Control of Beach Vitex (*Vitex rotundifolia*) with Foliage and Cut Stem Herbicide Applications[1]

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Abstract

The many invasive characteristics of *Vitex rotundifolia* L. f. [beach vitex (BV)] and the ecological concerns surrounding its presence along the coast have necessitated the development of effective control methods. The purpose of these studies was to evaluate various herbicides using cut stem and foliar application methods to develop effective control strategies. An observational case study on a beach dune site indicated that beach vitex regrowth occurred three years after the initial cut stem glyphosate (treatments at 2.4 g ai·cm^{-1} (0.2 oz ai·in^{-1}) and served to direct experiments using both greenhouse and field studies. Glyphosate, imazapyr, and triclopyr were evaluated in greenhouse studies. An imazapyr solution at 1.2 g ai·cm^{-1} (0.1 oz ai·in^{-1}) applied to recently cut stems effectively controlled beach vitex in both greenhouse and field studies. Foliar applications of imazapyr in greenhouse and field studies confirmed that it effectively controlled beach vitex at rates of 1.0, 1.4 and 2.0 kg ai·ha^{-1} (0.89, 1.25 and 1.79 lb ai·A^{-1}). Imazapyr effectively controlled beach vitex in these studies whether applied either as a cut stem treatment or as a foliar spray application. Ineffective control was observed from glyphosate and triclopyr applications, which resulted in beach vitex regrowth.

Index words: invasive plant, beach dune, landscape plant, herbicide susceptibility, glyphosate, imazapyr, imazamox, triclopyr.

Herbicides used in this study: glyphosate (Roundup Pro) N-(phosphonomethyl) glycine, imazapyr (Habitat) 2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*imidazol-2-yl]-3-pyridinecarboxylic acid, imazamox (Clearcast) 2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-y]-5-(methoxymethyl)-3-pyridinecarboxylic acid, triclopyr (Renovate 3) 3,5,6-tricholoro-2-pyridinyloxyacetic acid.

Species used in this study: beach vitex (*Vitex rotundifolia* L. f.).

Significance to the Horticulture Industry

Landscape plants can become invasive and the green industry is concerned about the management of invasive landscape plants, especially in a beach environment. Beach vitex was introduced by the green industry in the 1980s as a salt-tolerant woody groundcover with attractive foliage and flowers that prevents beach erosion. It reproduces by seed and by rooting at the nodes from long vegetative stems. Beach vitex vegetation will dominate primary beach dunes and reduce populations of sea oats (*Uniola paniculata* L.) and other native plants and may influence the nesting of sea turtles. A waxy substance moves from the deciduous leaves and seeds, causing hydrophobic sand and soils, giving beach vitex a competitive advantage. This research focused on controlling beach vitex with foliar or cut stem applications of herbicides. Imazapyr (Habitat) was effective either applied as foliage spray or as a cut stem treatment. Many beach vitex infestations were treated with imazapyr over a five year period (2008 to 2013) with excellent results, however follow-up treatments for seedling emergence and shoot regrowth will be necessary for complete control.

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Introduction

The control of invasive plants and restoration of native communities on primary beach dunes is critical to maintaining these sensitive ecosystems. One such invasive threat, beach vitex (BV), was introduced to the horticulture landscape industry in North and South Carolina in the 1980s (BVTF 2011). It is native to parts of mainland Asia, Northern Australia, and Pacific islands (Pope 1968). This deciduous, low-growing, tenaciously spreading shrub has attractive foliage and flowers, and its salt tolerance allows it to thrive in the harsh beach environment of the primary dune (Dirr 1998). Beach vitex reproduces by both seeds and rooted stems.

Seeds are contained within a spherical, black drupe with a persistent calyx that has a diameter of approximately 5 mm; fruits are hard, non-fleshy, and contain up to 4 seeds in separate compartments (Cousins et al. 2010). BV may produce as many as 6,000 viable seeds per m^2 (Gresham and Neal 2004). Seeds require an 8 to 12 week temperature stratification period to emerge and a substantial seed bank (1833 viable seed·m^{-2} 15 cm deep) was discovered on previously infested South Carolina beaches (Cousins et al. 2010). Viable seeds were present 4 years after vegetation removal (Cousins et al. 2010).

The dominant method of invasion appears to be from its long running branches that root easily on the beach. In the coastal areas of North and South Carolina where planted, BV dominated primary dunes and excluded native species (Gresham and Neal 2004). Gresham and Neal (2004) found that BV composed 73 to 84% of all plant stems in BV-dominated areas while native species such as sea oats and beach grass (*Ammophila breviligulata* Fernald.) composed only 2.8 to 12.4% of the stems. Sea turtle enthusiasts believe that the thick growth of BV prevents egg-laying activities by inhibiting the turtle's ability to travel to appropriate locations (BVTF 2011).

Murren et al. (2014) reported that vegetative reproduction, sexual reproduction and viable seed set rates were high and the invasion potential in coastal environments was significant. Management practices that minimize the vegetative expansion and seed dispersal are the highest priority. Herbicides in combinations with other management practices are effective in minimizing spread of invasive plants (Langeland and Meisenburg 2009; Ward, Williams and Worthy 2010). True (2010) evaluated several herbicides for BV control and reported that foliar sprays of glyphosate and imazapyr provided the greatest control (83 and 90%, respectively) 8 months after treatment. A limited amount of research has been published concerning the short and long-term control of BV.

Since BV is a problem invasive plant, a task force involving multiple agencies/institutions and volunteers was developed to detect and eliminate this invasive plant from the North and South Carolina coast before it spreads further and becomes a larger environmental problem. This task force was active in encouraging legislation and ordinances to support removal efforts while raising awareness of the dangers associated with this plant's invasive potential (BVTF 2011).

This research consisted of evaluating herbicides using both cut stem and foliar applications to support BV eradication efforts. A case study led to directed greenhouse experiments that culminated in field experiments. The objective of this project was to evaluate the use of herbicides for controlling BV in infested coastal regions. The herbicides evaluated are labeled for aquatic sites and are documented as effective on similar species.

Materials and Methods

Case study. In 2004, a primary dune (855 Parker Ave) location on North Litchfield Beach, South Carolina, was selected for *in situ* exploration of potential control protocols. During December 2004, control efforts began at that location. Seven years of growth had resulted in BV plants with basal stems that measured more than 30 cm in diameter. Stem density was approximately 20 stems·m^2. Plants possessed rooted runners 3 to 5 cm in diameter buried 5 to 20 cm below the surface. Some of the runners were too deep to remove from the sand and these were the source for most of the regrowth following herbicide application. The site was planted with 9 BV plants in 1997 and BV covered a total 158 m^2 in 2004. Treatment and evaluation months are reported in Table 1.

All above ground plant parts were removed manually (December 8, 2004) and as the shoots were cut, a glyphosate (Roundup Pro, Monsanto, St. Louis, MO, USA) mixture (50% v/v) was sprayed on the cut stems at approximately 10 ml per cm (approximately 2.4 g ai·cm^{-1} or 0.2 oz ai·in^{-1}) of cut stem. On May 14, 2005, live stems were counted and removed; approximately half of the stems producing active growth were cut and treated with glyphosate (same as above method), and the other half were cut and treated with triclopyr (Renovate 3, SePRO Corporation, Carmel, IN, USA) [50% v/v, 1.8 g ai·cm^{-1} (0.15 oz ai·in$^{-1)}$]. Live stems were counted and removed and the same herbicides/application method was used in September and November 2005 and May 2006. Live stems were considered to be new growth primarily from buried stems, indicating reduced efficacy from the herbicides. Seedlings were also observed as un-branched shoots that were easily hand removed. After regrowth was treated and removed on May 15, 2005, sea oats (100 10-cm-wide rooted plants) and sweetgrass (*Hierochloe odorata* L. P. Beauv.) (100 10-cm-wide rooted plants) were planted at least 15 cm deep. Existing sea oat plants and new plantings were fertilized with slow release fertilizer (Osmocote 14-14-14) to promote growth in the sparsely vegetated areas resulting from BV removal.

Greenhouse cut stem studies. Plant stems from untreated BV were rooted in mist beds to obtain uniform rooted plants and grown under greenhouse conditions in 3 L (0.8 gal) pots for approximately 8 months before treatments. Plants were grown in Fafard 3B (Conrad Fafard Inc. Anderson, SC, USA) media in glass greenhouses with 31 C maximum and 22 C minimum temperatures from September 2006 until the end of the studies in 2007. Plants were 60 to 80 cm (24 to 32 in) in height at the time of treatment. Herbicides evaluated in greenhouse and field studies were labeled for aquatic uses.

The commercial formulations of three herbicides, glyphosate (480 g ai·L^{-1}), imazapyr (Habitat, BASF Corporation, Research Triangle Park, NC, USA) (240 g ai·L^{-1}) and triclopyr (360 g ai·L^{-1}) were diluted 50% and evaluated for control of BV beginning March 2, 2007. An individual plant served as a replicate, and 5 plants received each treatment. BV plants were cut 10 cm above the substrate surface, and a 0.5 ml aliquot of the 50% solutions were applied to the cut surface using a syringe. Untreated plants were cut and served as controls. The experiment was rated visually for control with 0 = no control and 100 = complete kill approximately 2 and 4 months after treatment (MAT). At 4 MAT, the above ground growth and roots were harvested separately and fresh weight determined. The entire study was repeated beginning April 10, 2007.

Field cut stem study. BV plants (vegetatively propagated) were grown in the greenhouse using Fafard 3B media and planted in sand beds at Clemson University in June of 2005. Plants were grown in the field two years before treatments were initiated. These plants were drip irrigated (4 hours per day at 1.9 liters per hour) for the first 3 months of growth. Weeds were removed through hand weeding and careful application of contact herbicides.

Plants were randomly assigned to one of two groups of 8. Each group corresponded to a treatment date (June 25, 2007, September 3, 2007, and November 4, 2007). On each treatment date, the runners of all 8 plants assigned to that date were cut back to approximately 1 m. They were then randomly assigned to either treated (n = 4), or untreated. A randomized block design was used with four single plant replications. The treatment consisted of imazapyr (50% v/v solution) was applied by horizontally cutting one main stem per plant with clippers and spotting 0.5 ml of the herbicide solution on the stem immediately following cutting. An untreated control treatment consisted of removing BV stems to within 5 cm (2 in) of the main stem. The experiment was visually rated with 0 = no control and 100 = complete kill from August to November 2007 and June 2008. Regrowth was removed from the plants and fresh weight was determined on June 16, 2008.

Foliar spray greenhouse experiments. A greenhouse foliar spray study was established to determine the efficacy of her-

Table 1. Litchfield beach case study of Beach Vitex control after above ground biomass removal and cut stem applications of glyphosate and triclopyr with treatment dates, evaluation dates, and points of regrowth.

Treatment date	Herbicide	Evaluation date	Points of regrowth[z]	Notes from evaluation date
Dec. 2004	glyphosate treatment to entire plot	May 2005	30	95% control of BV vegetation
May 2005	glyphosate triclopyr	Sept 2005	44 28	90% control of vegetation. Regrowth occurred from deeply rooted stem nodes.
Sept 2005	glyphosate triclopyr	Nov 2005	2 0	Regrowth occurred from deeply rooted nodes.
Nov 2005	glyphosate triclopyr	May 2006	13 3	Seedlings observed
May 2006	glyphosate triclopyr	May 2007	12 8	Seedlings survived and were less than 3 cm in height.

[z]Points of regrowth were green shoots usually growing from beach vitex stems buried in the sand.

bicides to control BV. Four-month-old seedling (30 to 50 cm in height or 12 to 20 in) BV plants in 3 liter pots were used in this study. Formulations of glyphosate, imazapyr, imazamox (Clearcast, BASF Corporation, Research Triangle Park, NC, USA and triclopyr were evaluated. They were applied at two concentrations. Most of these herbicides were labeled for a 2% (v/v) solution of the selected formulation for control of woody plants. All herbicides were applied at 2.5 and 5% v/v which equals glyphosate at 2.0 and 4.0 kg ai·ha^{-1} (1.8 and 3.6 lb ai·A^{-1}), imazapyr at 1.0 and 2 kg ai·ha^{-1} (0.9 and 1.8 lb ai·A$^{-1)}$ imazamox at 1.0 and 2 kg ai·ha^{-1} (0.9 and 1.8 lb ai·A$^{-1)}$, and triclopyr at 1.5 and 3.0 kg ai·ha^{-1} (1.4 and 2.8 lb ai·A^{-1}). A nonionic surfactant (Induce, Helena Chemical Co. West Des Moines, IA 50266) was added at the rate of 0.5% (v/v). Applications were made using spray bottles calibrated to deliver 5 ml of spray in 4 sprays to each plant. This dosage translates to approximately 50 liters·ha^{-1}. The treatments were made in a greenhouse, and the plants were allowed to dry overnight before they were arranged in a randomized block design with 5 single plant replicates. An untreated control treatment was included.

Injury was determined visually on a 0 to 100 (percentage) scale with 0 showing no injury and 100 denoting completely defoliated and brown. Visual ratings were made at 1, 3, and 8 months after treatment (MAT). The initial study started in September 2005. A second iteration began in February of the following year. The plants used in this study were 6 months old and measured 50 to 70 cm in height.

Field foliar spray experiment: In 2006, single beach vitex plants (30 to 50 cm (12 to 20 in) tall) were planted 3 m (10 ft) apart in sand beds. Plants were pruned to 10 cm (4 in) above the soil level in spring of 2008 and allowed to regrow. Plants averaged 0.5 m (1.6 ft) in height and 1 m in diameter at treatment. Treatments were applied June 11, 2009, to fully leafed out BV plants with a few flower inflorescences.

Spray applications were made with a hand held pump up sprayer at the rate of 102 L·ha^{-1} (27 gal·A^{-1}). Imazapyr and triclopyr were applied at the rate 1.4 and 1.8 kg ai·ha^{-1} (1.3 and 1.7 lb ai·A^{-1}), respectively. A combination treatment was included with both herbicides mixed together and applied at the same rates. All treatments contained a nonionic surfactant (Induce) at the rate of 10 ml·L^{-1} (1%). Treatments were arranged in a randomized complete block design with 5 single plant replications.

The plants were visually evaluated each month from July 2009 to June 2010 for percent BV control with 0 = no injury and 100 = complete kill with no leaves present. Green foliage was clipped at 15 cm (6 in) from the soil level of all BV plants and weighed to obtain fresh weight of the regrowth one year after application to further quantified BV control.

Statistical analysis. Analyses were conducted using JMP (Version 6.0 or 9.1, SAS Inst., Cary NC, USA), and means were compared using a t-test ($\alpha = 0.05$) following ANOVA.

Results and Discussion

Case study. The initial plant removal and treatment with glyphosate resulted in an estimated 95% control when evaluated in May 2005 (Table 1). At that time, 30 points of regrowth were observed. Points of regrowth were new green shoots primarily from deeply rooted runners. There was no regrowth from the original cut stems of the plants. In further attempts to help the dune recover from BV infestation, sea oats and sweetgrass were planted on this date. During the planting of the sea oats and sweetgrass, strongly hydrophobic beach sand was observed where the BV had infested the primary dune. Cousins et al. (2009) later documented and characterized this observation. It was determined that waxes from both the leaves and drupes of BV accumulated in the top few inches of the beach sand and contributed to the hydrophobicity. Both beach grasses were established after BV removal but irrigation was needed during the first few weeks of growth to overcome the hydrophobic environment.

The second treatment (one half treated with glyphosate and the other half treated with triclopyr) resulted in what was described as 90% control of the original BV density (as observed in September 2005) with some of the plants that regrew plants possessing runners (more than 2 m in length), flowers, and immature fruits (data not presented). The triclopyr and glyphosate-treated plots had BV that regrew at 28 points and 44 points, respectively. After the third treatment (observed November 15, 2005), plots resulted in only two points of regrowth from the glyphosate-treated area and none from the triclopyr-treated area. Since BV is deciduous, the late date may indicate a natural reduction in growth due to environmental conditions.

On May 15, 2006 (fourth observation), there were 13 areas of live stems in the glyphosate-treated area and 3 points of regrowth in the area treated with triclopyr. Seedlings of BV were observed in areas near a water hydrant used to wash sand off of feet. At the May 2007 observation and treatment, numerous seedlings were present; most of the seedlings survived the growing season and were approximately 3 cm in height with four to six leaves. It is significant that after three years of treatment and vegetation removal that live stems continued to emerge and seedlings were established, indicating strong potential for reestablishment.

Glyphosate and triclopyr did reduce total BV infestation but multiple points of regrowth occurred after treatments and these treatments did not eliminate the reestablishment potential of BV. There was no observational difference between triclopyr and glyphosate. True (2010) reported a moderate amount of ^{14}C glyphosate from cut stem applications translocated to the first root section and a minimal amount moved to root segments greater distances from the cut stem. Our observations also indicated that glyphosate and triclopyr mobility was limited in horizontal runners.

With cut stem glyphosate and triclopyr treatments, multiple treatments over several seasons will be required to remove this plant where a significant infestation is present. Additionally, it has become clear that BV can become established from seed, but we are uncertain as to how aggressive seedlings would be and the time required for seedlings to produce seed and develop an aggressive growth habit. The authors have observed test plot seedlings at Clemson that were capable of producing seeds the second year after planting, but the more nutrient deficient beach environment would make second year seed production unlikely.

Greenhouse cut stem studies. At 2 MAT, all of the herbicides demonstrated significant control of BV (Table 2). Imazapyr consistently provided a high level of control (greater than 99%). However, glyphosate (99 vs. 59%) and triclopyr (100 vs. 69%) caused much lower levels of injury in the second trial. At 4 MAT, the trend continued with imazapyr providing consistent control above 99% while glyphosate (74 vs. 0%) and triclopyr (100 vs. 40%) provided diminished control in the second trial. Fresh weight biomass measures of roots and shoots supported the control ratings. Imazapyr-treated plants had low levels or no regrowth while glyphosate and triclopyr-treated plants had growth that differed greatly between two trials. The first trial was treated in the fall with shorter day lengths and likely more movement of herbicides to the root systems after clipping while the second trial was treated in the spring/summer with possibly less herbicide movement to the root areas thereby providing less control and more regrowth.

Biomass was altered by the herbicide treatments as measured at 4 months with all of the herbicide-treated plants having large decreases in above ground regrowth and root mass compared to nontreated plants. Imazapyr plants regrew only slightly while regrowth from the triclopyr and glyphosate-treated plants was significant.

The differences in the performance of the various herbicides in the study are likely due to the fact that these deciduous plants were kept vegetative during the winter. By the time the second experiment started, treatments conditions and BV were more reflective of summer growth patterns. Other research has demonstrated that glyphosate and triclopyr applications were less effective in summer compared to spring or fall applications. Chinese privet (*Ligustrum sinense* Lour.) control was not as effective with foliar applications of glyphosate in the summer compared to fall or spring applications (Harrington and Miller 2005). Triclopyr provided only 50% control of the woody shrub *Calotropis procera* (Aiton) W.T.Aiton through the use of stump application, but up to 90% control when herbicide was applied to areas where bark had been removed (Vitelli et al. 2008). Our results clearly indicate that imazapyr is the most effective treatment for BV control followed by triclopyr. Glyphosate did not perform well in either iteration of the study. The ability to achieve effective control using an imazapyr solution applied directly to a cut surface constitutes a powerful tool in the control of BV.

Field cut stem study. The field study provided valuable insight regarding control methods. Imazapyr was selected for its replicable performance early and late in the season as noted in the greenhouse studies. In the field, imazapyr treatments controlled BV following treatment for three years, indicating no regrowth from the imazapyr-treated plants (vi-

Table 2. Beach vitex control ratings determined visually, fresh root weight and fresh shoot weight after cut stem applications of three herbicides two and four months after treatment (MAT) in greenhouse experiments[z].

Herbicide	g ai·L^{-1}[y]	% Visual control[x]				Root fresh wt. (g)		Shoot fresh wt.(g)	
		2 MAT		4 MAT		4 MAT		4 MAT	
		Trial 1 %	Trial 2 %	Trial 1 %	Trial 2 %	Trial 1 g	Trial 2 g	Trial 1 g	Trial 2 g
Glyphosate	3.8	*99a	*59b	*74b	*0c	*34.7b	*99.8a	*21.9b	*147.8a
Imazapyr	12	100a	99a	100a	99a	41.0b	48.3b	0.0b	0.9c
Triclopyr	8	*100a	*69ab	*100a	*40b	*45.2b	*82.2ab	*0.0b	*70.1b
Untreated	—	0b	0c	0c	0c	85.9a	112.7a	*208.5a	*132.9b

[z]Pairs of values (same herbicide treatment and rating date) from different trials that are significantly different as determined by t-test with $\alpha = 0.05$ are marked with an asterisk. Means followed by the same letter within a column are not different according ANOVA and t-test with $\alpha = 0.05$.

[y]Grams active ingredient per liter of applied.

[x]Visual control: average (n = 5) visual rating based on 0 = no injury and 100 = complete control.

Table 3. Beach vitex control[z] determined visually in greenhouse trials with foliar treatments of two rates each of four herbicides at 1, 3, 6 and 8 months after treatment (MAT).

Herbicide	kg ai·ha^{-1}	Control					
		1 MAT		3 MAT		6 MAT	8 MAT
		Trial 1 %	Trial 2 %	Trial 1 %	Trial 2 %	Trial 1 %	Trial 2 %
Glyphosate	2.0	42b	40b	78ab	75a	75b	16cd
Glyphosate	4.0	44b	55b	99a	99a	99b	42bc
Imazamox	0.5	7c	27bc	*58b	*94a	94a	28bcd
Imazamox	1.0	*8c	*42b	62a	74a	100a	90b
Imazapyr	1.0	*8c	*38b	*88a	100a	100a	100a
Imazapyr	2.0	13c	36b	100a	100a	100a	100a
Triclopyr	1.5	43b	42b	*60b	10b	12c	0d
Triclopyr	3.0	42b	33b	*71b	96a	96a	0d
Untreated	0	0c	0c	0c	0b	0d	0d

[z]Control: average (n = 5) visual rating based on 0 = no injury and 100 = complete control.

*Pairs of values (same herbicide treatment and rating date) from different trials that are significantly different as determined by t-test with $\alpha = 0.05$ are marked with an asterisk. Means followed by the same letter are not different according ANOVA and t-test with $\alpha = 0.05$ within the column.

sual observations data not included). The date of treatment did not affect the control of BV with imazapyr. Treatment times were selected based on herbicide performance in the foliar studies that showed better efficacy when plants were treated closer to the end of the growing season. There was no regrowth from any of the imazapyr-treated plants in June, 2008 however the untreated plants had fresh weight values of 3.9, 2.4, and 1.2 kg for the June, September, and November pruning dates, respectively.

Application date did not impact the effectiveness of imazapyr applied as a cut stem treatment to field-grown BV. June, September or November applications to cut stems completely controlled BV and did not allow regrowth one and three years later. This provides a wide window of opportunity for effective treatments further establishing imazapyr as a premier tool to eliminate BV from coastal communities.

Greenhouse foliar spray study. A greenhouse foliar herbicide application study evaluated and scored plants for control at 1, 3, 6, and 8 MAT. Data are presented in Table 3. After 1 month, control ratings indicated less than 55% injury, with glyphosate (high rate) providing the greatest control ratings. After 3 months, all treatments except imazamox provided greater than 74% control. Except for the lowest rate of imazamox, the results of the trials were similar at three months after treatments. Imazapyr provided greater than 88% control at both rates.

The final ratings occurred at differing dates with the first and second trials — 8 MAT and 6 MAT, respectively. Ratings were conducted in this fashion because of the differences in experiment start date. It was believed that ratings prior to the end of the typical growing season (6 MAT rating occurred in August for the second trial) would be most indicative of ultimate plant response. As a result of different rating times, the two cannot be directly compared; however, there are several important inferences to be made. In general, the plants from trial 2 appeared to be overcoming the herbicide effects at the 6 MAT rating. This occurred in all cases except for the herbicide imazapyr that provided 100% control at 6 MAT. Herbicide effects increased from 1 MAT to 3 MAT and then decreased from 3 MAT to 6 MAT. This indicates that the plants from trial two survived exposure to all herbicides save imazapyr. At 8 MAT for the first trial, we noted general consistency between the 3 MAT and 8 MAT results. Nearly all herbicides increased or maintained effective control.

In the greenhouse, control values for the ratings at 1 and 3 MAT were consistent in most cases (data not included). However, there were large differences between the two studies as inferred from the final rating dates. All herbicides except imazapyr elicited different responses in each trial at final rating dates. It should be noted that the plants used in the second trial were larger than the plants from the first trial. Also, the first trial began in September while the second trial began in February. The larger plants were better able to recover from herbicide exposure as indicated by the results on the final rating date. Additionally, plants were growing more actively in September than in February, meaning that plants in September were more likely and more able to translocate herbicides throughout the plant, increasing treatment effects. The herbicide imazapyr (at both concentrations) performed consistently, with the highest level of control among the treatments in both trials. Similarly, Vitelli et al. (2008) observed 100% control of a woody shrub (*Callotropis procera*) through the use of foliar sprays of imazapyr. While results for the other herbicides were variable between the first and second iterations of this experiment, imazapyr activity was consistent across both studies; all other herbicide treatments were attenuated when applications were made in February versus September (especially when based on inferences on the last data point). This attenuation is likely the result of better plant tolerance at the beginning of the season when the plants grow less aggressively. Harrington and Miller (2005) reported variable Chinese privet control with fall applications of triclopyr and glyphosate. Additionally, Vitelli et al. (2008) found that a treatment of triclopyr and picloram resulted in 0% *Calotropis procera* mortality. These findings support our own with regard to triclopyr efficacy.

Field foliar spray study. The results from the field foliar spray study were similar to greenhouse studies in that BV injury increased from one month to three months after treatment with maximum control observed at four months after

Table 4. **Beach vitex control determined visually from foliar applications by months after treatment (MAT) in 2009 and 2010 and fresh weight of regrowth June 2010 (12 months after treatment) in a field trial.**

		% Visual control[z]					Shoot fresh weight
Herbicide	**kg ai·ha^{-1}**	**1 MAT**	**2 MAT**	**3 MAT**	**4 MAT**	**12 MAT**	**12 MAT (kg)[y]**
Imazapyr	1.4	38b[x]	67a	89a	97a	100a	0.00
Triclopyr	1.8	55a	56a	59b	66b	20b	1.15b
Imazapyr + triclopyr	1.4 + 1.8	62a	68a	70ab	92a	94a	0.14c
Untreated	0.0	0c	0b	0c	0c	0c	2.47a

[z]Visual control:average (n = 5) visual rating based on 0 = no injury and 100 = complete control.

[y]Kg of fresh shoot weight per plant.

[x]Means followed by the same letter are not different according ANOVA and t-test with $\alpha = 0.05$.

herbicide application (Table 4). Control ratings increased with triclopyr but declined by one year after treatment whereas plants treated with imazapyr did not recover. The mixture of triclopyr and imazapyr did not improve control of BV over imazapyr alone. Regrowth as measured by above ground biomass indicated control efficacy similar to the control ratings with no regrowth from imazapyr-treated plants.

The results of the field study indicated the effectiveness of imazapyr although it was fairly slow acting, taking at least three months to see significant injury and four months for almost complete desiccation. There was no enhancement of adding triclopyr to imazapyr either in speed of action or in long term control. In fact, we did observe some regrowth with the tank mixture but none with imazapyr alone.

The mode of action of imazapyr is the inhibition of enzyme system acetolactate synthase (ALS) that blocks branch chain amino acid synthesis (Shaner et al. 1984). This is likely the reason that this herbicide required three months to reach an appreciable visual control level; it acts relatively slowly due to its mode of action. Imazamox has the same mode of action though the compound is slightly different. BV was not as susceptible to imazamox as it was to imazapyr.

Findings from greenhouse and field studies indicated that BV was susceptible to imazapyr. Greenhouse studies demonstrated that treatments using imazapyr were highly effective. The field studies simulated the dune environment and demonstrated that imazapyr (1.2 g ai·cm^{-1} (0.1 oz ai·in^{-1}) approximately 50% v/v solution) applied directly to cut stems effectively controlled established BV. This treatment at three application dates was effective when measured one year after the initial application date and also at three years after initial treatment. Field and greenhouse foliar application studies also indicated that imazapyr was highly effective in controlling BV. Field observations (from a spray technician that used cut stem imazapyr treatments on beach vitex infestations for >100 beach properties) indicated minimum herbicide injury to adjacent native vegetation (data not shown).

A critical observation from this research is that efforts to remove this invasive plant from the dune environment will require a concerted effort for multiple seasons to offset regrowth and seedling emergence from well-established monocultures. As a final note, care must be taken with cleared sites so as to avoid infestations from other invasive species such as greenbriar (*Smilax* sp.). Significant greenbriar growth was noted soon after BV removal left an open niche. Additional efforts will be required to prevent a simple trade of one invasive plant monoculture for another.

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