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Evaluation of Aerial Herbicide Application for Reduction of Woody Vegetation in a Floodplain Marsh

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ABSTRACT

Aerial herbicide applications were evaluated for control of Carolina willow (*Salix caroliniana*) and buttonbush (*Cephalanthus occidentalis*) in the Upper St. Johns River Basin, Florida from May 2005 to 2007. Carolina willow density (stems/m^2) was significantly reduced in plots treated with 0.02 kg a.i./ha metsulfuron methyl, 0.04 kg a.i./ha metsulfuron methyl, 0.15 kg a.e./ha imazapyr, and 0.15 kg a.e. imazapyr + 3.30 kg a.e. triclopyr/ha compared to pre-treatment densities. Buttonbush densities (stems/m^2) were significantly reduced in plots treated with 0.15 kg a.e./ha imazapyr and 0.15 kg a.e. imazapyr + 3.30 kg a.e. triclopyr/ha. All treatments resulted in reduction in canopy cover and increases in forb ground cover at 2 years post-treatment. Quantitative evaluation of shrub, forb, fern, and graminoid density indicated that at two years post-treatment, plots treated with 0.02 kg a.i./ha metsulfuron methyl, 0.04 kg a.i./ha metsulfuron methyl, 0.15 kg a.e./ha imazapyr, and 0.15 kg a.e. imazapyr + 3.30 kg a.e. triclopyr/ha were dominated by native forbs instead of a closed canopy of Carolina willow and buttonbush with limited ground cover. We observed increases ($P < 0.003$) in species richness and diversity at two years post treatment for all six treatments. Our results indicate that herbicides can be used as an alternative to mechanical treatment or prescribed fire to reduce woody vegetation and canopy cover in a floodplain marsh, while concomitantly creating a mosaic habitat dominated by herbaceous vegetation.

Key words: Shrub control, herbicide application, St. Johns River, floodplain marsh.

INTRODUCTION

Tree islands and slough habitat form extremes in hydrology within the Upper Basin of the St. Johns River floodplain, Florida, but other wetland habitat (flag, maidencane, sawgrass, and shrub swamp) are intermediate in hydrology (Hanselman et al. 2005). Thus, small hydrological fluxes due to human alterations can change the structure and composition of wetland habitat from flag, maidencane, or sawgrass to shrub swamp dominated by Carolina willow (*Salix caroliniana*) and buttonbush (*Cephalanthus occidentalis*). The natural floodplain of the headwaters of the St. Johns River has been severely altered by the construction of levees and canals (Hall 1987). Areas that were originally inundated much of the year are now only periodically under water, while areas that were seldom under water may now be permanently under water. Significant changes in plant community composition have occurred due to hydrological alterations. Herbaceous species have been replaced by woody species. It is estimated that the area coverage of shrub communities dominated by woody vegetation in the Upper Basin of the St. John's River has increased 9-fold while shallow and deep water marsh communities have declined 21% and 80%, respectively, since the 1940s (Hall 1987).

In the Everglades, a change from herbaceous species to more woody species has been attributed to changes in drainage that resulted in lower water levels (Bartow et al. 1996). Additionally, the lack of fire can result in structural and composition changes to wetland plant communities (White 1994). Within the past 40 years, there has been a substantial shift from herbaceous marsh to shrub swamp dominated by willow and buttonbush (Hall 1987). Management of wetlands, including controlling woody plant encroachment, in the Upper St. Johns River Basin has become necessary due to increased human disturbance and alteration (Brenner et al. 2001).

Efforts to restore marsh habitat to their historical plant structure and composition are currently underway throughout the St. Johns River Water floodplain. The use of prescribed fire, both during the dormant and growing seasons, has been shown to reduce willow basal area and cover but repeated fires are needed due to regrowth (Lee et al. 2005a, 2005b.). Roller-chopping has proven effective in controlling Carolina willows with no live stems observed 3 years post treatment, but its use is limited to extreme dry periods and may alter topography and drainage patterns, and result in compacted soil (Ponzio et al. 2006). While herbicides are commonly used to manage and control invasive plants, few restoration efforts in wetland habitat have considered herbicide use to control native species as part of the restoration effort in shrub swamp dominated by Carolina willow and buttonbush.

Relative to mechanical control of vegetation, which results in significant soil disturbance in peat soils, aerial herbicide treatment of undesired vegetation is relatively inexpensive, results in no soil disturbance, and may have minimal impact to nontarget vegetation due to lack of presence or capture of the spray by tree canopy. We conducted this study adjacent to

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woody vegetation that was previously roller chopped (Ponzio et al. 2006) for comparison of applied management techniques. The objective of this study was to evaluate the effectiveness of six different herbicide treatments applied aerially to reduce woody vegetative coverage in an effort to restore habitat back to grasses, sedges, and other herbaceous plants.

MATERIALS AND METHODS

The study was conducted in Three Forks Marsh Conservation Area (TFMCA) in the headwater region of the St. Johns River basin in east central Florida, Brevard County (28°00.935N, 080°46.743W). The TFMCA is about 21,000 ha with the first evident channels of the St. Johns River arising in the southern part of the site. The floodplain of TFMCA has been severely impacted from diking and draining for agriculture and flood control purposes. The study site located about 1.5 km east of Lake Hell "n" Blazes is a shrub swamp dominated by a canopy of Carolina willow and an understory of buttonbush. Herbaceous vegetation was sparse (< 5% coverage) but included scattered patches of waterhemp (*Amaranthus* spp.), false nettle (*Boehmeria cylindrical*), sawgrass (*Cladium jamaicense*), bedstraw (*Galium* spp.), pennywort (*Hydrocotyle* spp.), royal fern (*Osmunda regalis*), maidencane (*Panicum hemitomon*), mock Bishop's weed (*Ptilimnium capillaceum*), white vine (*Sarcostemma clausum*), butterweed (*Senecio glabellus*), and marsh fern (*Thelypteris* spp.) on slightly elevated areas. Water levels at the site varied over a 24 month period from 0 to121 cm from May 2005 to May 2007. Within the treatment area, water levels varied from 15 cm in depth during pre-treatment monitoring in April 2005 and the time of application, to 121 cm during October 2005, and 0 cm during post-treatment monitoring in April 2006 and May 2007.

Nine circular plots (10.5 m^2) were randomly placed throughout the original proposed six treatment sites plus a control site prior to herbicide application in May 2005. Aerial treatments of metsulfuron methyl [methyl 2-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]benzoic acid], triclopyr [[(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid] and imazapyr [(+/-)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-3-pyrridinecarboxylic acid] were mistakenly applied by helicopter over six linear strips (about 73 m by 274 m) adjacent to the plots in May 2005. Application rates of each herbicide (Table 1) included 0.24 L Silenergy non-ionic surfactant mixed in 187 L water diluent per hectare.

Aerial herbicide was applied adjacent to pre-treatment evaluation plots on 9 May, 2005 from 0815 to 0915. Environmental conditions during treatments were clear and sunny skies, 69% relative humidity and 4.8 kph southwest winds. Because pre-treatment plots were not aerially treated, we established an additional nine circular plots (10.5 m^2) randomly within each treated site at 1 year post-treatment adjacent to pre-treatment plots to evaluate differences between pre-treatment and post-treatment shrub densities, canopy cover, and ground cover at 1 and 2 years post-treatment. Post-treatment evaluations were conducted in April 2006 and May 2007. Within each plot, the number of live stems of Carolina willow and buttonbush were counted. The density (stems/m^2) of dominant forbs, ferns, and graminoids in each plot were also counted. Canopy coverage was estimated between 0-100% at 1.5 m above ground level using a concave densitometer (Forest Densiometer, Bartlesville, OK). Ground coverage < 1.5 m was visually estimated within the circular plot at 0-100% vegetation coverage.

Descriptive statistics (mean, standard error or 95% confidence intervals) were calculated for original pre-treatment plots, and for adjacent treated plots at 1 and 2 year post-treatment for Carolina willow, buttonbush, canopy and ground cover, species richness and Simpson's Index of Diversity (Krebs 1989) over the evaluation periods. Data were analyzed for each treatment over time (i.e. pre-treatment vs 1 year post-treatment and pre-treatment vs 2 year post-treatment) using an independent sample t-test ($P < 0.05$) assuming unequal variances (SPSS 2001) for Carolina willow and buttonbush density (stems/m^2), percent canopy and ground cover, and species richness and Simpson's Index of Diversity. Pre-treatment plots were not sprayed, which eliminated comparison among herbicide treatments and analyses were conducted on each herbicide over time.

RESULTS AND DISCUSSION

Carolina willow densities were reduced at 1 and 2 years post treatment in plots treated with 0.02 kg/ha ($P = 0.04$ and $P = 0.03$) or 0.04 kg/ha ($P = 0.003$ and $P = 0.001$) metsulfuron methyl, 0.15 kg /ha imazapyr ($P < 0.001$ for both one and two years post-treatment) and 0.15 kg a.e. imazapyr + 3.30 kg triclopyr/ha ($P < 0.001$ for both 1 and 2 years post-treatment) (Table 2). We observed > 70% reduction of Carolina willow stems in plots treated with metsulfuron methyl and > 80% reduction in plots imazapyr and imazapyr + triclopyr compared to untreated original plots. There was no reduction in Carolina willow densities (stems/m^2) using triclopyr rates of 3.30 kg a.e. ($P = 0.858$) or 6.60 kg a.e. ($P = 0.635$) compared to untreated original plots. In a study comparing imazapyr and triclopyr to control two species of thicket-forming rhododendron (*Rhododendron ponticum* and *R. flavum*), foliar application of imazapyr provided better con-

TABLE 1. HERBICIDE TREATMENTS TO REDUCE WOODY VEGETATION COVER IN THREE FORKS MARSH CONSERVATION AREA.

Herbicide	Product Name	Applied Rate (kg a.i. or a.e / ha)	Maximum Label Rate (kg a.i. or a.e /ha)
Metsulfuron methyl	Escort XP	0.02 kg a.i.	0.08 kg a.i.
Metsulfuron methyl	Escort XP	0.04 kg a.i.	0.08 kg a.i.
Triclopyr amine	Renovate 3	3.30 kg a.e.	6.60 kg a.e.
Triclopyr amine	Renovate 3	6.60 kg a.e.	6.60 kg a.e.
Imazapyr	Habitat	0.15 kg a.e.	0.30 kg a.e.
Imazapyr + triclopyr amine	Habitat + Renovate 3	0.15 kg a.e + 3.30 kg a.e.	0.30 kg a.e. + 6.60 kg a.e.

Table 2. Carolina willow density (stems / m²) and 95% confidence interval at pre-treatment, 1 year post treatment, and 2 years post treatment for six aerial herbicide treatments.

	Herbicide (rate/ha)						
	Metsulfuron Methyl (0.02 kg a.i.)	Metsulfuron Methyl (0.04 kg a.i.)	Triclopyr Amine (3.30 kg a.e.)	Triclopyr Amine (6.60 kg a.e.)	Imazapyr (0.15 kg a.e.)	Imazapyr (0.15 kg a.e.) + Triclopyr amine (3.30 kg a.e.)	Control
	Carolina willow density (stems / m²)						
Pre-treatment							
Stems/m²	0.8	0.7	0.6	0.8	0.8	1.1	0.9
95% CI	0.2 - 1.3	0.6 - 0.8	0.4 - 0.8	0.7 - 1.0	0.6 - 1.0	0.9 - 1.3	0.7 - 0.9
1 Year Post Trt.							
Stems/m²	0.2*	0.2*	0.6	0.7	0.1*	0.2*	0.7
95% CI	0.0 - 0.3	0.0 - 0.5	0.3 - 1.0	0.3 - 1.0	0.0 - 0.2	0.1 - 0.4	0.6 - 0.8
2 Year Post Trt.							
Stems/m²	0.2*	0.2*	0.5	0.6	0.1*	0.2*	0.7
95% CI	0.1 - 0.3	0.1 - 0.4	0.3 - 0.8	0.4 - 0.8	0.0 - 0.2	0.1 - 0.3	0.6 - 0.8

*—Indicates significant differences ($P < 0.05$) compared to pre-treatment based on independent sample t-tests for unequal variances.

trol of both species than triclopyr (Esen and Zedaker 2004). Our results indicate that Carolina willow exhibit some tolerance to triclopyr at the rates used in this study. Using mechanical treatment, Carolina willow (stems/m²) was reduced from 1.8 to 0.0 3 years following treatment (Ponzio et al. 2006). The use of prescribed fire resulted in no significant change in Carolina willow densities at pre-treatment (1.7 stems/m²) and 3 years post treatment (1.2 stems/m²) (Lee et al. 2005a). In this study, Carolina willow stems/m² were reduced from 0.7 to 1.1 stems/m² pre-treatment to 0.1to 0.2 stems/m² 2 years post treatment using metsulfuron methyl, imazapyr or imazapyr + triclopyr compared to adjacent untreated plots.

Buttonbush densities (stems/m²) were reduced in plots treated with 0.15 kg a.e./ha imazapyr ($P < 0.001$) and 0.15 kg a.e. imazapyr + 3.30 kg a.e. triclopyr/ha ($P < 0.001$) comparing pre-treatment densities to 1 and 2 years post treatment densities (Table 3). The addition of triclopyr did not result in better control of buttonbush than 0.15 kg a.e./ha of imazapyr used alone. Neither rate of triclopyr reduced buttonbush stems ($P > 0.05$) comparing pre-treatment and two years post-treatment buttonbush stem densities. We observed an increase in buttonbush stems at 1 and 2 years post-treatment for 3.30 kg a.e. triclopyr compared to pre-treatment densities. Overall, imazapyr at rates of 0.15 kg a.e./ha provided the greatest reduction of woody vegetation (Carolina willow and buttonbush).

Table 3. Buttonbush density (stems / m²) and 95% confidence interval at pre-treatment, 1 year post treatment, and 2 years post treatment for six aerial herbicide treatments.

	Herbicide (rate / ha)						
	Metsulfuron Methyl (0.02 kg a.i.)	Metsulfuron Methyl (0.04 kg a.i.)	Triclopyr Amine (3.30 kg a.e.)	Triclopyr Amine (6.60 kg a.e.)	Imazapyr (0.15 kg a.e)	Imazapyr (0.15 kg a.e.) + Triclopyr amine (3.30 kg a.e.)	Control
	Buttonbush density (stems / m²)						
Pre-treatment							
Stems/m²	2.1	2.0	2.6	4.3	3.3	4.2	4.1
95% CI	1.2 - 2.9	1.5 - 2.6	1.9 - 3.4	2.7 - 5.9	2.8 - 3.8	3.3 - 5.2	3.3 - 4.9
1 Year Post Trt.							
Stems/m²	2.1	3.5*	3.8*	3.7	1.2*	1.7*	3.2
95% CI	0.9 - 3.2	2.4 - 4.5	3.1 - 4.6	2.7 - 4.8	0.4 - 2.0	0.9 - 2.5	2.9 - 3.6
2 Year Post Trt.							
Stems/m²	1.7	2.9	3.3	2.9	0.8*	1.3*	3.4
95% CI	0.6 - 2.8	1.9 - 4.0	2.7 - 3.8	2.2 - 3.7	0.3 - 1.3	0.6 - 2.0	3.0 - 3.7

*—Indicates significant differences ($P < 0.05$) compared to pre-treatment based on independent sample t-tests for unequal variances.

The upper and mid-canopy layers of Carolina willow were completely moribund in plots treated with both rates of metsulfuron methyl and both imazapyr treatments. The majority of live Carolina willow stems counted post-treatment both years were from coppice sprouts or sprouts from rooted limbs. Epinasty and chlorosis were commonly observed on many Carolina willow and buttonbush in the lower canopy post-treatment. The lack of control of buttonbush may be due to herbicide interception by Carolina willows because the mean canopy cover at pre-treatment throughout the study area was 48%.

All treatments reduced percent canopy cover at one and two years post-treatment ($P < 0.01$ for all treatments; Table 4), while canopy cover did not change in control plots. Canopy cover was decreased by 90 and 87% for plots treated 0.15 kg a.e. imazapyr + 3.30 kg a.e. triclopyr/ha and 0.15 kg a.e./ha imazapyr, respectively. Reduction in percent canopy cover to levels < 6% was achieved using either imazapyr treatment. This is important from a management standpoint because canopy cover from Carolina willows shades out understory species (Lee et al. 2005b). In a previous study adjacent to this one in which woody vegetation was mechanically removed, percent canopy coverage was completely eliminated at 3 years post treatment, but the severe disturbance uprooted many Carolina willow (Ponzio et al. 2006). Canopy cover of Carolina willow in areas where prescribed fire was applied was reduced from 45% pre-treatment to 14% 3 years post-treatment (Lee et al. 2005a). In the current study, the elimination of canopy cover promoted a substantial increase in herbaceous plants at two years post-treatment, but we observed no increase in sawgrass and maidencane, species typical of marsh habitat in the Upper Basin of the St. John's River.

Ground cover increased at 2 years post-treatment for all treatments ($P < 0.001$ for all treatments; Table 5), but was primarily limited to forbs (Figure 1). There was no change in ground cover ($P > 0.12$) for control plots over the 2 year study. Ground cover vegetation increased 7.1 to 16.3-fold for all treatments. At 2 years post-treatment, dominant vegetation shifted from Carolina willow and buttonbush to dogfennel (*Eupatorium capillifolium*), swamp rosemallow (*Hibiscus grandiflorus*), winged loosestrife (*Lythrum alatum* var. *lanceolatum*), climbing hempvine (*Mikania scandens*), rosy camphorweed (*Pluchia rosa*), denseflower knotweed (*Polygonum densiflorum*), and wood sage (*Teucrium canadense*). There was no increase in sawgrass or maidencane density (stems/m^2) from pre-treatment to 2 years post-treatment for all treatments ($P > 0.05$), with the exception of sawgrass densities which decreased ($P = 0.004$) in plots treated with imazapyr. Sawgrass and maidencane were not common in any plot during pre-treatment evaluations. Maidencane densities were not affected in plots treated with imazapyr ($P = 0.17$). Ponzio et al. (2006) reported that in roller-chopped areas adjacent to this study, graminoids increased from 1 to 13% over a 4 year period. Due to variable water levels at this site with extreme drought and flooded conditions (Ponzio et al. 2006), additional time might be required for grasses and sedges to become established.

There were differences ($P < 0.003$) in species richness at 1 and 2 years post-treatment compared to pre-treatment for each herbicide treatment (Table 6). Increased species diversity was significant ($P < 0.02$) for all treatments at 2 years post treatment compared to pre-treatment (Table 7). In all treatments, we observed an increase in species richness and diversity at two years post treatment from woody vegetation to forbs indicating that herbicide treatment is effective in increasing vegetation diversity. Within control plots, there were no differences from pre-treatment to 2 years post treatment for species richness ($P = 0.75$) and species diversity ($P = 0.342$). While canopy coverage of Carolina willow in control plots ranged from 50 to 67% over the 2 year study at 1.5 m above ground, we did not estimate additional cover of buttonbush below 1.5 m. Foliage cover of both Carolina willow

Table 4. Mean canopy cover (%) and 95% confidence interval at pre-treatment, 1 year post treatment, and 2 years post treatment for six aerial herbicide treatments.

	Herbicide (rate/ha)						
	Metsulfuron Methyl (0.02 kg a.i.)	Metsulfuron Methyl (0.04 kg a.i.)	Triclopyr Amine (3.30 kg a.e.)	Triclopyr Amine (6.60 kg a.e.)	Imazapyr (0.15 kg a.e.)	Imazapyr (0.15 kg a.e.) + Triclopyr amine (3.30 kg a.e.)	Control
	Canopy Cover (%)						
Pre-treatment							
% Canopy	54.9	47.8	48.9	48.3	43.3	42.2	50.0
95% CI	29.5 - 80.3	25.4 - 70.2	27.4 - 70.4	20.6 - 76.1	19.0 - 67.6	22.4 - 62.0	27.1 - 72.9
1 Year Post Trt.							
% Canopy	7.3*	15.7*	17.2*	12.2*	5.2*	3.3*	66.7
95% CI	0.5 - 14.2	0.0 - 32.7	6.7 - 27.8	6.8 - 17.7	0.2 - 10.2	0.0 - 8.3	49.4 - 83.9
2 Year Post Trt.							
% Canopy	8.3*	15.8*	17.2*	12.8*	5.6*	4.4*	61.7
95% CI	3.3 - 13.4	7.8 - 23.8	8.8 - 25.6	5.8 - 19.7	0.0 - 11.5	1.4 - 7.5	48.1 - 75.3

*—Indicates significant differences ($P < 0.05$) compared to pre-treatment based on independent sample t-tests for unequal variances.

TABLE 5. MEAN % GROUND COVER FOR ALL PLANTS AT 0.0-1.5 M ABOVE GROUND LEVEL AND 95% CONFIDENCE INTERVAL AT PRE-TREATMENT, 1 YEAR POST TREATMENT, AND 2 YEARS POST TREATMENT FOR SIX AERIAL HERBICIDE TREATMENTS.

	Herbicide (rate / ha)						
	Metsulfuron Methyl (0.02 kg a.i.)	Metsulfuron Methyl (0.04 kg a.i.)	Triclopyr Amine (3.30 kg a.e.)	Triclopyr Amine (6.60 kg a.e.)	Imazapyr (0.15 kg a.e.)	Imazapyr (0.15 kg a.e.) + Triclopyr amine (3.30 kg a.e.)	Control
	Ground Cover (%)						
Pre-treatment							
% Ground cover	5.3	10.6	9.6	7.0	9.4	7.9	2.6
95% CI	1.8 - 8.9	5.7 - 15.4	4.1 - 15.0	1.5 - 12.5	6.4 - 12.4	2.2 - 13.6	0.8 - 4.4
1 Year Post Trt.							
% Ground cover	15.6 *	16.1	17.2	18.3*	15.0*	9.4	2.8
95% CI	10.3 - 20.8	10.8 - 21.5	10.3 - 24.2	11.7 - 24.9	10.3 - 19.7	3.9 - 15.0	0.8 - 4.8
2 Year Post Trt.							
% Ground cover	91.7 *	94.4 *	92.2*	93.9*	96.1*	95.6*	6.2
95% CI	87.8 - 95.5	87.9 - 100.0	86.1 - 98.3	88.5 - 99.2	92.4 - 99.8	90.3 - 100.0	4.3 - 8.1

*—Indicates significant differences ($P < 0.05$) compared to pre-treatment based on independent sample t-tests for unequal variances.

and buttonbush likely blocks most sunlight from the ground and limits seed germination of herbaceous vegetation and graminoids.

Mechanical treatment was highly effective in eliminating Carolina willow and buttonbush from an 8 ha area directly adjacent to this project, but limitations include unstable peat soil, heavy soil disturbance and cost (Ponzio et al. 2006). The cost for roller-chopping was $325/ha (Ponzio et al. 2006), while the cost for each herbicide treatment in this study was $130/ha. An additional concern with mechanical treatment is the spread of noxious weeds such as para grass (*Urochloa mutica*) and torpedo grass (*Panicum repens*) into the proposed restoration area. These two grass species are capable of forming monocultures and reducing native plant density. Both species occur in the project area and were not observed in any herbicide treated plot during pre-treatment monitoring, but were observed along the edge of several herbicide treated plots during post-treatment monitoring. Ponzio et al. (2006) reported an increase in species richness for roller-chopped plots adjacent to this study, but indicated that three of the species were exotic. Prescribed fire has also been used to control woody vegetation during growing and dormant season burns, but repeated fires are required to reduce woody vegetation and burns are often inconsistent in coverage (Lee et al. 2005a, 2005b).

In this study, canopy coverage of Carolina willow may have inhibited control of buttonbush, which occurs in the understory, by intercepting herbicides. Resprouts were also observed on Carolina willow in the lower canopy. If management objectives require a greater reduction in woody vegetation, then a second herbicide application will be required < 6 months after the initial treatment to further reduce woody vegetation stem densities. However, if management objectives are to create a mosaic of habitat dominated by herbaceous vegetation and scattered woody vegetation, then one aerial application of metsulfuron methyl or imazapyr will achieve this goal temporarily. If long term management goals are to restore the site to vegetation dominated by graminoids, then a second application of metsulfuron methyl could be applied to control surviving woody vegetation and re-sprouts. Some marsh species such as sawgrass and maidencane are tolerant of metsulfuron methyl up to 168 g a.i./ha (Langeland and Link 2006), and an additional treatment with metsulfuron methyl would not be expected to harm these species. An additional application of metsulfuron methyl or imazapyr would impact forbs and ferns because some of these species are highly susceptible to rates of metsulfuron methyl as low as 10.5 g a.i./ha (Chiconela et al. 2004, Hutchinson and Langeland 2008).

This study indicates that herbicides are effective in reducing stem densities and canopy cover of encroaching woody vegetation in a floodplain marsh, with a concomitant increase in herbaceous ground cover at 2 years post-treatment. Plots treated with 0.15 kg a.e./ha imazapyr, 0.15 kg a.e. imazapyr + 3.30 kg a.e. triclopyr/ha, 0.02 kg a.i./ha metsulfuron methyl, and 0.04 kg a.i./ha metsulfuron methyl all provided control of shrubs and canopy reduction than triclopyr at rates of 3.30 kg a.e. and 6.60 k.g. a.e./ha. All treatments in this study resulted in increases in herbaceous ground cover, but no change in graminoids was observed at 2 years post-treatment. The increase in herbaceous vegetation observed for all treatments act as fine fuels that facilitate the use of prescribed fire to further reduce willow density and promote establishment on non-woody vegetation. Repeated prescribed burns have been shown to further reduce Carolina willow densities, especially re-sprouts (Lee et al. 2005a). We hypothesize that an integrated management approach using herbicide application and subsequent prescribed fire 2-3 years post-herbicide treatment will result in greater reduction of woody vegetation densities than either method used alone.

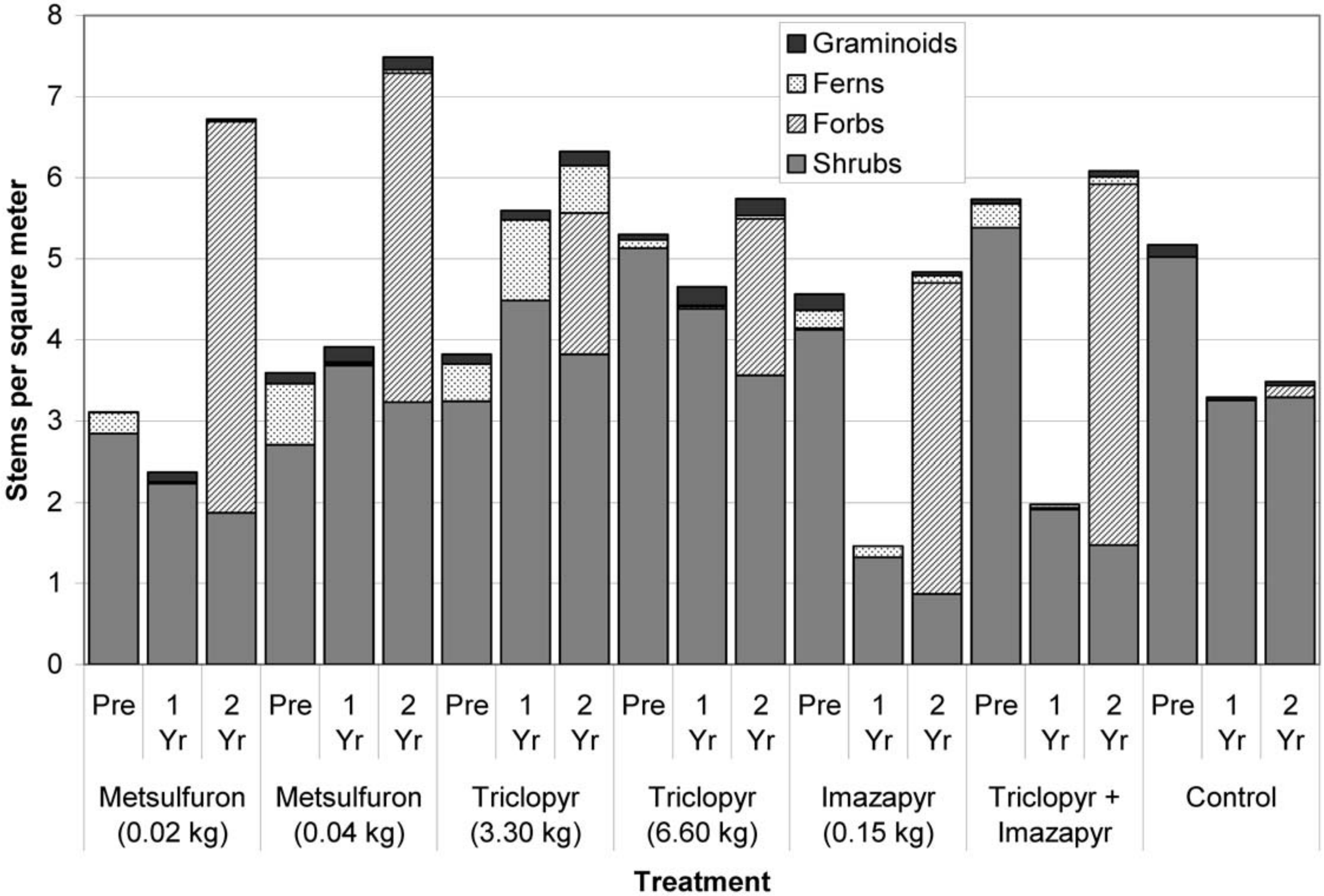

Figure 1. Stem density / m^2 of shrubs, forbs, ferns, and graminoids showing the effects from pre-treatment to 2 years post-treatment for six aerial herbicide application plots and control plots.

As suggested by Ponzio et al. (2004) in analyzing the effects of fire on marsh vegetation, long term monitoring is important to understand the overall relationship of a treatment method in reducing woody vegetation and the re-establishment of vegetation typical of marsh habitat. While our results indicate that herbicides are effective in reducing the densities and canopy cover of woody vegetation over 2 years, further research is needed to determine their impacts on the long-term reduction of woody vegetation and the response of native and exotic grasses, sedges, and other herbaceous species within the treated area. We have shown that herbicide treatment reduces woody vegetation and increases herbaceous vegetation 2 years post-treatment.

Our results using aerial herbicide treatments are comparable with prescribed fire (Lee et al. 2005a, 2005b) and mechanical treatment (Ponzio et al. 2006) but each experiment was different and conducted at different times. Some conclusions based on these studies are that prescribed fire is not effective in controlling woody vegetation (i.e. Carolina willow, buttonbush) unless repeated fires are applied to sites (Lee et al. 2005a, 2005b), mechanical treatment is very effective but not feasible over large areas because the peat soils will not support equipment in most sites where Carolina willow occurs, resulting in severe soil disturbance (Ponzio et al. 2006). With aerial herbicide treatment, our results indicate significant reduction of woody vegetation, reduction of canopy cover, and increases in species richness and species diversity without soil disturbance using metsulfuron methyl, imazapyr and imazapyr + triclopyr at 2 years post-treatment. Additionally, large scale spatial application of selective herbicides to control native woody vegetation can be implemented at lower costs and with less soil disturbance than mechanical treatments and will provide greater long term control of woody vegetation than prescribed fire.

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TABLE 6. SPECIES RICHNESS, P-VALUE AND STANDARD ERROR AT PRE-TREATMENT, 1 YEAR POST TREATMENT, AND 2 YEARS POST TREATMENT FOR SIX AERIAL HERBICIDE TREATMENTS.

	Species Richness		
	Mean (S.E.)		
Herbicide (rate/ha)	Pre-trt	1-Yr Post	2-Yr Post
Metsulfuron methyl (0.02 kg a.i.)	2.7 (0.3)	2.2 (0.2)	4.8* (0.3)
Metsulfuron methyl (0.04 kg a.i.)	3.3 (0.4)	2.7 (0.2)	5.4* (0.4)
Triclopyr (3.30 kg a.e.)	3.6 (0.4)	3.5 (0.4)	6.1* (0.5)
Triclopyr (6.60 kg a.e.)	2.7 (0.3)	3.2 (0.4)	5.4* (0.3)
Imazapyr (0.15 kg a.e)	3.8 (0.3)	2.0* (0.2)	5.6* (0.4)
Imazapyr (0.15 kg) + triclopyr amine (3.3 kg)	3.2 (0.3)	2.2 (0.2)	5.6* (0.4)
Control	2.9 (0.5)	2.6 (0.2)	2.8 (0.3)

*—Indicates significant differences ($P < 0.05$) compared to pre-treatment based on independent sample t-tests for unequal variances.

TABLE 7. SIMPSON'S INDEX OF DIVERSITY, P-VALUE AND STANDARD ERROR AT PRE-TREATMENT, 1 YEAR POST TREATMENT, AND 2 YEARS POST TREATMENT FOR SIX AERIAL HERBICIDE TREATMENTS.

	Simpson's Index of Diversity		
	Mean (S.E.)		
Herbicide (rate/ha)	Pre-trt	1-Yr Post	2-Yr Post
Metsulfuron methyl (0.02 kg a.i.)	0.40 (0.06)	0.24 (0.06)	0.63* (0.02)
Metsulfuron methyl (0.04 kg a.i.)	0.51 (0.05)	0.20* (0.05)	0.65* (0.03)
Triclopyr (3.30 kg a.e.)	0.43 (0.02)	0.38 (0.07)	0.64* (0.03)
Triclopyr (6.60 kg a.e.)	0.33 (0.05)	0.33 (0.04)	0.65* (0.03)
Imazapyr (0.15 kg a.e)	0.40 (0.03)	0.23* (0.06)	0.63* (0.04)
Imazapyr (0.15 kg) + triclopyr (3.3 kg)	0.40 (0.03)	0.26* (0.04)	0.59* (0.06)
Control	0.35 (0.03)	0.37 (0.03)	0.39 (0.04)

*—Indicates significant differences ($P < 0.05$) compared to pre-treatment based on independent sample t-tests for unequal variances.

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