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An evaluation of reduced hack and squirt (RHS) treatment with aminocyclopyrachlor and aminopyralid for invasive tree control in Florida

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Research Article

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Abstract

Reduced hack and squirt (RHS) is a herbicide-injection technique that controls woody species with a limited number of hacks. When used with aminopyralid or aminocyclopyrachlor, the technique controls multistemmed shrubs such as Brazilian peppertree (*Schinus terebinthifolia* Raddi) and Surinam cherry (*Eugenia uniflora* L.). However, additional data are needed to compare its effectiveness on other woody invasive species against standard individual-plant treatment techniques. We compared RHS with aminocyclopyrachlor or aminopyralid administered with 0.5 ml of undiluted concentrate (240 g L^{-1}) against traditional basal bark and cut stump techniques using triclopyr at 96 and 120 g L^{-1}, respectively, on six invasive trees in Florida, USA. For all species tested, the RHS technique with aminocyclopyrachlor was not different or was more effective than basal bark or cut stump treatment with triclopyr. The RHS technique with aminopyralid was effective on certain species but did not control as many species as RHS with aminocyclopyrachlor or cut stump treatment with triclopyr. The RHS technique required significantly less time than cut stump treatment but was not different from basal bark treatment. Across all species, when compared with basal bark and cut stump treatment with triclopyr, the RHS approach resulted in reductions of average total herbicide mix applied by 98% and 89%, respectively. For herbicide active ingredient, when compared with basal bark and cut stump treatment with triclopyr, RHS resulted in reductions of 95% and 86%, respectively. These results indicate that when compared to conventional individual plant treatment (IPT) approaches with triclopyr, the RHS approach yielded a high level of target efficacy on a broad spectrum of species, comparable or shorter application times, and substantial reductions in herbicide mix and active ingredient applied. Future research should seek continued refinement of this technique for woody plant control on other troublesome invaders.

Introduction

Individual-plant treatments (IPTs), including basal bark, cut stump, foliar spot treatments, and hack and squirt, were developed with the advent of herbicide discovery. These techniques are most effective on woody perennials recalcitrant to mechanical methods. Additionally, they serve a vital role in woody invasive plant management in natural areas where conventional broadcast herbicide treatments are often not feasible or advisable. Individual plant treatments are labor-intensive but may also result in highly selective control and protection of surrounding native species, which is a critical component of protecting biological diversity (Randall 1996).

Among IPT approaches, hack and squirt is a common technique that has been used to control woody plants for many decades (Campbell 1985; Campbell and Peevy 1950; Rumbold 1920). The technique was developed as a way of selectively controlling individual trees where other approaches such as basal bark, foliar, or cut stump treatment were not feasible. The general technique is to make downward diagonal cuts around the circumference of the tree trunk and expose the vascular cambium to direct application of the herbicide. This approach circumvents the need for herbicide foliar absorption through a waxy leaf cuticle and long-distance translocation from the upper canopy to the root collar of the tree. For example, aerial applications of glyphosate tank mixed with imazapyr have resulted in limited control of punktree [*Melaleuca quinquenervia* (Cav.) S.F. Blake], while the same herbicides applied as a girdle + spray treatment are highly effective (Laroche et al. 1992). Direct delivery into the phloem near the base of the tree also allows for a highly concentrated dose of herbicide placed in close proximity to the root collar and roots, which is beneficial for controlling prolific resprouting species (Enloe et al. 2023).

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Management Implications

Reduced hack and squirt (RHS) treatment with aminocyclopyrachlor was highly effective on tungoil tree [*Vernicia fordii* (Hemsl.) Airy-Shaw], Chinese tallow [*Triadica sebifera* (L.) Small], Javanese bishopwood (*Bischofia javanica* Blume), beach sheoak (*Casuarina equisetifolia* L.), and punktree [*Melaleuca quinquenervia* (Cav.) S.F. Blake] but not white leadtree [*Leucaena leucocephala* (Lam.) de Wit]. RHS with aminopyralid was comparable in efficacy for all species except *M. quinquenervia*. This is a surgical application method with precision dosing resulting in essentially 100% delivery into the vascular system of the target plant. We found these herbicides were very effective when applied as a 0.5-ml undiluted dose to a single hack to trees in the range of 10- to 17-cm diameter at breast height. The technique did not differ in application time from basal bark treatment with triclopyr and was faster than cut stump treatment with triclopyr. The RHS technique presents an innovative way to achieve effective control of many hard to kill woody species in Florida. Additional testing should be conducted for other troublesome woody species.

Although a wide range of chemicals were tested for hack and squirt in the early 20th century (Campbell and Peavy 1950; Rumbold 1920), the technique has evolved over the last 50 yr to primarily utilize systemic auxin mimic and amino acid inhibitor herbicides, including picloram, triclopyr, imazapyr, and glyphosate (Gresham 2010; Peevy 1972; Sterrett 1969). For these herbicides, hack spacing around the circumference of the tree may range from continuous, overlapping hacks to one hack per 2.5 to 7.5 cm (1 to 3 in.) of stem diameter. The utility of many of these hack and squirt herbicide treatments has been most beneficial in silvicultural weed control, particularly for control of nuisance native hardwoods (Kochenderfer et al. 2001, 2012). In practice, effective control was not predicated on mortality, but rather on canopy removal to increase light penetration and release the tree crop from early competition (Campbell 1985; Campbell and Peevy 1950; Tappeiner and Pabst 1987; Yeiser 1986). In that context, recovery from basal or epicormic sprouts was lessened in its importance, as it occurred beyond the critical period of juvenile desirable tree growth. However, the silvicultural view of successful weed control is generally not appropriate for invasive plant management in natural areas where complete mortality is paramount (Enloe et al. 2018).

Forestry studies previously mentioned identified the need for continuous or relatively narrow hack spacings to achieve successful suppression or control of target species. This increases the time and labor required and also prevents the use of typical hack and squirt approaches on multistemmed individuals, where structural complexity may obstruct the process. However, Leary et al. (2013, 2015) demonstrated that a reduced hack and squirt (RHS) approach with a very limited number of hacks was feasible for several invasive tropical trees when using aminocyclopyrachlor, aminopyralid, and imazapyr. Likewise, Enloe et al. (2023) recently demonstrated successful control of three invasive shrubs in Florida with the RHS approach. In those studies, control was achieved with a 0.5-ml dose of undiluted aminocyclopyrachlor applied to single hacks per stem for all species and aminopyralid for certain species. This was validated in an operational study of Brazilian peppertree (*Schinus terebinthifolia* Raddi) control conducted by Bell et al. (2023). In that work, the researchers found that the RHS approach with aminocyclopyrachlor was similar in application time and provided comparable efficacy to basal bark treatment with triclopyr but used significantly less herbicide.

Land managers in Florida and many other parts of the world are challenged with managing a wide diversity of tropical woody invasive plants using a complex of different techniques and herbicides tailored to each species (Enloe et al. 2022). Given the apparent broad range of efficacy exhibited by aminopyralid and aminocyclopyrachlor, an expansion of species tested with the RHS approach would be useful to many land managers. Therefore, the objectives of this research were to compare the application parameters and efficacy of RHS treatment with aminopyralid and aminocyclopyrachlor to basal bark and cut stump treatment with triclopyr or a girdle + spray treatment with glyphosate and imazapyr on six woody invasive species.

Materials and Methods

Target Species

Two deciduous species selected for study were members of the Euphorbiaceae family and included Chinese tallow [*Triadica sebifera* (L.) Small] and tungoil tree [*Vernicia fordii* (Hemsl.) Airy-Shaw]. Four evergreen species included members of the Myrtaceae (*M. quinquenervia*), Casuarinaceae (beach sheoak [*Casuarina equisetifolia* L.]), Fabaceae (white leadtree [*Leucaena leucocephala* (Lam.) de Wit]) and Phyllanthaceae (Javanese bishopwood [*Bischofia javanica* Blume]). All six species were purposefully introduced into the United States for a variety of reasons, including oilseed production (Bruce et al. 1997; Minogue 2019; Rinehart et al. 2015; Snow 2013), agroforestry (Sharma et al. 2022), horticulture (Morton 1984), windbreaks and soil stabilization (Morton 1980), and other uses (Campbell et al. 2019). All have become invasive in Florida and are now classified as Category I or II species by the Florida Invasive Species Council and have suspected or documented negative ecosystem impacts (FISC 2023; Lemmens et al. 1995; Morton 1984; Vogt et al. 2021). Complete descriptions and ecological summaries for all species are available online UF/IFAS Center for Aquatic and Invasive Plants website (https://plants.ifas.ufl.edu).

Experimental Approach

The *V. fordii* and *T. sebifera* sites were located in north Florida, while all other sites were located in south Florida. In north Florida, the *V. fordii* site was located in San Felasco Hammock Preserve State Park (29.760027°N, 82.452925°W) in an upland hardwood forest. The overstory was a mix of *V. fordii*, pignut hickory [*Carya glabra* (Mill.) Sweet], southern magnolia (*Magnolia grandiflora* L.), and Florida maple [*Acer floridanum* (Chapm.) Pax]. Understory species included redbud (*Cercis canadensis* L.), beautyberry (*Callicarpa americana* L.), and flowering dogwood (*Cornus florida* L.). Soils were composed of Millhopper sand (loamy, siliceous, semiactive, hyperthermic Grossarenic Paleudults) and Lochloosa fine sand (Loamy, siliceous, semiactive, hyperthermic Aquic Arenic Paleudults). Most experimental units were single stemmed and averaged 1.2 ± 0.1 stems with a total stem diameter of 13.3 ± 1.5 cm (Table 1). The *T. sebifera* sites were located on privately held land near Lake Butler, FL (30.034180°N, 82.362974°W) on the margins of a heavily modified wet pasture. The overstory was a near monotypic stand of *T. sebifera* with a few bald cypress [*Taxodium distichum* (L.) Rich.] scattered

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Table 1. Experimental unit (rootstock) and application parameters (mean ± standard error) for *Vernicia fordii*, *Bischofia javanica*, and *Triadica sebifera*.

Treatment by species[a]	Stem count	Total DBH[b]	Time to treat	Total mix applied[c]	Herbicide applied[d]
Vernicia fordii	*n*	cm	s	ml	g ae
Aminocyclopyrachlor (RHS)	1.2 (0.1)	13.2 (1.6)	5.8 (0.3)	0.6 (0.04)	0.14 (0.01)
Aminopyralid (RHS)	1.1 (0.1)	13.6(1.7)	5.4 (0.4)	0.5 (0.03)	0.12 (0.01)
Triclopyr ester (basal bark)	1.3 (0.1)	13.1 (1.1)	8.7 (0.6)	37.3 (3.2)	3.6 (0.29)
Triclopyr amine (cut stump)	1.3 (0.2)	13.9 (1.9)	59 (10.3)	7.3 (1.3)	1.3 (0.22)
Nontreated	1.2 (0.1)	12.8 (1.3)	—	—	—
Bischofia javanica					
Aminocyclopyrachlor (RHS)	1.8 (0.3)	17.2 (3.8)	8.4 (2.0)	0.9 (0.2)	0.22 (0.05)
Aminopyralid (RHS)	1.4 (0.2)	14.6 (2.3)	7.5 (1.3)	0.7 (0.1)	0.17 (0.02)
Triclopyr ester (basal bark)	1.3 (0.2)	12.8 (1.6)	9.1 (1.4)	22.5 (2.6)	2.2 (0.24)
Triclopyr amine (cut stump)	1.6 (0.3)	15.0 (2.7)	55.3 (10.1)	7.3 (1.3)	1.3 (0.25)
Nontreated	1.7 (0.2)	15.2 (2.3)	—	—	—
Triadica sebifera					
Aminocyclopyrachlor (RHS)	2.0 (0.4)	13.2 (1.9)	11.6 (3.1)	1.0 (0.2)	0.24 (0.01)
Aminopyralid (RHS)	1.8 (0.3)	12.4 (1.6)	12.9 (2.6)	0.9 (0.1)	0.22 (0.02)
Triclopyr ester (basal bark)	1.6 (0.2)	12.0 (1.4)	13.6 (1.1)	23.1 (3.2)	2.21 (0.29)
Triclopyr amine (cut stump)	1.9 (0.3)	14.4 (2.3)	62.1 (14.5)	5.7 (0.8)	1.04 (0.14)
Nontreated	1.5 (0.2)	12.0 (1.6)	—	—	—

[a]RHS, reduced hack and squirt.
[b]Total DBH is the sum of stems for each rootstock. DBH, diameter at breast height.
[c]Total mix is the herbicide and carrier applied per individual. For each species, the total mix and herbicide for the basal bark treatment is a composite of all 10 experimental units.
[d]Herbicide is the actual herbicide applied per individual.

throughout. Soils were a sandy loam (Arents moderately wet, which is characterized as unclassified due to a lack of evident soil layers due to mixing during disturbance). Many rootstocks were multistemmed and averaged 1.8 ± 0.3 stems with a total stem diameter of 12.8 ± 1.8 cm (Table 1). Over the entire study period, average annual precipitation at the north Florida sites was approximately 1,402 mm, which was 114% of the 30-yr normal (1,227 mm) (Florida Climate Center 2024).

In south Florida, the first *B. javanica* site was located near Coral Springs, FL (26.229040°N, 80.297237°W) in a forest stand located along the L-36 canal. The stand was dominated by *B. javanica* with *S. terebinthifolia* and coco plum (*Chrysobalanus icaco* L.) in the understory. Soils were a Hallandale fine sand (siliceous, isohyperthermic Lithic Psammaquents). The second *B. javanica* site was located on a South Florida Water Management District Property near Opa-Locka, FL (25.957333°N, 80.419300°W). The site was a seasonal wetland on a Dania muck soil (euic, hyperthermic, shallow Lithic Haplosaprists) with a dense overstory of the target species and an understory of shoebutton ardisia (*Ardisia elliptica* Thunb.) and *S. terebinthifolia*. Many rootstocks were multistemmed and averaged 1.6 ± 0.2 stems with a total stem diameter of 15.0 ± 2.5 cm (Table 1).

The *L. leucocephala* (26.228130°N, 80.297328°W), *C. equisetifolia* (26.206519°N, 80.297508°W), and *M. quinquenervia* sites were also located along the L-36 canal (26.190667°N, 80.296626°W), in the forest stand, 0.1 to 4.4 km south of the first *Bischofia* site. The *L. leucocephala* site overstory was a mix of the target species and Java plum [*Syzygium cumini* (L.) Skeels] and earleaf acacia [*Acacia auriculiformis* (A. Cunn. ex Benth.)], with *C. icaco* in the understory. Many rootstocks were multistemmed and averaged 1.9 ± 0.1 stems with a total stem diameter of 12.6 ± 1.6 cm (Table 2). The *C. equisetifolia* and *M. quinquenervia* sites were near monotypic stands with few other woody species present. Soils were a Hallandale fine sand for all three of these sites. All*C. equisetifolia* rootstocks were single stemmed and averaged 11.2 ± 1.3 cm in diameter. Almost all *M. quinquenervia* rootstocks were single stemmed and averaged 1.1 ± 0.1 stems and 15.1 ± 1.6 cm in diameter (Table 2). Over the entire study period, average annual precipitation at the south Florida sites was approximately 1,527 mm, which was 114% of the 30-yr normal (1,747 mm) (Florida Climate Center 2024).

Experiments were conducted independently for each species and repeated. For *V. fordii* and *T. sebifera*, treatments were applied in the first experimental run in early November 2015 and the second experimental run in late November of the same year. At these application dates, both species were nearing leaf drop but still retained many green and yellowing leaves. For *B. javanica*, *C. equisetifolia*, *L. leucocephala*, and *M. quinquenervia*, treatments were applied in the first experimental run in early December 2015 and repeated in January 2016. As evergreens in south Florida, all species retained their leaves throughout the fall and winter and remained photosynthetically active.

For each species, individual trees, spaced at least 3 m apart, were considered experimental units (hereafter referred to as rootstocks) with 10 replicates per treatment. Treatments were arranged in a randomized complete block design and blocked by stem diameter. Pretreatment stem size and stem number per rootstock are given for each species in Tables 1 and 2. For useful comparisons, rootstocks for all six species were in the range of stem sizes where basal bark, cut stump, or the girdle spray treatment specific to *M. quinquenervia* could be effectively used (Miller et al. 2015).

The treatments used for all species consisted of two RHS treatments, one cut stump treatment, one basal bark treatment, and a nontreated control. Due to the thick, spongy periderm on *M. quinquenervia*, a girdle + spray treatment replaced the basal bark treatment. All treatment techniques are presented in Figure 1. The RHS treatments evaluated undiluted formulations (240 g L^{-1}) of aminocyclopyrachlor (Method® 240SL, Bayer Crop Science Whippany, NJ, USA) and aminopyralid (Milestone®, Corteva, Indianapolis, IN, USA). We did not include triclopyr as a hack and squirt treatment due to its ineffectiveness in the previous work by Leary et al. (2015). Using a machete, a single incision was made at a 45° downward angle to each stem of the rootstock to expose the

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Table 2. Experimental unit (rootstock) and application parameters (mean ± standard error) for *Casuarina equisetifolia*, *Leucaena leucocephala*, and *Melaleuca quinquenervia*.

Treatment by species[a]	Stem count	Total DBH[b]	Time to treat	Total mix applied[c]	Herbicide applied[d]
Casuarina equisetifolia	*n*	cm	s	ml	g ae
Aminocyclopyrachlor (RHS)	1.0	11.2 (1.3)	5.0 (0.2)	0.5 (0)	0.12 (0)
Aminopyralid (RHS)	1.0	12.0 (1.4)	4.7 (0.5)	0.5 (0)	0.12 (0)
Triclopyr ester (basal bark)	1.0	11.2 (1.0)	9.4 (0.6)	34.9 (3.2)	3.36 (0.03)
Triclopyr amine (cut stump)	1.0	11.0 (1.3)	44.5 (8.4)	5.6 (0.8)	1.01 (0.14)
Nontreated	1.0	10.8 (1.3)	—	—	—
Leucaena leucocephala					
Aminocyclopyrachlor (RHS)	1.1 (0.1)	13.0 (1.4)	5.3 (0.5)	0.5 (0.03)	0.12 (0.01)
Aminopyralid (RHS)	1.1 (0.1)	13.7 (1.8)	4.6 (0.4)	0.6 (0.03)	0.14 (0.01)
Triclopyr ester (basal bark)	1.2 (0.1)	12.6 (1.7)	9.6 (0.8)	47.3 (6.4)	4.56 (0.62)
Triclopyr amine (cut stump)	1.3 (0.2)	10.4 (1.4)	38.8 (6.2)	4.7 (0.7)	1.1 (0.14)
Nontreated	1.1 (0.1)	13.4 (1.7)	—	—	—
Melaleuca quinquenervia					
Aminocyclopyrachlor (RHS)	1.1 (0.1)	14.4 (1.4)	8.6 (1.3)	0.6 (0.05)	0.14 (0.01)
Aminopyralid (RHS)	1.0 (0)	14.7 (1.4)	7.2 (0.6)	0.5 (0)	0.12 (0)
Glyphosate + imazapyr (G+S)	1.2 (0.1)	15.9 (1.2)	71.3 (6.1)	39.4 (3.1)	7.65 (0.66)
Triclopyr amine (cut stump)	1.2 (0.1)	15.4 (1.9)	44.0 (6.2)	6.1 (0.8)	3.1 (0.4)
Nontreated	1.1 (0.1)	15.4 (1.9)	—	—	—

[a]RHS, reduced hack and squirt; G+S, girdle + spray.
[b]Total DBH is the sum of stems for each rootstock. DBH, diameter at breast height.
[c]For each species, the total mix for the basal bark treatment is a composite mean of all 10 experimental units. Total mix is the herbicide and carrier applied per individual.
[d]Herbicide is the actual herbicide applied per individual.



Figure 1. Treatment techniques tested in the current study. Top left: girdle spray treatment applied to *Melaleuca quinquenervia* only; top right: reduced hack and squirt (RHS) applied to all species; bottom left: cut stump treatment applied to all species; bottom right: basal bark treatment applied to all species except *M. quinquenervia*.

cambium layer. Each cut was slightly pried open to create a well for retaining a 0.5-ml treatment dose (120 mg) administered using an adjustable veterinary syringe drawing from a 2.5-L backpack reservoir (Simcro, Hamilton, New Zealand), similar to protocols described by Enloe et al. (2023) and Leary et al. (2013). For each rootstock, treatments were administered to all stems greater than 2.5 cm in diameter, with cuts made at 90 cm above ground level.

Basal bark treatments consisted of triclopyr butoxyethyl ester (Garlon® 4 Ultra, Corteva) mixed at 20% (v/v) with Bark oil blue (UAP Distribution, Greeley, CO, USA) oil carrier for a triclopyr concentration of 96 g L^{-1}. The basal bark treatment was applied around the entire base of the rootstock (i.e., including all stems up to 30 cm above ground level. A 1.75-L hand pump sprayer with a single adjustable cone nozzle (Viagrow®, Chesterfield, MO, USA)

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was calibrated to dispense 3.3 ml s^{-1}. Total application amounts varied by rootstock size.

For the girdle + spray treatment specific to *M. quinquenervia*, a 15-cm band of the entire periderm was removed with a machete around the circumference of each stem at 90 cm above ground level. Immediately following bark removal, the exposed shallow sapwood was sprayed to wet with a tank mix of glyphosate at 192 g L^{-1} with Roundup® Custom at 40% (v/v) (Bayer Crop Science, St Louis, MO, USA) and imazapyr at 24 g L^{-1} with Habitat® at 10% (v/v) (BASF, Research Triangle Park, NC, USA) diluted in water. We used a handheld spray bottle (HDX, Home Depot, Atlanta, GA, USA) to treat each girdle. The spray header was estimated to deliver 1.2 ml $stroke^{-1}$, and the number of strokes applied to each rootstock was recorded.

For the cut stump treatments, all trees were cut at a stump height of approximately 10 cm above the soil surface with a chainsaw (model MS 193 T, Stihl, Virginia Beach, VA, USA). Sawdust was removed from the stump top before treatment. Triclopyr amine was applied at 180 g L^{-1} with Garlon® 3A at 50% (v/v) in water (Corteva) to a 5-cm band around the circumference of the stump top to fully cover the inner bark (phloem), cambium, and new sapwood. Treatments were applied with the same spray bottle described for cut stump treatment, and the number of strokes applied to each stump was recorded.

Baseline data collection for each rootstock included a count of all stems greater than 2.5 cm, stem diameters at 90 cm, and treatment time per tree. Treatment times were recorded for each rootstock, which included the entire mechanical process of making the cut followed by the herbicide dose delivery. The total herbicide dose was also measured for each rootstock based on the calibrated outputs for the RHS and cut stump treatments. Basal bark treatments were estimated by the total herbicide dose used to treat all rootstocks divided by the total diameter, with the assumption that applications were consistently applied per unit of stem area.

Evaluations were made by visual estimation of percent canopy defoliation, where 0 = no defoliation and 100 equals complete defoliation. While almost all evaluations were conducted by the same individual, a calibration was conducted for an additional evaluator by dividing the canopy into four quadrants and estimating each quadrant independently before averaging for a single value. This greatly assisted with irregularly shaped canopies, which was very common among the species tested. Evaluations were conducted at 90, 180, 360, 540, and 720 d after treatment (DAT). The presence of epicormic stump sprouts was also recorded, as were lateral root sprouts within a 30-cm radius of each rootstock at the final sampling date. Mortality was determined for each rootstock based on the criteria of 100% defoliation and no live sprouts.

Statistical Analysis

For each species, experimental run was incorporated as a random effect for ANOVA and analysis of covariance (ANCOVA). Due to nonnormality, the arcsine square-root transformation was used for the analysis of percent defoliation data at 90, 180, 360, 540, and 720 DAT. The ANOVA for percent mortality of rootstocks within a treatment, percent of rootstocks with root sprouts, and percent of rootstocks with epicormic sprouting at final evaluation were performed as a generalized linear model with rootstock category (yes, no) considered a binomial random variable with a logit link function. Treatments with 0% or 100% rootstock mortality or sprouting were excluded from the statistical analysis due to a lack of variance and either complete success or failure. ANCOVA was used to relate treatment time to stem count (or natural log of stem count) and total diameter (summed of stem diameters in a rootstock) as covariates for hack and squirt, basal spray, girdle, and cut stump treatments. Nonsignificant covariates were excluded from final models. ANCOVA utilized a generalized linear model approach with the gamma distribution and log link function (Schabenberger and Pierce 2002) to resolve heterogeneity of residuals (variation increased with stem count or total diameter). Analysis was performed using the PROC GLIMMIX (Littell et al. 2006) package of SAS® v. 9.4 software (SAS Institute, Cary, NC, USA). Treatment means were compared using Tukey's adjustment for multiplicity as appropriate.

Results and Discussion

Herbicide Use

Across all six species, RHS with either aminocyclopyrachlor or aminopyralid used approximately 98% and 89% less total herbicide mix than basal bark and cut stump treatments with triclopyr, respectively (Tables 1 and 2). Likewise, for *M. quinquenervia*, RHS used 99% less herbicide mix than the conventional *M. quinquenervia* girdle + spray treatment with glyphosate + imazapyr. These reductions present a considerable decrease in herbicide mix required to be transported to the site and carried by applicators into the treatment area. This would be highly advantageous in areas that are difficult to access such as remote locations with steep slopes or uneven terrain, dense thickets of woody vegetation, or seasonally dry wetlands. Furthermore, these reductions in total herbicide mix reduce the need for backpack sprayers as a 1,000-ml handheld squirt bottle delivering 0.5 ml $stroke^{-1}$ would be capable of treating up to 2,000 stems comparable in size to those tested herein. This exceeds the stem number most applicators could treat in a day, as Kochenderfer et al. (2001) found applicators could treat a total of 70 stems h^{-1} (each ~12.7-cm diameter at breast height [DBH]) using conventional hack and squirt.

In addition to total herbicide mix, RHS with either herbicide used 95% and 86% less herbicide than basal bark or cut stump treatment with triclopyr, respectively. For *M. quinquenervia*, RHS used 98% less herbicide than the conventional girdle spray treatment. These results indicate the use of the RHS technique may result in substantial herbicide use reductions, which is highly desirable to many land managers.

Treatment Efficacy

At 180 DAT, both RHS treatments with aminocyclopyrachlor and aminopyralid resulted in almost complete defoliation (>98%) of *V. fordii* that was maintained through 720 DAT (Table 3). The basal bark treatment with triclopyr was much slower to work with significantly less defoliation than both RHS treatments at 180 and 360 DAT. At 720 DAT, defoliation was significantly less than RHS with aminocyclopyrachlor. At 720 DAT, all herbicide treatments completely prevented lateral and epicormic sprouts and resulted in 97% or greater mortality (Table 4). Miller et al. (2015) specified that triclopyr is effective against *V. fordii* when applied as a basal bark or cut stump application. Our data are in agreement with those control recommendations and further establishes RHS with aminocyclopyrachlor or aminopyralid as an effective, alternative management option.

Bischofia javanica responded to the RHS treatments in a manner comparable to *V. fordii*. Both the aminopyralid and

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Table 3. Percent defoliation response to reduced hack and squirt and basal bark treatments.

Treatment by species[a]	Defoliation[b] 180 DAT	360 DAT	540 DAT	720 DAT
Vernicia fordii	%			
Aminocyclopyrachlor (RHS)	98 a	100 a	100 a	100 a
Aminopyralid (RHS)	97 a	96 a	96 a	98 ab
Triclopyr ester (basal bark)	23 b	57 b	80 a	87 b
Nontreated	2 b	c	0 b	0 c
Bischofia javanica				
Aminocyclopyrachlor (RHS)	98 a	98 a	97 a	100 a
Aminopyralid (RHS)	96 ab	87 ab	89 a	89 ab
Triclopyr ester (basal bark)	69 b	65 b	63 a	61 b
Nontreated	0 c	0 c	0 b	0 c
Triadica sebifera				
Aminocyclopyrachlor (RHS)	100 a	100 a	98 a	97 a
Aminopyralid (RHS)	98 a	97 a	94 a	92 a
Triclopyr ester (basal bark)	92 a	100 a	97 a	95 a
Nontreated	5 b	3 b	1 b	5 b

[a]RHS, reduced hack and squirt.
[b]Means within columns followed by the same letter are not significantly different (P = 0.05). DAT, days after treatment.

Table 4. Treatment response for % lateral root and epicormic sprouting and % mortality at 720 days after treatment[a].

Treatment by species[b]	Lateral root sprouting	Epicormic sprouting	Mortality
Vernicia fordii	%		
Aminocyclopyrachlor (RHS)	0	0 a	100 a
Aminopyralid (RHS)	0	0 a	98 a
Triclopyr ester (basal bark)	0	0 a	97 a
Triclopyr amine (cut stump)	0	0 a	100 a
Nontreated	0	5 a	0 b
Bischofia javanica			
Aminocyclopyrachlor (RHS)	0	0	95 a
Aminopyralid (RHS)	0	15 a	75 ab
Triclopyr ester (basal bark)	0	0	50 b
Triclopyr amine (cut stump)	0	10 a	85 ab
Nontreated	0	11 a	0
Triadica sebifera			
Aminocyclopyrachlor (RHS)	6 a	6 a	94 a
Aminopyralid (RHS)	6 a	18 a	76 a
Triclopyr ester (basal bark)	6 a	0	88 a
Triclopyr amine (cut stump)	27 a	0	73 a
Nontreated	11 a	22 a	0

[a]Treatments with zero observations in a category in both runs were excluded from the analysis. Means within columns followed by the same letter are not significantly different (P = 0.05).
[b]RHS, reduced hack and squirt.

aminocyclopyrachlor RHS treatments resulted in 87% to 100% defoliation and were not different at any sample date (Table 3). Triclopyr ester applied as a basal bark treatment resulted in a maximum of 69% defoliation and was not as effective as the aminocyclopyrachlor RHS treatment at any sample date. This was consistent for mortality at 720 DAT (Table 4). Cut stump treatment with triclopyr amine resulted in 10% resprouting from stump sprouts and 85% mortality at 720 DAT, which was not different from any other herbicide treatment.

Bischofia javanica is a prolific resprouter following cutting. Tanaka et al. (2010) reported little success in controlling it with cutting or girdling, and resprouting was apparent even 6 yr after the initial control effort. Both cut stump and basal bark treatments with triclopyr are recommended for *B. javanica* control (Enloe et al. 2018). However, it was clear from this study that these techniques were not as effective as RHS with aminocyclopyrachlor. Additionally, other injection approaches have been effective on this species. Itou et al. (2014) found glyphosate controlled *B. javanica* when applied with a very labor-intensive drill, fill, and plug application. However, drill and fill–type approaches have rarely been evaluated in the United States. This is the first known study demonstrating the effectiveness of the auxin-type herbicides for injection IPT approaches for this species.

Triadica sebifera was effectively controlled with all herbicide treatments and techniques. Percent defoliation was 92% or greater for all treatments across all application timings, and there were no differences between any herbicide treatments at any sample date (Table 3). At 720 DAT, all herbicide treatments resulted in some lateral root sprouting, with mortality ranging from 73% to 94% and not significantly different among treatments (Table 4). Enloe et al. (2015) found cut stump and basal bark applications with triclopyr actually stimulated lateral root sprouting compared with the nontreated control. Gresham (2010) found hack and squirt applications were effective on *T. sebifera*, with imazapyr resulting in greater defoliation than triclopyr. However, we did not test either with our RHS approach. In general, the RHS approach provided comparable long-term control to both cut stump and hack and squirt treatment with triclopyr.

Casuarina equisetifolia defoliation was 97% or greater for the aminocyclopyrachlor RHS treatment at all sample dates. The aminopyralid RHS treatment resulted in 76% to 89% defoliation, and the triclopyr ester basal bark treatment ranged from 61% to 72% defoliation (Table 5). Neither was statistically different from the aminocyclopyrachlor treatment at almost all sample dates. However, the aminocyclopyrachlor treatment was the only treatment different from the nontreated control at 720 DAT. There was considerable variation in the performance of both the aminopyralid RHS and triclopyr ester basal bark treatments, which may have muddied a clear difference among the treatments. No *C. equisetifolia* in either experimental run exhibited any lateral root sprouting following treatment (Table 6). However, triclopyr amine cut stump was the only treatment with lower epicormic sprouting than the nontreated controls. Mortality was higher in the triclopyr amine cut stump treatment than in the aminopyralid RHS treatment and the nontreated control. There are few published studies evaluating herbicidal control of *C. equisetifolia*. Hata et al. (2015) found glyphosate applied with the drill and fill technique, which is similar in principle to hack and squirt, effectively controlled the species. In Florida, the standard operational practice is a cut stump treatment with triclopyr or a chainsaw girdle followed by a triclopyr application to the entire circumference of the girdle (Enloe et al. 2018). However, this is a labor-intensive

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Table 5. Percent defoliation response to reduced hack and squirt (RHS) and basal bark treatments.

Treatment by species[a]	Defoliation[b] 180 DAT	360 DAT	540 DAT	720 DAT
Casuarina equisetifolia	— % —			
Aminocyclopyrachlor (RHS)	98 a	100 a	97 a	97 a
Aminopyralid (RHS)	89 ab	76 ab	81 a	77 ab
Triclopyr ester (basal bark)	69 ab	61 bc	72 a	62 ab
Nontreated	31 b	21 c	16 b	18 b
Leucaena leucocephala				
Aminocyclopyrachlor (RHS)	89 a	72 a	81 a	—
Aminopyralid (RHS)	90 a	82 a	77 a	—
Triclopyr ester (basal bark)	69 a	72 a	65 a	—
Nontreated	31 b	0 b	1 b	—
Melaleuca quinquenervia				
Aminocyclopyrachlor (RHS)	98 a	95 a	96 a	89 a
Aminopyralid (RHS)	53 b	43 b	45 b	15 b
Glyphosate + imazapyr (G+S)	100 a	100 a	100 a	100 a
Nontreated	0 c	0 c	1 c	2 b

[a]RHS, reduced hack and squirt; G+S, girdle + spray.
[b]Means within columns followed by the same letter are not significantly different (P = 0.05). DAT, days after treatment.

Table 6. Treatment response for lateral root and epicormic sprouting and % mortality at 720 days after treatment[a].

Treatment by species[b]	Lateral root sprouting	Epicormic sprouting	Mortality
Casuarina equisetifolia		— % —	
Aminocyclopyrachlor (RHS)	0	20 ab	80 ab
Aminopyralid (RHS)	0	35 ab	40 bc
Triclopyr ester (basal bark)	0	15 ab	60 ab
Triclopyr amine (cut stump)	0	5 b	95 a
Nontreated	0	55 a	10 c
Leucaena leucocephala			
Aminocyclopyrachlor (RHS)	0	15 a	60 ab
Aminopyralid (RHS)	0	10 a	45 b
Triclopyr ester (basal bark)	0	0	55 ab
Triclopyr amine (cut stump)	0	15 a	95 a
Nontreated	0	0 a	0
Melaleuca quinquenervia			
Aminocyclopyrachlor (RHS)	0	0	88 a
Aminopyralid (RHS)	0	0	13 b
Glyphosate + imazapyr (G+S)	0	0	100
Triclopyr amine (cut stump)	0	0	100
Nontreated	0	0	0

[a]Treatments with zero observations in a category in both runs were excluded from the analysis. Means within columns followed by the same letter are not significantly different (P = 0.05).
[b]RHS, reduced hack and squirt; G+S, girdle + spray.

practice, and our results indicate RHS with aminocyclopyrachlor would provide an effective alternative.

For *L. leucocephala*, all herbicide treatments resulted in greater defoliation than the nontreated control at all sample dates. By 540 DAT, treatments ranged from 65% to 81% defoliation, but considerable new canopy growth was observed (Table 5). Additionally, vigorous epicormic sprouting was observed on both RHS treatments and the cut stump treatment. Mortality was 45% to 60% for the RHS and basal bark treatments, respectively, and these were less than mortality for the cut stump treatment (Table 6). *Leucaena leucocephala* has proven very difficult to control with standard basal bark treatment and often requires the use of cut stump treatment for effective control. In these studies, RHS was not effective with single hacks per stem for either aminocyclopyrachlor or aminopyralid. In several instances, localized loss of outer and inner bark and cambium tissue from around the hack was observed (SFE, personal observation). One possible explanation for low efficacy could be reduced translocation of the herbicide due to necrosis in these localized tissues collapsing the vascular system. Reduced translocation has been identified across multiple herbicides with different modes of action, including 2,4-D in Sumatran fleabane [*Conyza sumatrensis* (Retz.) E. Walker] (Queiroz et al. 2020) and glyphosate in giant ragweed (*Ambrosia trifida* L.) (Moretti et al. 2017).

For *M. quinquenervia*, RHS treatment with aminocyclopyrachlor resulted in almost complete defoliation by 180 DAT (Table 5). This was maintained through 720 DAT and resulted in 88% mortality (Table 6). Aminopyralid was not effective as an RHS treatment, resulting in a maximum of 53% defoliation at 180 DAT and 13% mortality at 720 DAT. The girdle + spray treatment of glyphosate + imazapyr resulted in 100% defoliation at all sample dates and 100% mortality at 720 DAT. Similarly, cut stump treatment with triclopyr resulted in no rootstocks with new sprouts and 100% mortality at 720 DAT. Although extremely time- and labor-intensive per treated individual, the girdle + spray treatment is the current standard for control (Enloe et al. 2018). The efficacy of the RHS aminocyclopyrachlor treatment in these studies could make this a promising alternative. However, from an application perspective, creating a single hack to deliver the herbicide was very challenging. *Melaleuca quinquenervia* outer bark can be several centimeters thick and may comprise 15% to 20% of a stem's total volume (Chiang and Wang 1984). In this study, the hack would quickly close, and we were not sure that all of the dose was absorbed into the cambium. Future work should examine a different reduced hack approach for this thick-barked species.

Time to Treat

The ANCOVA of treatment time indicated that there were significant interactions between treatments and stem count and/or total diameter covariates for all species. Across all species, for hack and squirt, application time was driven by the number of stems per rootstock (Table 7). Only for *M. quinquenervia* did total stem diameter influence application time. These results are logical, as increasing the number of stems would increase application, while stem diameter should generally not be important when a single hack per stem is made. The explanation for *M. quinquenervia*, where stem diameter did influence application time for hack and squirt, is likely because of the much thicker bark on the larger individuals. It was difficult to get clean singular cuts through the

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Table 7. Parameters for equations that estimate treatment time per rootstock by species[a].

Species	Treatment[b]	a_0	Pr > |t|	a_1	Pr > |t|	a_2	Pr > |t|
Vernicia fordii	RHS	1.0986	0.003	0.5503	<0.001	—	0.780
	Basal bark	1.7419	<0.001	—	0.113	0.0307	0.015
	Cut stump	3.1142	<0.012	−0.253	0.0124	0.0812	<0.001
Bischofia javanica	RHS	1.1568	0.003	0.4699	<0.001	—	0.617
	Basal bark	1.3341	0.008	—	0.655	0.0591	<0.001
	Cut stump	3.0761	<0.001	—	0.249	0.0509	<0.001
Triadica sebifera	RHS	1.1668	<0.001	0.5859	<0.001	—	0.657
	Basal bark	1.9492	<0.001	0.2011	0.005	0.0239	0.021
	Cut stump	2.7979	<0.001	−0.195	0.014	0.0927	<0.001
Casuarina equisetifolia[c]	RHS	1.5488	0.001	—	—	—	0.434
	Basal bark	1.8398	0.004	—	—	0.0350	0.016
	Cut stump	2.2524	0.002	—	—	0.1092	<0.001
Leucaena leucocephala	RHS	1.1381	0.007	0.3680	0.008	—	0.433
	Basal bark	1.5573	0.003	0.2960	0.019	0.0247	0.002
	Cut stump	2.5095	<0.001	−0.250	0.010	0.1225	<0.001
Melaleuca quinquenervia	RHS	1.1405	0.004	0.5261	<0.001	0.02049	0.007
	G+S	3.4369	<0.001	—	0.053	0.0496	<0.001
	Cut stump	2.8672	<0.001	−0.528	<0.001	0.0912	<0.001

[a]The equation is treatment time (s) = $\exp(a_0 + a_1\text{stem count} + a_2\text{total diameter})$. The equation uses stem count per rootstock and total diameter (cm) per rootstock. Stem count or total DBH terms were removed when not significantly different from zero (Pr > |*t*|). DBH, diameter at breast height.
[b]RHS, reduced hack and squirt; G+S, girdle + spray.
[c]The *C. equisetifolia* rootstocks were all single stem; therefore, stem count was not included in model.

outer bark of the larger trees, and the cut would rapidly close up following removal of the machete.

Across the five species where basal bark was applied, application time was driven by the total stem diameter per rootstock (Table 7). Results were inconsistent between species for the influence of stem number on application time, with no effect for *V. fordii* and *B. javanica*, and a significant effect for *T. sebifera* and *L. leucocephala*. This inconsistency is not easily explained but was likely influenced by the ability to treat multiple stems at the same time for those species where it was not significant. Stem architecture may vary widely for multistemmed woody species depending on the branching height and angle (McPherson et al. 2016), which would likely influence the ability of an applicator to basally treat multiple stems at once.

Across four of the five species tested with multiple stems per individual, application time was driven by total stem number and total stem diameter per rootstock (Table 7). The only exception was *B. javanica*, for which total stem number did not influence application time. This would indicate the chainsaw operator was able to cut multiple stems simultaneously due to a branching pattern just above the 10-cm cutting height. This was similar to results for *S. terebinthifolia* and crapemyrtle (*Lagerstroemia indica* L.) from similar recently published studies (Enloe et al. 2023).

Average predicted treatment time ± standard error of the mean, lower quartile, and upper quartile of total rootstock diameter and stems per rootstock are compared by treatment and species in Figures 2 and 3. The consistent pattern across species indicated that cut stump treatment required much more time per rootstock than hack and squirt or basal bark treatments, and this was exacerbated by increasing stem number per rootstock. Additionally, for *M. quinquenervia*, the girdle + spray treatment required more time than the cut stump treatment (Figure 3).

Finally, for each species, we specifically compared the estimated treatment time between hack and squirt and basal bark treatments in terms of stems per rootstock using average total diameter for stems per rootstock in the prediction equations. Across all species, treatment times were not different between hack and squirt and basal bark treatments for rootstocks with fewer than four stems per rootstock (data not shown). For almost all of these species except *T. sebifera*, there were few rootstocks with more than three stems. For *T. sebifera*, there were also no differences when there were four or five stems per rootstock (data not shown). These results are consistent findings from similar studies on the shrubs *S. terebinthifolia*, Surinam cherry (*Eugenia uniflora* L.), and *L. indica* that indicated no difference in treatment time between the two techniques when there were fewer than four stems per rootstock (Enloe et al. 2023). Overall, the time-saving benefits are clear for RHS and basal bark treatments over cut stump and girdle + spray treatments, as there is much greater effort involved for the latter two. However, the generally similar times required between RHS and basal bark treatment across species does carry some trade-offs. For example, RHS requires the use of a sharp cutting tool, which may pose some hazard to the applicator, especially as fatigue increases throughout the day. In contrast, basal bark treatment does not carry that hazard but does incur the burden of the backpack sprayer weight and increased difficulty in navigating through dense vegetation and uneven terrain. Future operational studies to directly assess energy expenditures and applicator stress and fatigue between the two techniques would be valuable for improving crew performance and safety.

The results from these studies indicate that the RHS approach with aminocyclopyrachlor effectively controlled five out of the six species tested, with *L. leucocephala* being the only species not controlled. For aminopyralid, the RHS approach was somewhat less effective, as *C. equisetifolia*, *L. leucocephala*, and *M. quinquenervia* were not effectively controlled. For all species controlled, the RHS approach with either herbicide used less herbicide and total herbicide mix but was generally similar in application time to basal bark treatment. These results are in general agreement with Enloe et al. (2023), who found RHS with aminocyclopyrachlor controlled three invasive shrubs (*S. terebinthifolia*, *E. uniflora*, and *L. indica*), while RHS with aminopyralid was only effective on *S. terebinthifolia* and *L. indica*. The current study provides the second example of a lack of effective control of species in the Myrtaceae family with aminopyralid injection. Some

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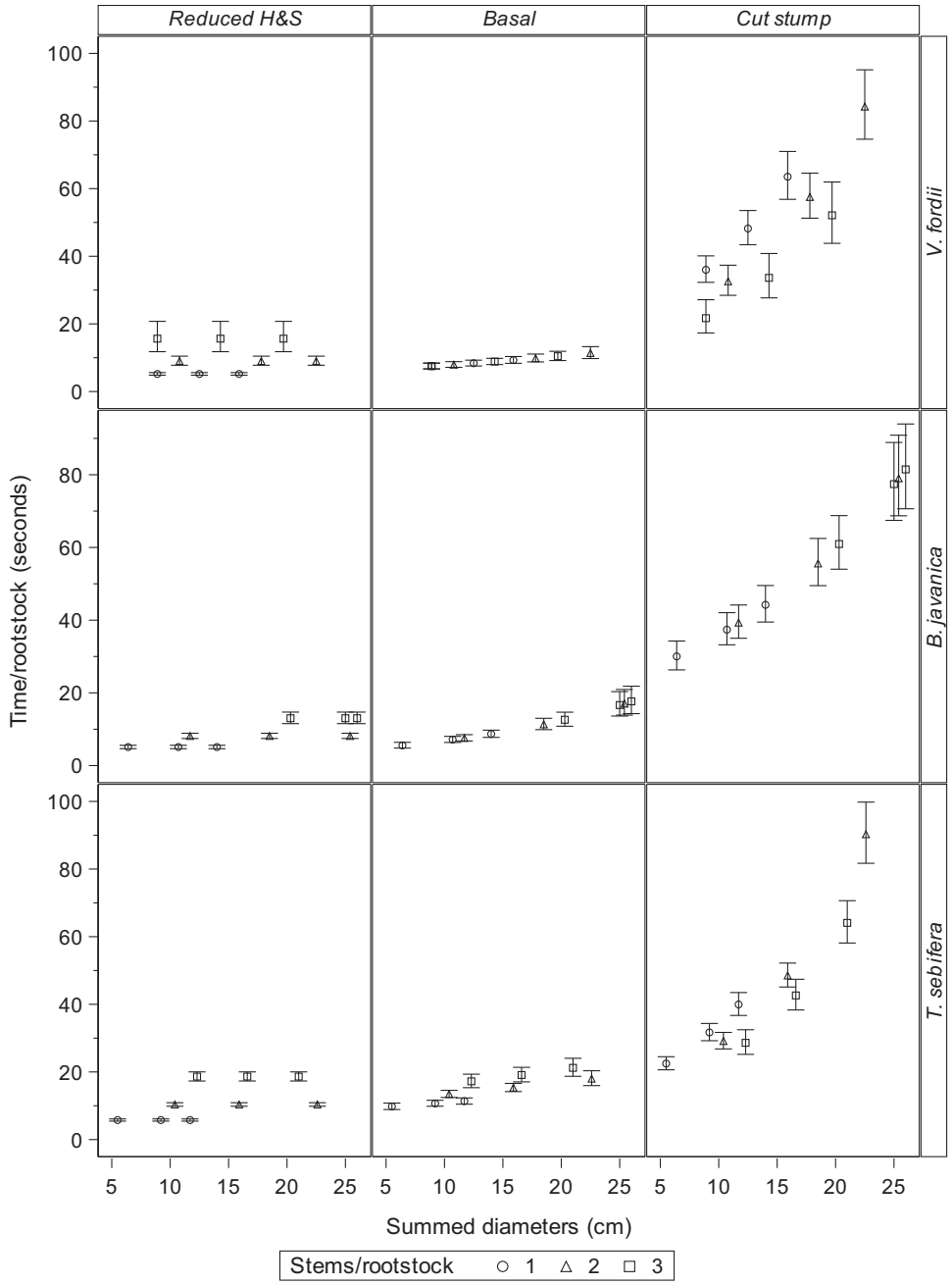

Figure 2. Estimated treatment time by species (*Triadica sebifera*, *Bischofia javanica*, *Vernicia fordii*) as a function of summed stem diameters and number of stems per rootstock. Average time ± standard error are shown for the mean, lower quartile, and upper quartile of summed diameters. Predictions for more than three stems are not shown.

dicotyledonous species in the Asteraceae have exhibited tolerance to aminopyralid with foliar applications (Mikkelson and Lym 2013), but this has not been well established for members of the Myrtaceae. Additionally, the current study demonstrated aminopyralid efficacy for the Euphorbiaceae species and closely related Phyllanthaceae species tested. However, aminopyralid has not been well tested on many species in either of those families beyond leafy spurge (*Euphorbia esula* L.), for which it was ineffective (Lym 2005). This may suggest that in some cases, injection directly into the phloem could improve efficacy for other woody species that are not controlled with foliar treatments. Future research should examine this with the RHS approach with lower concentrations of aminocyclopyrachlor, aminopyralid, and other herbicides, including imazapyr, on additional species.

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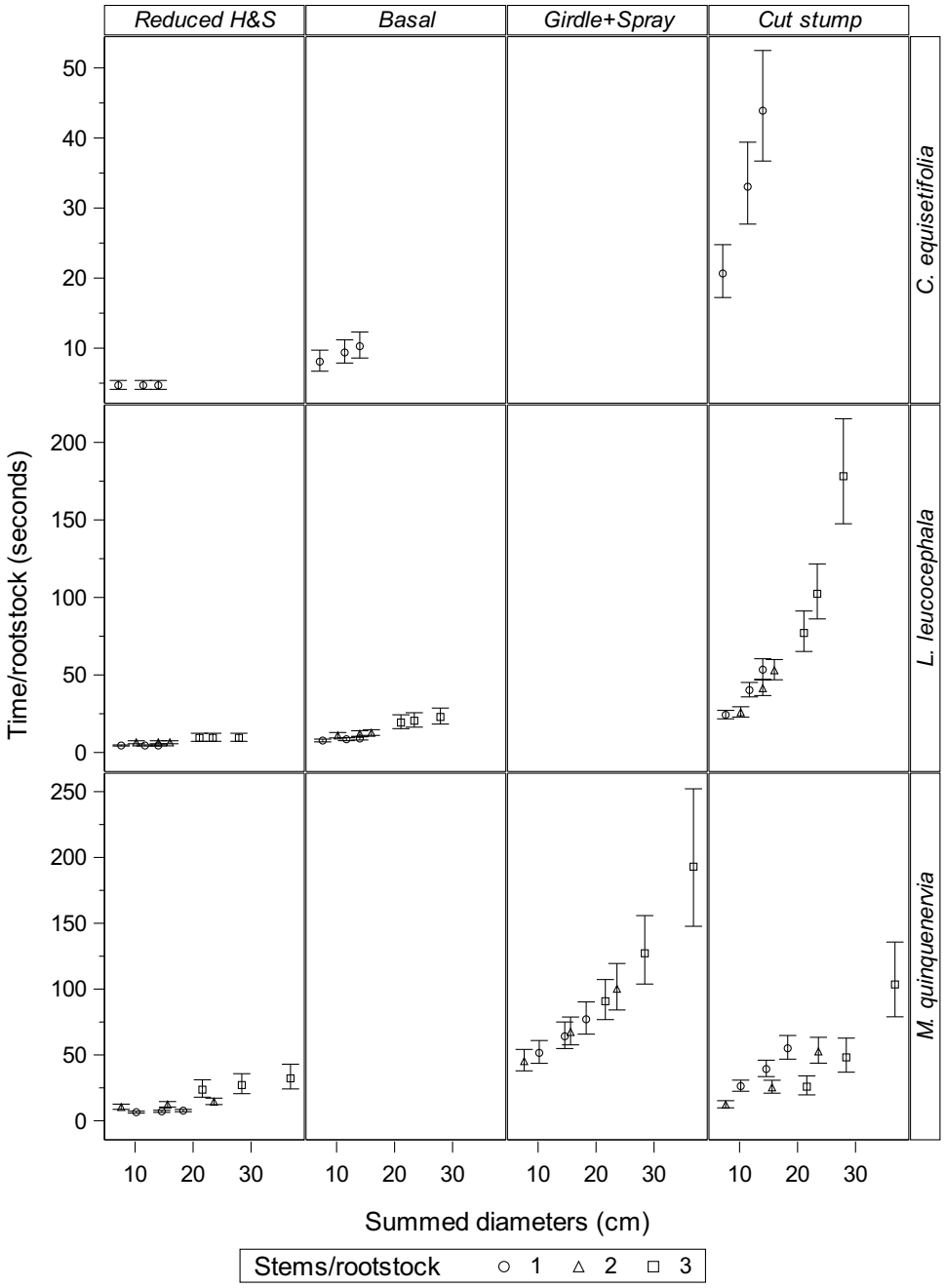

Figure 3. Estimated treatment time by species (*Melaleuca quinquenervia*, *Leucaena leucocephala*, *Casuarina equisetifolia*) as a function of summed stem diameters and number of stems per rootstock. Average time ± standard error are shown for the mean, lower quartile, and upper quartile of summed diameters. *C. equisetifolia* is a single stem species.

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References

[FISC] Florida Invasive Species Council (2023) List of Invasive Plant Species. https://www.floridainvasivespecies.org. Accessed: March 3, 2024

Bell ME, Enloe SF, Leary JK, Lauer DK (2023) A contractor comparison of novel IPT tools and techniques for Brazilian peppertree (*Schinus terebinthifolia*) management. Invasive Plant Sci Manag 16:170–176

Bruce KA, Harcombe PA, Jubinsky G (1997) Introduction, impact on native habitats, and management of a woody invader, the Chinese tallow tree, *Sapium sebiferum* (L.) Roxb. Nat Area J 17:255–260

Campbell RS, Peevy FA (1950) Poisoning certain undesirable southern hardwoods for forest and range improvement. Am Midl Nat 44:495–505

Campbell S, Vogler W, Brazier D, Vitelli J, Brooks S (2019) Weed leucaena and its significance, implications and control. Trop Grassl-Forrajes Trop 7:280–289

Campbell TE (1985) Hardwood topkill by four herbicides injected at wide spacings. South J Appl For 9:99–102
Chiang SHT, Wang SC (1984) The structure and formation of melaleuca bark. Wood Fiber Sci 3:357–373
Enloe S, Leary J, Lastinger CG, Lauer D (2023) Reduced hack and squirt treatment with aminocyclopyrachlor and aminopyralid for invasive shrub control. Invasive Plant Sci Manag 16:64–72
Enloe SF, Langeland K, Ferrell J, Sellers B, MacDonald G (2022) Integrated Management of Invasive Plants in Natural Areas of Florida. SP242/WG209. Gainesville, FL: EDIS. 35 p. https://doi.org/10.32473/edis-wg209-2018. Accessed: April 15, 2024
Enloe SF, Loewenstein NJ, Streett D, Lauer DK (2015) Herbicide treatment and application method influence root sprouting in Chinese tallowtree (*Triadica sebifera*). Invasive Plant Sci Manag 8:160–168
Enloe SF, O'Sullivan SEG, Loewenstein NJ, Brantley E, Lauer, DK (2018) The influence of treatment timing and shrub size on Chinese Privet (*Ligustrum sinense* Lour.) control with cut stump herbicide treatments in the southeastern US. Invasive Plant Sci Manag 11:49–55
Florida Climate Center (2024) Home page. https://climatecenter.fsu.edu. Accessed: November 20, 2024
Gresham CA (2010) Efficacy of "hack and squirt" application of imazapyr, triclopyr, and glyphosate to control the invasive tree species Chinese tallowtree. Gen. Tech. Rep. SRS-121. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. Pp 121–122
Hata K, Kawakami H, Kachi N (2015) Higher soil water availability after removal of a dominant, nonnative tree (*Casuarina equisetifolia* Forst.) from a subtropical forest. Pac Sci 69:445–460
Itou T, Hayama K, Sakai A, Tanouchi H, Okuda S, Kushima H, Kajimoto T (2014) Developing an effective glyphosate application technique to control Bischofia javanica Blume, an invasive alien tree species in the Ogasawara Islands. J For Res 20(1):248–253. https://doi.org/10.1007/s10310-014-0457-y
Kochenderfer JD, Miller GW, Kochenderfer JN (2012) A Comparison of Two Stem Injection Treatments Applied to American Beech in Central West Virginia. Res. Pap. NRS-21. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 10 p
Kochenderfer JD, Zedaker SM, Johnson JE, Smith DW, Miller GW (2001) Herbicide hardwood crop tree release in central West Virginia. North J Appl For 18:46–54
Laroche FB, Thayer DD, Bodle J (1992) Melaleuca response to various herbicides and methods of application. Aquatics 14:14–19
Leary J, Beachy J, Gustine J (2015) Efficacy of undiluted herbicide injections on tropical woody species in Hawaii. Proc West Weed Sci Soc 68:58
Leary J, Reppun Beachy J, Hardman A, Gustine Lee J (2013) A Practitioner's Guide for Testing Herbicide Efficacy with the Incision Point Application (IPA) Technique on Invasive Woody Plant Species. WC-11. Manoa: University of Hawaii. 8 p
Lemmens RHMJ, Soerianegara I, Wong WC, eds (1995) Plant Resources of South-East Asia No. 5 (2). Timber Trees: Minor Commercial Timbers. Bogor, Indonesia: Prosea Foundation; Leiden: Backhuys. 655 p
Littell RC, Milliken GA, Stroup WW, Wolfinger RD, Schabenberger O (2006) SAS® for Mixed Models. 2nd Ed. Cary, NC: SAS Institute. 814 p
Lym RG (2005) Control of invasive weeds with aminopyralid in North Dakota. Proc West Soc Weed Sci 58:60
McPherson EG, van Doorn NS, Peper PJ (2016) Urban Tree Database and Allometric Equations. Gen. Tech. Rep. PSW-GTR-253. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 86 p
Mikkelson JR, Lym RG (2013) Effect of aminopyralid on desirable forb species. Invasive Plant Sci Manag 6:30–35
Miller JH, Manning ST, Enloe SF (2015) A Management Guide for Invasive Plants in Southern Forests. Gen. Tech. Rep. SRS–131. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 133 p
Minogue PJ (2019) Tung Oil Production in Florida: FOR351/FR420. EDIS 2019(5):3. https://doi.org/10.32473/edis-fr420-2019
Moretti ML, Van Horn CR, Robertson R, Segobye K, Weller SC, Young BG, Johnson WG, Sammons DR, Wang D, Ge X, d'Avignon A, Gaines TA, Westra P, Green AC, Jeffery T, et al. (2017) Glyphosate resistance in *Ambrosia trifida*. Part 2. Rapid response physiology and non-target-site resistance. Pest Manag Sci 74:1079–1088
Morton J (1984) Nobody loves the *Bischofia* anymore. Proc Fla State Hort Soc 97:241–244
Morton JF (1980) The Australian pine or beefwood (*Casuarina equisetifolia* L.), an invasive "weed" tree in Florida. Proc Fla State Hortic Soc 93:87–95
Peevy F (1972) Injection treatments for killing bottom-land hardwoods. Weed Sci 20:566–568
Queiroz ARS de, Delatorre CA, Lucio FR, Rossi CVS, Zobiole LHS, Merotto A Jr (2020) Rapid necrosis: a novel plant resistance mechanism to 2,4-D. Weed Sci 68:6–18
Randall J (1996) Weed control for the preservation of biological diversity. Weed Technol 10:370–383
Rinehart T, Shockey J, Edwards N, Spiers JM, Klasson T (2015) *Vernicia fordii* 'Spiers,' a new tung tree for commercial tung oil production in the Gulf Coast region. HortScience 50:1830–1832
Rumbold C (1920) Effect on chestnuts of substances injected into their trunks. Am J Bot 7:45–56
Schabenberger O, Pierce FJ (2002) Contemporary Statistical Models for the Plant and Soil Sciences. Boca Raton, FL: Taylor & Francis. 738 p
Sharma P, Kaur A, Batish DR, Kaur S and Chauhan BS (2022) Critical insights into the ecological and invasive attributes of *Leucaena leucocephala*, a tropical agroforestry species. Front Agron 4:890992
Snow WA (2013) Tung Tried: Agricultural Policy and the Fate of a Gulf South Oilseed Industry, 1902–1969. Ph.D dissertation. Starkville, MS: Mississippi State University. 403 p
Sterrett JP (1969) Injection of hardwoods with dicamba, picloram, and 2,4-D. J For 67:820–821
Tanaka N, Fukasawa, K, Otsu K, Noguchi E, Koike F (2010) Eradication of the invasive tree species *Bischofia javanica* and restoration of native forests on the Ogasawara Islands. Pages 161–171 *in* Kawakami K, Okochi I, eds. Restoring the Oceanic Island Ecosystem. Tokyo: Springer
Tappeiner JC, Pabst RJ (1987) Stem treatments to control tanoak sprouting. West J Appl For 2:41–45
Vogt JT, Olatinwo R, Ulyshen MD, Lucardi RD, Saenz D, McKenney JL (2021) An overview of *Triadica sebifera* (Chinese tallowtree) in the southern United States, emphasizing pollinator impacts and classical biological control. Southeast Nat 20:536–559
Yeiser JL (1986) Tree injection for early pine seedling release in the Ozark mountains of Arkansas. South J Appl For 10:249–251

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