of the herbicide in liters and BD equals the plant's basal stem diameter in mm.

Statistical analysis

The percentage plant mortality was subjected to an analysis of variance after an arcsine transformation and the means were separated by Fisher's Protected Least Significant Difference test. The size class and seed viability data were analyzed using Systat 9.0 general linear model procedures (SPSS Inc., Chicago, USA).

RESULTS

Plant density

Hiptage was very abundant at Mossman and averaged 158 700 (SEM: 597) plants ha^{-1}, irrespective of plant size (Table 2), with an additional surface seed load of 39.2 seeds m^2. No seeds were found below the soil surface. Stem diameters (130 cm above the main rooting point) at the site ranged from 1.4–135.4 mm, with 82% of the plants measured having stem diameters of 20 mm (Fig. 1). In the Mossman study area, 13% (SEM: 6.3) of

Table 2. The population structure of a hiptage infestation growing along a section of the South Mossman River, Mossman, Queensland

Population	Mean (individuals/m^2)	SEM	Minimum	Maximum
Plants >130 cm in length	1.5	0.31	0.8	2.6
Plants <130 cm in length	14.4	5.77	1.0	34.0
Surface seed bank	39.2	17.16	8.0	99.0
Buried seeds	0.0	0.00	0.0	0.0

SEM, standard error of the mean.

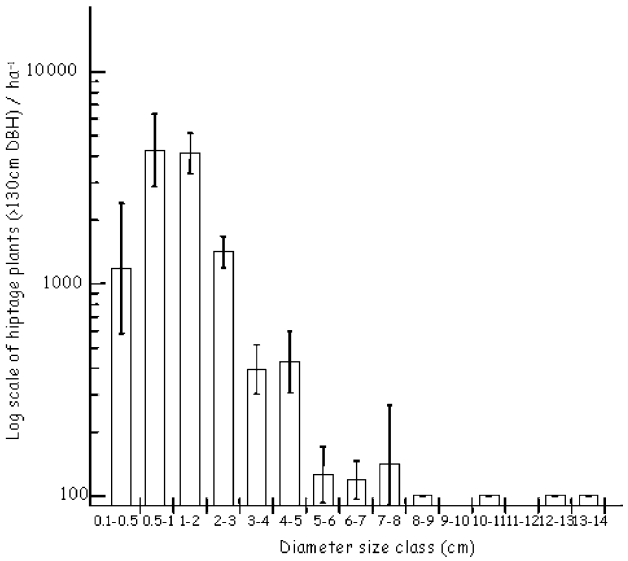

Fig. 1. Size class distribution of the hiptage plants growing along the South Mossman River, Mossman, Queensland, with >0.1 cm stem diameters (taken 130 cm above the main rooting point). The vertical bars indicate the standard error of the mean. DBH, Diameter at Breast Height.

the hiptage plants were freestanding. Hiptage was ascending only 21% (SEM: 4.3) of the trees within the plots, but at canopy level, the vines had spread and intertwined in the crown of 82% (SEM: 7.7) of the trees. The hiptage plants that were probably large enough to influence or cause damage to the trees were common as, on average, 508 plants ha^{-1} with a 5 cm diameter and 308 plants ha^{-1} with a diameter of ≥10 cm were present within the trial area.

Seed viability

The seed viability was significantly different ($P < 0.0005$) between the fresh (62%) and 2 year old, laboratory-stored fruit (0%), with seed removed from the samara recording the highest viability (65%) (Fig. 2). The germinability for the viable, fresh hiptage seed was high (>98%). Twenty-three percent of the seeds were polyembryonic, with two gametophytes originating from the same ovule.

Herbicide treatment efficacy

Foliar application

More than 75% of the hiptage seedlings treated were controlled by the foliar herbicides, dicamba (100 g 100 L^{-1}), fluroxypyr (100 g 100 L^{-1}), and triclopyr/picloram (100/33.3 g 100 L^{-1}) (Fig. 3). In contrast, the same foliar herbicides were ineffective at

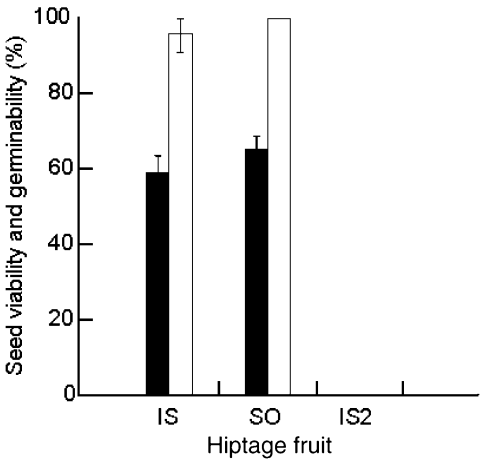

Fig. 2. Hiptage seed viability of the fresh intact samara fruit (IS), the seed removed from the samara (SO), and 2 year old, laboratory-stored intact samara fruit (IS2). The vertical bars indicate the standard error of the mean. (■), Viable; (□), germinability (as a proportion of viability).

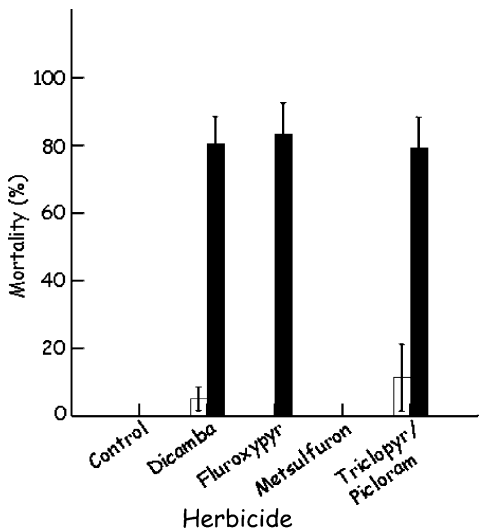

Fig. 3. Hiptage mortality following the application of foliar herbicides 269 days after treatment on a property located 2 km south-east of Mossman, Queensland. The vertical bars indicate the standard error of the mean. (■); Seedlings (□), mature plants.

controlling the mature hiptage plants (the highest kill was 11%).

Basal bark and cut stump application

When the three treatments, diesel, fluroxypyr, and triclopyr/picloram, were compared between the basal bark and cut stump methods, a significantly higher ($P < 0.0005$) percentage of hiptage plants was killed on

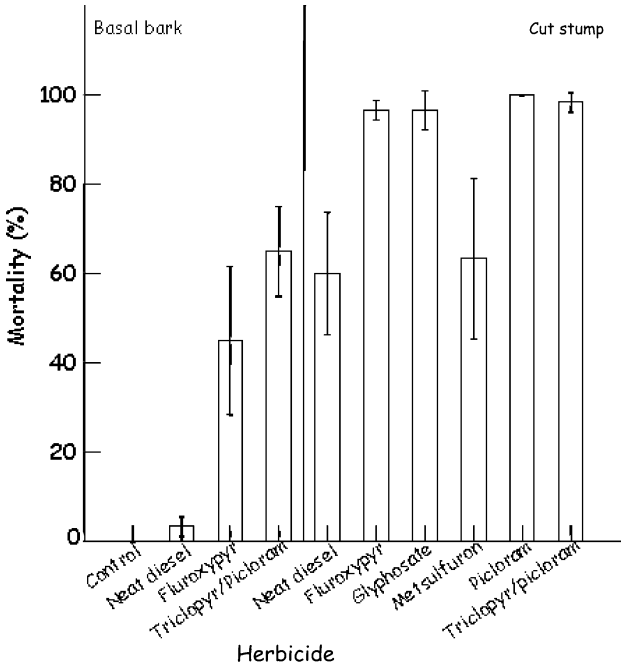

Fig. 4. Hiptage mortality following the application of herbicides as a basal bark or cut stump method 198 days after treatment on a property located 2 km south-east of Mossman, Queensland. The vertical bars indicate the standard error of the mean.

average by the cut stump method (85%) than the basal bark method (38%). Kills of >95% were obtained using the cut stump method for the herbicides, fluroxypyr (667 g 100 L^{-1}), glyphosate (18 000 g 100 L^{-1}), and triclopyr/picloram (400/200 g 100 L^{-1}), with 100% mortality obtained with picloram (4300 g 100 kg^{-1}) (Fig. 4).

Treatment costs

November 2007 retail prices were used to determine the cost of 100 L of spray solution. Costs ranged from $A6.15–401.10 (Table 2) depending on the herbicide, dose rate, and spray carrier used. The picloram gel mix cost $A81.40 kg^{-1} (Table 2). Prices were based on purchases of the largest commercial size available. Based on the regression equations of Vitelli *et al.* (2008), the application of treatments to control hiptage-infested ecosystems (based on 85 000 plants ha^{-1}) could cost $A14 324 ha^{-1} for the cut stump application with picloram, $A5294 ha^{-1} and $A2676 ha^{-1} for the cut stump application with glyphosate and fluroxypyr, respectively, and $A1830 ha^{-1} for the foliar application of dicamba for seedling control. Thus, the cost of the herbicide would range from 2–17 cents per plant.

DISCUSSION

Hiptage seedlings can be controlled effectively with the foliar-applied herbicides, dicamba, fluroxypyr, and triclopyr/picloram. The cut stump method was most effective (kills of >95%) for applying herbicides to control hiptage plants >1.3 m in height. Depending on the herbicide used, these herbicides can be applied mixed with diesel (fluroxypyr: 667 g 100 L^{-1} or triclopyr/picloram: 400/200 g 100 L^{-1}), with water (glyphosate: 18 000 g 100 L^{-1}), or applied as a neat gel (picloram: 4300 g 100 kg^{-1}).

Fredericksen (2000) observed that 2,4-D (5000 g 100 L^{-1}) that was applied to the freshly cut surface of several liana species, irrespective of the family (Apocynaceae, Bignoniaceae, Combretaceae, Malpighiaceae, and Trigoniaceae), growing in the tropical forests of eastern Bolivia, killed 60% of the treated stems within 7 months after treatment, while the application of triclopyr (24 000 g 100 L^{-1}), as a basal bark method, killed 75% of the plants treated. Lianas that were cut but not treated with herbicide had 70% of the stems reshoot (Fredericksen 2000). Appanah and Putz (1984) cut and treated lianas growing in Pahang, Malaysia, with 2,4,5-T (16 000 g 100 L^{-1}) in diesel and killed 94.5% of the treated stumps. The basal bark results of Fredericksen (2000) (75% kill) are comparable to the results obtained in this hiptage trial (65% kill), using triclopyr/picloram (400/200 g 100 L^{-1}). The higher levels of kill (>95%) obtained in our trial using the cut stump method are similar to those reported by Appanah and Putz (1984) and could be explained by the height at which the plants were cut prior to the application of the herbicide. Fredericksen cut the lianas 100 cm above ground level, while Appanah and Putz cut the lianas near their base. The hiptage plants in the Mossman trial were cut 5 cm above ground level. Other researchers (Carmona *et al.* 2001; Vitelli *et al.* 2008) have experienced a decline in efficacy (≤90% reduction in plant mortality) the higher the plants are cut above ground level prior to the application of the herbicides. Our study also showed that ~10% of the cut hiptage stems resprouted roots from the hanging stem. In order to prevent this, a second cut at shoulder height (~1.5 m above ground level) is recommended. An added benefit of a second cut would be to reduce the availability of hanging dead lianas to be used as trellises for new liana sprouts (Gerwing 2001; Perez-Salicrup *et al.* 2001). The cut stem section (ramet) would need to be removed from the area or treated with a herbicide (both cut stem surfaces to be soaked in a herbicide mix for 30 s) to prevent the stem from reshooting.

Vidal *et al.* (1997) found that felling trees with many liana connections resulted in canopy gaps that were twice as large as those of liana-free felled trees. The trees also were likely to collapse or snap under the weight of lianas, such as hiptage (Putz 1995). The estimated hiptage dry weight biomass within the study site was 35 492 kg ha^{-1} (SEM: 10 949), based on the allometric equation, AGB = exp(−1.484 + 2.657 ln[D]), where D is the diameter at 130 cm from the roots expressed in cm and AGB is the predicted above-ground, oven-dried weight of the liana in kg (Schnitzer *et al.* 2006). Schnitzer *et al.* (2006) based this model that relates diameter and biomass on 424 lianas, with many species and a range of diameter size classes from five independent datasets collected from four countries (Brazil, Venezuela, French Guiana, and Cambodia). The benefits of cutting and treating climbing hiptage with herbicides include an increased plant mortality, a reduction in the weight of hiptage in the tree canopy, and the removal of the intercrown connection of lianas and trees, resulting in less damage to the tree and to neighboring trees should a tree fall. A number of researchers also have reported that lianas reduce tree growth, with studies showing a doubling in the mean annual diameter growth of the trees in plots where all the lianas were cut, compared to liana-laden control trees (Perez-Salicrup & Barker 2000; Gerwing 2001; Grauel & Putz 2004). The annual diameter increase of the trees with stem diameters ≥5 cm at breast height in the liana-dominated forests of Paragominas, Para, Brazil, was 1.3 mm $year^{-1}$, compared with 3.0 mm $year^{-1}$ in the plots in which the lianas were cut (Gerwing 2001).

Considering the time that hiptage has had to invade the complex mesophyll rainforest of Mossman (~50–60 years) (Logan P., 2007, personal communication), any continued future spread of hiptage gives cause for concern. Germination and seedling recruitment have been observed after fruit fall in summer following summer rains (Logan P., 2007, personal communication). However, the results from this study, which show the lack of a seed bank below the soil surface, >98% germinability of the viable seed, and a seed longevity of <2 years (based on laboratory-stored fruit), are encouraging. The seed bank appears to be very transient and the seeds do not persist for long in a favorable moist environment. If any external seed input is eliminated, a hiptage infestation can be treated with minimal follow-up control. Finding and controlling hiptage should be considered a priority for local government authorities of both infested and surrounding areas. Although this study provides baseline data on the efficacy and cost of treatments, the operational feasibility of these treatments will largely depend upon local labor costs, the availability of chemicals, and the location in which hiptage has naturalized.

A hiptage control program, involving the cut stump method and utilizing triclopyr/picloram (1000/500 g 100 L^{-1}, respectively) in water by the Douglas Shire Council, Queensland, has been in place for 3 years and, by 2007, ~50% of the known infested areas (25 ha) has been treated (Logan P., 2007, personal communication). The program has operated under the minor use permit, PER7485, which allows environmental weeds to be controlled in non-agricultural areas, bushland, forests, wetlands, and coastal and adjacent areas (APVMA 2004). The cost to control a 1.2 ha stretch of the South Mossman River, involving four Douglas Shire Council staff and six commercial contractors, was $A18 140. The labor and equipment accounted for $A16 000 and the herbicides cost $A2140. The area took 5 days to cut and spray, with ~84 670 plants treated at a cost of 21 cents per plant. Mortality in the treated area averaged 95.5%, with seedling recruitment 12 months after spraying averaging 0.1 seedlings m^{-2}. Anecdotal evidence from the Mossman hiptage eradication control program suggests that the hiptage plants take 3 years from germination to reproductive maturity. Treating the plants prior to flowering (the peak flower production is September to February) would reduce seed production and minimize seed dispersal by wind and water. The short-lived seeds and time required to reach reproductive maturity suggest that hiptage would require one or two follow-up treatments after the initial control to eradicate it from an area.

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