Sethoxydim performance on torpedograss (*Panicum repens*) and sand cordgrass (*Spartina bakeri*) as affected by carrier volume and rate

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Abstract

Greenhouse experiments were conducted in 2020 to investigate the effects of carrier volume and sethoxydim rate on torpedograss (*Panicum repens* L.) control and sand cordgrass (*Spartina bakeri* Merr.) response from a single application. *Panicum repens* control and biomass reduction generally increased with increasing sethoxydim rates in evaluations at 14, 28, and 42 d after treatment (DAT); however, increasing the rate to 2X the maximum labeled rate did not always result in increased efficacy. In the first experimental run, which consisted of small plants, *P. repens* control and biomass reductions were largely similar among tested carrier volumes (37, 187, and 935 L ha^{-1}). However, in run 2, which consisted of larger, mature *P. repens* plants, efficacy increased when carrier volume was reduced. *Spartina bakeri* injury increased with sethoxydim rate, reaching a maximum of 45% by 42 DAT. However, no differences in *S. bakeri* injury among carrier volumes were observed at 14 and 28 DAT evaluations. *Spartina bakeri* aboveground biomass reductions were also largely driven by sethoxydim rate increases rather than reduced carrier volumes, reaching 40% to 50% reduction in initial aboveground biomass. However, *S. bakeri* belowground biomass was 20% to 32% greater in treatments applied at 37 or 187 L ha^{-1} compared with those at 935 L ha^{-1}. Overall, these data suggest that selective *P. repens* control with sethoxydim may be enhanced through reducing carrier volumes from 935 L ha^{-1} and that native, perennial, caespitose grasses may exhibit greater tolerance to sethoxydim compared with the rhizomatous *P. repens*. Future research should further test these hypotheses under field conditions at operational scales.

Introduction

Torpedograss (*Panicum repens* L.) is a perennial rhizomatous grass native to Africa and Eurasia that was introduced to the United States during the 1800s (Langeland et al. 2008). It was widely distributed throughout Florida for use as a wetland cattle forage in the early 1900s but escaped cultivation; by 1992, it was observed in more than 70% of public waters in the state (MacDonald et al. 2008). *Panicum repens* is found in both terrestrial and aquatic habitats, including lakeshores, marshes, and riparian systems (Wunderlin et al. 2019). In aquatic systems, it grows along shorelines and in the water as floating mats, where it negatively impacts fish habitat and alters water quality (Hanlon and Brady 2005; Hanlon and Langeland 2000). *Panicum repens* tolerates moderate levels of salinity and can be found in both freshwater and some brackish environments (Hossain et al. 1999; Prince and Macdonald 2020; Smith et al. 1999).

Sand cordgrass [*Spartina bakeri* Merr.] is a native caespitose grass found primarily in Florida but also present in Georgia, South Carolina, and Texas. It is abundant in both fresh and brackish marsh systems, including those around Lake Okeechobee (Zhang et al. 2021), Indian River Lagoon (Schmalzer 1995), Ten Thousand Islands National Wildlife Refuge (Howard et al. 2017), and generally across coastal prairies of peninsular Florida (Wade et al. 1980). *Spartina bakeri* is a robust perennial, growing to heights of 2 m, and can form large dense clumps. It is an important graminoid component in the fire ecology of Florida marshes (Schmalzer et al. 1991). Although not well studied, *S. bakeri* co-occurs with prominent marsh invaders, including *P. repens* and old world climbing fern [*Lygodium microphyllum* (Cav.) R. Br.] (Hutchinson and Langeland 2008). Therefore, *S. bakeri* is often a non-target concern for invasive plant control operations in marsh systems. While its response to fire and flooding have been studied (Schmalzer 1995), limited data exist on its tolerance to herbicides. Hutchinson and Langeland (2008) examined the impact of the herbicide metsulfuron on several native marsh species, including *S. bakeri*, and found a high degree of tolerance to rates commonly used for *L. microphyllum* control. This type of selectivity is highly desirable in

Management Implications

Panicum repens (torpedograss) is an invasive wetland grass in the southeastern United States. Glyphosate and imazapyr are commonly used for its control but are nonselective and may have non-target effects on valued native species such as *Spartina bakeri* (sand cordgrass). Sethoxydim is a grass-specific herbicide that was recently granted a 24(c) special local needs label for use in Florida. While it has shown some efficacy on *P. repens* and selectivity toward native dicot species, there is a need to optimize its use both to control *P. repens* and to limit damage to native grasses. Here, we evaluated the effect of application carrier volume and sethoxydim rate on *P. repens* and *S. bakeri*. Based on our results, managers may control or suppress *P. repens* by reducing carrier volumes from 935 L ha^{-1} to 187 or 37 L ha^{-1} with improved selectivity on *S. bakeri*. Overall, injury to *S. bakeri* was less than 40% across application rates and carrier volumes, suggesting that sethoxydim may provide some level of selectivity toward this native grass species. Managers may wish to use sethoxydim instead of glyphosate or imazapyr in areas where *P. repens* and *S. bakeri* are co-occurring, or as a follow-up treatment for regrowth of *P. repens* in areas where *S. bakeri* has been planted for restoration.

invasive plant management. However, herbicide selectivity between invasive and native grasses is generally lacking.

Current management strategies for *P. repens* rely on nonselective, systemic herbicides such as glyphosate and imazapyr (Enloe and Netherland 2017; Hanlon and Langland 2000). However, repeated applications are often necessary to achieve control of *P. repens*, and there are concerns about non-target damage to native species (Enloe and Netherland 2017; Smith et al. 1993). This has led to increased interest in the use of graminicides such as sethoxydim, which was granted a 24(c) special local needs label for invasive grass management in aquatic habitats in Florida (Anonymous 2017). Sethoxydim inhibits fatty-acid synthesis by targeting the acetyl-coenzyme A carboxylase (ACCase) enzyme and is highly selective toward native dicot species (Burton et al. 1989; Enloe and Netherland 2017). However, little is known about its selectivity toward non-target native grasses such as *S. bakeri*.

While greenhouse experiments suggest high efficacy of sethoxydim on *P. repens* (Enloe and Netherland 2017), field evaluations have resulted in marginal control compared with glyphosate and imazapyr and required multiple applications per season, which significantly increases management costs (Enloe et al. 2018). In addition, sethoxydim may be less effective on *P. repens* under flooded conditions (Prince et al. 2019). Consequently, the product has not been widely adopted by managers in Florida. One possible way to increase sethoxydim efficacy is to alter its application technique. Foliar aquatic herbicide applications are largely made via airboat using high carrier volumes (average 935 L ha^{-1}) (Haller 2020). However, spray retention on the target plant can be low when using high carrier volumes (Sperry et al. 2022), and recent research suggests that reducing carrier volume to 187 L ha^{-1} increases efficacy of glyphosate, diquat, and 2,4-D on the aquatic plant water hyacinth [*Eichhornia crassipes* (Mart.) Solms] (Sperry and Ferrell 2021). Buhler and Burnside (1984) reported increased phytotoxicity of sethoxydim on forage sorghum [*Sorghum bicolor* (L.) Moench] and yellow foxtail [*Setaria pumila* (Poir.) Roem. & Schult.] with decreasing carrier volume. Likewise, Lassiter and Coble (1987) reported enhanced control of large crabgrass

[*Digitaria sanguinalis* (L.) Scop.], fall panicum (*Panicum dichotomiflorum* Michx.), and goosegrass [*Eleusine indica* (L.) Gaertn.] with sethoxydim when carrier volume was reduced. However, other research suggests the effect of carrier volume on sethoxydim efficacy for other annual grasses may be influenced by environmental conditions (Harrison et al. 1986). Therefore, it would be very useful to also understand how these application characteristics influence potential sethoxydim injury on non-target native grasses. This is especially important for species like *S. bakeri* that are prominent in Florida marshes. Given these issues, our objective was to evaluate the effect of carrier volume and sethoxydim rate on *P. repens* control and *S. bakeri* response. Understanding this issue would potentially improve *P. repens* management within a restoration context.

Materials and Methods

A greenhouse experiment was conducted in 2020 at the University of Florida's Center for Aquatic and Invasive Plants (CAIP) in Gainesville, FL (29.721542°N, 82.417300°W). The experiment was set up as a completely randomized design with four replications and a factorial arrangement of treatments plus a nontreated control (NTC). Factors consisted of carrier volume (935, 187, and 37 L ha^{-1}) and sethoxydim rate (263, 526, and 1,052 g ai ha^{-1}) (TIGR™ herbicide, SePRO, Carmel, IN, USA). Carrier volumes represented a typical high-volume spray-gun application, common broadcast application volume, and a low-volume application (Haller 2020). Sethoxydim rates represented 0.5X, 1X, and 2X the maximum label rate per hectare per application. Two independent runs were conducted. The first treatment was on June 8, 2020, and the second on June 25, 2020.

Panicum repens was established from stolons collected independently in early and mid-April for experimental runs 1 and 2, respectively, from a population growing in a pond at the University of Florida CAIP. Stolon fragments, 15 cm in length, were placed into tubs filled with water. Two weeks later, fragments that initiated new shoots and roots were selected for uniformity and planted into forty 3.8-L pots containing potting mix (Sun Gro® Metro-Mix 510, Sun Gro Horticulture, Agawam, MA, USA) amended with slow-release fertilizer (15-9-12, Osmocote® Plus, Scotts, Maryville, OH, USA) for each run. For *S. bakeri*, 1-yr-old established plants in 2.3-L pots were purchased from the Chiappini Farm Native Nursery (Hawthorne, FL, USA). A single plant from each pot was then subdivided equally into four separate pots. A total of 40 pots were planted in this manner for each run. *Spartina bakeri* plants were watered once daily via overhead irrigation, and *P. repens* plants were placed in 7-L tubs and subirrigated with well water. The water level in *P. repens* tubs was evaluated daily and maintained at 5 cm. Greenhouse temperatures were maintained at 29/24 C (max./min.) for the duration of the experiment. For both experimental runs, plants were allowed to establish for 8 wk before treatment.

Herbicide treatments were applied using a two-nozzle handheld boom and a CO$_2$-pressurized backpack sprayer. The sprayer was calibrated to deliver 935, 187, or 37 L ha^{-1} using XR11005, XR11002, and XR1100067 nozzles (TeeJet®, Spraying Systems, Wheaton, IL, USA) at 276 kPa, respectively. Travel speed was adjusted to deliver the desired volumes. All treatments included a methylated seed oil (MSO) surfactant (Alligare MSO, Alligare, Opelika, AL, USA) at 0.25 % v/v. To reduce spray drift potential and cross-contamination, plants were sprayed outside the greenhouse and allowed to dry before being returned to greenhouse conditions.

Table 1. Visually evaluated *Panicum repens* percent control at 14, 28, and 42 d after treatment (DAT) as affected by main effects of sethoxydim rate and carrier volume from experiments conducted under greenhouse conditions in 2020.

	Panicum repens % control[a]					
	14 DAT		28 DAT		42 DAT	
Main effect	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2
Sethoxydim rate (g ai ha^{-1})						
263	84 C	2 c*	90 B	8 b*	83 B	19 c
526	93 B	33 b	98 A	44 a	99 A	41 b
1,052	99 A	41 a	100 A	48 a	100 A	65 a
Carrier volume (L ha^{-1})						
37	99 A	25 a	99 A	37 a	99 A	61 a
187	95 A	23 a	97 A	29 a	96 A	39 a
935	85 B	17 b*	96 A	27 b	94 A	24 c

[a]Means followed by the same letter within a column and main effect are not different according to Fisher's LSD test (α = 0.05). Means followed by an asterisk (*) are not different from the nontreated control according to paired *t*-test (α = 0.05).

Table 2. *Panicum repens* biomass percent reduction as affected by main effects of sethoxydim rate and carrier volume from experiments conducted under greenhouse conditions in 2020.

	Panicum repens biomass % reduction[a]					
	Initial aboveground		Final aboveground		Final belowground	
Main effect	Run 1	Run 2	Run 1	Run 2	Run 1	Run 2
Sethoxydim rate (g ai ha^{-1})						
263	71 B	1 b*	98 B	25 b	95 B	57 b
526	90 A	26 ab	100 A	22 b	100 A	61 b
1,052	93 A	37 a	100 A	57 a	100 A	81 a
Carrier volume (L ha^{-1})						
37	90 A	12 b*	100 A	45 a	99 A	74 a
187	74 B	54 a	100 A	36 ab	99 A	67 ab
935	91 A	0 b*	99 A	23 b	98 A	57 b
NTC (g)[b]	4.9	29.6	8.1	4.0	21.9	36.0

[a]Means followed by the same letter within a column and main effect are not different according to Fisher's LSD test (α = 0.05). Means followed by an asterisk (*) are not different from the nontreated control according to paired *t*-test (α = 0.05). Mean pretreatment aboveground and belowground biomass values were 1.9 and 1.6 g for run 1; and 2.7 and 2.4 g for run 2, respectively.
[b]NTC, nontreated control. Biomass given in grams.

Plants were visually evaluated for percent control (*P. repens*) or percent injury (*S. bakeri*) on a scale from 0% (no effect) to 100% (plant death) at 14, 28, and 42 d after treatment (DAT). After 42 DAT visual evaluations, aboveground biomass was harvested at the soil level, dried in a forced-air drying oven at 60 C for 5 d, and weighed. After 6 wk of regrowth, plants were evaluated for final oven-dried above- and belowground biomass. All data were subjected to two-way ANOVA, and means were separated using Fisher's LSD test (α = 0.05) in the AGRICOLAE package in R (v. 3.6.1; Mendiburu 2019; R Core Team 2019). Percent control or injury data were arcsine square-root transformed to meet ANOVA assumptions, but back-transformed means are presented. Biomass data were normalized to the NTC and also arcsine square-root transformed. Biomass treatment means were also compared with the NTC by a paired *t*-test (α = 0.05).

Results and Discussion

Panicum repens data are presented as separate experimental runs due to an interaction between run and main effects for both visually evaluated control and biomass reductions. The differential response between runs was likely driven by plant maturity at the time of treatment; plants in run 1 were smaller than those in run 2 and had not yet developed an extensive network of rhizomes. No interactions between main effects (carrier volume and sethoxydim rate) were detected for *P. repens* control or biomass reduction data; however, main effects (sethoxydim rate and carrier volume) were independently significant (Tables 1 and 2).

Panicum repens control increased with increasing sethoxydim rate in both experimental runs at 14 DAT (Table 1). In run 1, control increased from 84% to 99% for the 263 and 1,052 g ha^{-1} rates, respectively. In run 2, control increased from 2% to 41% for the same rates. Additionally, *P. repens* control at 14 DAT from the 263 g ha^{-1} rate in run 2 did not differ from the NTC. At 28 DAT, although the magnitude of control was different between runs, the pattern of sethoxydim activity was consistent. *Panicum repens* control in both runs was greatest in plants treated with 526 or 1,052 g ha^{-1} and the lowest sethoxydim rate in run 2 did not result in control levels different from that of the NTC. By 42 DAT in run 1, *P. repens* control was 99% or greater when at least 526 g ha^{-1} sethoxydim was applied. Conversely, *P. repens* control at 42 DAT in run 2 ranged from 19% to 65% and increased incrementally with sethoxydim rate.

Carrier volume effects on *P. repens* control in run 1 were only detected at 14 DAT, when maximum control was observed in the two lowest carrier volumes (Table 1). *Panicum repens* control was at least 94% by 28 and 42 DAT in run 1 regardless of carrier volume. However, carrier volume influenced *P. repens* control for run 2 for all data-collection dates. At 14 DAT, *P. repens* control was 6% to 8% greater in the two lowest carrier volumes than in treatments at 935 L ha^{-1}. By 28 DAT, *P. repens* control was greatest in treatments applied at 37 L ha^{-1} (37% control). By 42 DAT, the control achieved with a carrier volume of 37 L ha^{-1} was more than double the control that was achieved at 935 L ha^{-1}. In addition, control was greater in treatments applied at 187 L ha^{-1} than at 935 L ha^{-1}.

When analyzed by sethoxydim rate, *P. repens* initial aboveground biomass reduction generally followed a similar pattern between runs, with the highest sethoxydim rate providing a greater biomass reduction than the lowest rate (Table 2). Final aboveground biomass was reduced at least 98% in run 1, indicating very little regrowth at all three sethoxydim rates. However, in run 2, sethoxydim at 1,052 g ha^{-1} reduced *P. repens* final aboveground biomass 57% compared with only 25% and 22% at 263 and 526 g ha^{-1}, respectively. The final belowground biomass was reduced by 95% to 100% in run 1 and 57% to 81% in run 2.

The influence of carrier volume on *P. repens* biomass reduction differed between experimental runs (Table 2). In run 1, no meaningful differences were observed on smaller plants for final above- or belowground biomass. In run 2, the influence of carrier volume on larger, more established plants was not clear from the initial aboveground biomass harvest. This may be the result of variation in dead standing biomass at the time of initial harvest. However, the final aboveground and final belowground biomass harvests indicated that decreasing carrier volumes from 935 to 37 L ha^{-1} resulted in better *P. repens* control.

For *S. bakeri* data, there were no significant interactions found between main effects and experimental runs. Therefore, data were pooled across experimental runs. The lack of differences between experimental runs for *S. bakeri* contrasted with that observed for *P. repens*. This was likely due to the different belowground allocation strategies between caespitose and rhizomatous grasses. At 14 DAT, only the highest rate of sethoxydim resulted in injury (17%) that was different from that of the NTC; however, no differences in

Table 3. Visually evaluated *Spartina bakeri* percent injury at 14, 28, and 42 d after treatment (DAT) as affected by main effects of sethoxydim rate and carrier volume from experiments conducted under greenhouse conditions in 2020.

	Spartina bakeri % visual injury[a]		
Main effect	14 DAT	28 DAT	42 DAT
Sethoxydim rate (g ai ha^{-1})			
263	8 a*	20 b	23 b
526	11 a*	32 ab	37 a
1,052	17 a	37 a	45 a
Carrier volume (L ha^{-1})			
37	12 a	32 a	35 ab
187	13 a	32 a	40 a
935	9 a*	26 a	30 b

[a]Means followed by the same letter within a column and main effect are not different according to Fisher's LSD test ($\alpha = 0.05$). Means followed by an asterisk (*) are not significantly different from the nontreated control according to paired *t*-test ($\alpha = 0.05$).

Table 4. *Spartina bakeri* percent biomass reduction as affected by main effects of sethoxydim rate and carrier volume from experiments conducted under greenhouse conditions in 2020.

	Spartina bakeri biomass % reduction[a]		
Main effect	Initial aboveground	Final aboveground	Final belowground
Sethoxydim rate (g ai ha^{-1})			
263	36 b	2 b*	24 b
526	45 ab	11 b*	29 b
1,052	51 a	29 a	47 a
Carrier volume (L ha^{-1})			
37	46 a	18 a	48 a
187	41 a	18 a	36 a
935	44 a	6 a*	16 b
NTC (g)[b]	36.3	9.4	81.3

[a]Means followed by the same letter within a column and main effect are not different according to Fisher's LSD test ($\alpha = 0.05$). Means followed by an asterisk (*) are not different from the nontreated control according to paired *t*-test ($\alpha = 0.05$). Mean pretreatment aboveground and belowground biomass values were 26.2 and 22.4 g, respectively.
[b]NTC, nontreated control. Biomass given in grams.

injury were observed among the treated rates (Table 3). At 28 DAT, all three sethoxydim rates resulted in *S. bakeri* injury and ranged from 20% to 37%. A generally similar pattern of injury was observed at 42 DAT with the highest two sethoxydim rates, which resulted in 14% to 22% greater injury than the lowest rate (Table 3).

The influence of carrier volume on sethoxydim injury to *S. bakeri* did not follow a similar pattern to *P. repens*. At 14 DAT, *S. bakeri* injury was not different between any carrier volumes; however, treatments applied at 37 and 187 L ha^{-1} resulted in 12% and 13% injury, respectively, which was different from that of the NTC (Table 3). At 28 DAT, *S. bakeri* injury ranged from 26% to 32% among all three carrier volumes, with no differences among treated plants. By 42 DAT, injury ranged between 30% and 40%. Although these were all different from that of the NTC, there was no clear pattern of injury related to carrier volume.

Spartina bakeri biomass reduction was influenced by sethoxydim rate for all parameters measured. Sethoxydim at 1,052 g ha^{-1} reduced initial aboveground biomass by 51%, whereas 263 g ha^{-1} reduced biomass by 36% (Table 4). Final aboveground biomass was reduced by sethoxydim at the highest rate only. Final belowground biomass was reduced by all three sethoxydim rates and ranged from 24% to 47%, increasing with sethoxydim rate.

The influence of carrier volume on *S. bakeri* biomass varied by each biomass parameter measured (Table 4). All three carrier volumes resulted in 41% to 46% initial aboveground biomass reduction with no differences among treatments. For final aboveground biomass, the two lower carrier volumes resulted in an 18% reduction and were different from that of the NTC. The highest carrier volume did not differ in final aboveground biomass compared with that of the NTC. Final belowground biomass was reduced in all three carrier volume treatments compared with that of the NTC; however, reductions were greatest in the 37 and 187 L ha^{-1} treatments.

These results demonstrate several key points that contribute to our understanding of aquatic and wetland invasive grass management with sethoxydim. First, we observed significant differences in sethoxydim efficacy between the two runs, which was very likely plant size related. In the first run, the smaller, less-established *P. repens* plants were effectively controlled by all three sethoxydim rates. This was reflected in both the visually evaluated control and the above- and belowground biomass data. This supports the use of sethoxydim in treatment of incipient infestations before plants become well established where infested sites are likely to have greater plant diversity. In these scenarios, the use of traditional nonselective options, glyphosate and imazapyr, would likely cause excessive non-target damage. While aggressive monitoring would be required to implement this strategy, current maintenance control operations already in place for other invasive plants could be modified to monitor for new *P. repens* infestations in many public waters in Florida. Maintenance control has been well documented to be a more effective approach for management of nuisance and invasive floating plants in Florida (Joyce 1985), and incorporating selective *P. repens* control with sethoxydim could prevent new infestations from becoming problematic.

Second, when sethoxydim efficacy was less effective, we observed better control at the higher concentration tested, especially for belowground biomass. The current 24(c) sethoxydim label for Florida allows for single applications up to 526 g ha^{-1} (40 oz per acre) and spot treatments up to 5% v/v (Anonymous 2017). In our study, we found the 2X maximum labeled rate (1,052 g ha^{-1}), which would result in a greater solution concentration similar to a spot treatment, was more effective than the 1X max label rate for reducing *P. repens* belowground biomass. Our data are in agreement with previous greenhouse work in which sethoxydim applied at 560 g ai ha^{-1} in the summer and fall reduced *P. repens* biomass by approximately 60% and 75%, respectively (Enloe and Netherland 2017).

Third, we observed that reduced carrier volume improved *P. repens* control for sethoxydim in terms of final above- and belowground biomass harvests. While high-volume handgun applications are widely used for aquatic plant control, our work provides some support for reducing carrier volume, similar to other recent aquatic studies (Sperry and Ferrell 2021). Reducing carrier volume increases herbicide concentration of the spray solution, which in turn drives increased herbicide uptake and translocation, especially for systemic herbicides (Knoche 1994). Previous studies that evaluated terrestrial grass weeds also noted increased efficacy and consistency when sethoxydim was applied in lower carrier volumes (Lassiter and Coble 1987; McMullan 1995). Furthermore, these data confirm that sethoxydim efficacy could be maintained in aerial or ground broadcast applications that utilize much lower carrier volumes; however, the current label instructions require applications to be made at a minimum of 140 L ha^{-1} (Anonymous 2017).

Fourth, we observed some tolerance of *S. bakeri* to sethoxydim at all concentrations tested. While absolute sethoxydim selectivity,

which is typical for dicots that have an insensitive ACCase enzyme, was not observed, we did observe injury of 45% or less. This would likely be better than the nonselective herbicides glyphosate and imazapyr, as has been shown for other species (Enloe and Netherland 2017; Hedge et al. 2003; Mateos-Naranjo et al. 2009, 2012; Patten 2002). We did not test these in this study, as we chose to focus exclusively on sethoxydim concentration and carrier volume.

Finally, altered carrier volume did not have a consistent effect on *S. bakeri* injury, initial aboveground biomass, and final aboveground biomass. While these results were promising, we did observe the two lower carrier volumes reduced belowground biomass significantly more than the highest application volume. This pattern was also somewhat observed, albeit to a greater extent, in *P. repens* rather than the non-target *S. bakeri*. Future research should incorporate field studies that examine the carrier volume–sethoxydim concentration relationship for *P. repens* control and nontarget native grasses, including *S. bakeri*.

References

Anonymous (2017) TIGR herbicide FIFRA 24(c)-special local needs label. Carmel, IN: SePRO Corporation. 5 p

Buhler DD, Burnside OC (1984) Effect of application factors on postemergence phytotoxicity of fluazifop-butyl, haloxyfop-methyl, and sethoxydim. Weed Sci 32:574–583

Burton JD, Gronwold JW, Somers DA, Gengenback BG, Wyse DL (1989) Inhibition of corn acetyl-CoA carboxylase by cyclohexanedione and aryloxyphenoxypropionate herbicides. Pestic Biochem Physiol 34:76–85

Enloe SF, Netherland MD (2017) Evaluation of three-grass specific herbicides on torpedograss (*Panicum repens*) and seven nontarget, native aquatic plants. J Aquat Plant Manag 55:65–70

Enloe SF, Netherland MD, Lauer DK (2018) Evaluation of sethoxydim for torpedograss control in aquatic and wetland sites. J Aquat Plant Manag 56:93–100

Haller WT (2020) Aquatic herbicide application methods. Pages 191–196 *in* Gettys LA, Haller WT, Petty DG, eds. Biology and Control of Aquatic Plants: A Best Management Practices Handbook. 4th ed. Marietta, GA: Aquatic Ecosystem Restoration Foundation

Hanlon CG, Brady M (2005) Mapping the distribution of torpedograss and evaluating the effectiveness of torpedograss management activities in Lake Okeechobee, Florida. J Aquat Plant Manag 43:24–29

Hanlon CG, Langeland KA (2000) Comparison of experimental strategies to control torpedograss. J Aquat Plant Manag 38:40–47

Harrison SK, Wax LM, Bode LE (1986) Influence of adjuvants and application variables on postemergence weed control with bentazon and sethoxydim. Weed Sci 34:462–466

Hedge P, Kriwoken LK, Patten K (2003) A review of spartina management in Washington State, US. J Aquat Plant Manag 41:82–90

Hossain MA, Ishimine Y, Akamine H, Murayama S, Uddin SMM, Kuniyoshi K (1999) Effect of burial depth on emergence of *Panicum repens*. Weed Sci 47:651–656

Howard RJ, Day RH, Krauss KW, From AS, Allain L, Cormier N (2017) Hydrologic restoration in a dynamic subtropical mangrove-to-marsh ecotone. Restor Ecol 25:471–482

Hutchinson JT, Langeland KA (2008) Response of selected nontarget native Florida wetland plant species to metsulfuron-methyl. J Aquat Plant Manag 46:72–76

Joyce JC (1985) Benefits of maintenance control of waterhyacinth. Aquatics 7:11–13

Knoche M (1994) Effect of droplet size and carrier volume on performance of foliage-applied herbicides. Crop Prot 13:163–178

Langeland KA, Cherry HM, McCormick CM, Craddock Burks KA (2008) Identification and Biology of Nonnative Plants in Florida Natural Areas. Gainesville: University of Florida IFAS Communications Services. 193 p

Lassiter RB, Coble HD (1987) Carrier volume effects on the antagonism of sethoxydim by bentazon. Weed Sci 35:541–546

MacDonald GE, Ferrell J, Sellers B, Langeland K, Duperron-Bond OT, Ketterer-Guest E (2008) Torpedograss—Panicum repens. University of Florida Institute of Food and Agricultural Sciences, Center for Aquatic and Invasive Plants. https://plants-archive.ifas.ufl.edu/plant-directory/panicum-repens. Accessed: April 11, 2023

Mateos-Naranjo E, Cambrolle J, Lomas JGD, Parra R, Redondo-Gomez S (2012) Mechanical and chemical control of the invasive cordgrass *Spartina densiflora* and native plant community responses in an estuarine salt marsh. J Aquat Plant Manag 50:106–111

Mateos-Naranjo E, Redondo-Gomez S, Cox L, Cornejo J, Figueroa ME (2009) Effectiveness of glyphosate and imazamox on the control of the invasive cordgrass *Spartina densiflora*. Ecotoxicol Environ Saf 72:1694–1700

McMullan PM (1995) Effect of spray volume, spray pressure and adjuvant volume on efficacy of sethoxydim and fenoxaprop-*p*-ethyl. Crop Prot 14:549–554

Mendiburu F (2019) agricolae: Statistical Procedures for Agricultural Research. R Package Version 1.3-1. https://CRAN.R-project.org/package=agricolae. Accessed: April 11, 2023

Patten K (2002) Smooth cordgrass (*Spartina alterniflora*) control with imazapyr. Weed Technol 16:826–832

Prince CM, Macdonald GE (2020) Chemical control of torpedograss and common reed under altered salinity conditions. J Aquat Plant Manag 58:26–35

Prince CM, Quincy KH, Enloe SF, Macdonald GE, Netherland M (2019) Torpedograss response to herbicide treatment in saturated and flooded conditions. J Aquat Plant Manag 57:23–27

R Core Team (2019) R: A Language and Environment for Statistical Computing. Vienna, Austria: R Foundation for Statistical Computing. https://www.R-project.org

Schmalzer PA (1995) Biodiversity of saline and brackish marshes of the Indian River Lagoon: historic and current patterns. Bull Mar Sci 57:37–48

Schmalzer PA, Hinkle CR, Mailander JL (1991) Changes in community composition and biomass in *Juncus roemerianus* Scheele and *Spartina bakeri* Merr. marshes one year after a fire. Wetlands 11:67–86

Smith BE, Langeland KA, Hanlon CG (1999) Influence of foliar exposure, adjuvants, and rain-free period on the efficacy of glyphosate for torpedograss control. J Aquat Plant Manag 37:13–16

Smith BE, Shilling DG, Haller WT, MacDonald GE (1993) Factors influencing the efficacy of glyphosate on torpedograss (*Panicum repens* L.). J Aquat Plant Manage 31:199–202

Sperry BP, Ferrell JA (2021) Effect of carrier volume and application method on waterhyacinth (*Eichhornia crassipes*) response to 2,4-D, glyphosate, and diquat. Invasive Plant Sci Manag 14:29–34

Sperry BP, Mudge CR, Getsinger KD (2022) Simulated herbicide spray retention on floating aquatic plants as affected by carrier volume and adjuvant type. Weed Technol 36:56–63

Wade D, Ewel J, Hofstetter R (1980) Fire in South Florida Ecosystems. Asheville, NC: U.S. Department of Agriculture Forest Service General Technical Report SE-17. 125 p

Wunderlin RP, Hansen BF, Franck AR, Essig FB (2019) Atlas of Florida Plants. Landry SM, Campbell KN, application development, USF Water Institute. Tampa: Institute for Systematic Botany, University of South Florida. http://florida.plantatlas.usf.edu. Accessed: April 11, 2023

Zhang C, Denka S, Deepak RM (2021) Mapping freshwater marsh species in the wetlands of Lake Okeechobee using very high-resolution aerial photography and lidar data. Pages 4–22 *in* Chen Q, Kutser T, Collin A, Warner TA, eds. Fine Resolution Remote Sensing of Species in Terrestrial and Coastal Ecosystems. Oxfordshire, UK: Routledge T&F