Herbicide efficacy on the small floating weeds redroot floater and feathered mosquitofern

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Abstract. **Redroot floater and feathered mosquitofern are relatively recent invaders in Florida's waters. Both species are small (< 3 cm) obligate aquatic plants that float on the surface of the water with their roots dangling in the water column. We conducted greenhouse experiments in mesocosms to evaluate the efficacy of 13 foliar-applied aquatic herbicides alone and in combination for a total of 35 treatments. Plants were treated once and grown out for 6 weeks after treatment, then scored for visual quality and destructively harvested to determine dry biomass. Most herbicides provided effective control (reduction in visual quality and biomass of at least 90% compared to untreated controls) of redroot floater and feathered mosquitofern. Both species were susceptible to any mix that included diquat, and the majority of herbicides evaluated also performed well alone. These findings suggest that lackluster results after field management of these species are not due to herbicide tolerance, but are likely the result of other factors. Both species tolerate shoreline stranding, and stranded plants can escape herbicide treatments by persisting in wet soil**

along the banks of a treated area. Once floating populations have been killed as a result of herbicide treatment, stranded plants may flush back into the water, where they can quickly re-populate the treated area (which is now nutrient-enriched from the dying plants) with greatly reduced intraspecific competition. Therefore, it is critically important that all plants targeted for treatment – including those stranded along shorelines – actually receive herbicide applications.

Florida's waters are routinely invaded by new exotic plants. Although the invasion pathways for these species are varied, many introduced aquatic plants arrive in Florida's waters after escaping cultivation in water gardens and aquariums. Two relatively recent floating invaders are redroot floater (*Phyllanthus fluitans* Benth. ex Müll. Arg.) and the Federal Noxious Weed feathered mosquitofern (*Azolla pinnata* R. Brown).

Redroot floater, also called floating spurge, is a South American dicot in the Euphorbiaceae (USDA NRCS 2019a) or the Phyllanthaceae (USDA APHIS 2017) and was first reported in a canal attached to the Peace River west of Fort Ogden (Desoto County, Florida) in 2010 (Sowinski 2011). The species is an attractive free-floating ornamental plant with round, concave leaves that are up to 2 cm long and attached to the reddish stems in a distichous manner. There is a lack of information available regarding seed production and viability, but redroot floater reproduces easily via fragmentation (Wilder and Sowinski 2010). It is considered established in the Peace River (Sowinski 2017) and has not been found in other states in the US (USDA NRCS 2019a). However, redroot floater is naturalized in Mexico (Steinmann 2002) and its potential range includes the southeastern US as far north as North Carolina and west into Texas (USDA

APHIS 2017). Despite being a “high-risk” species, with the likelihood of it becoming a major or minor invader being 54% and 44%, respectively (USDA APHIS 2017), redroot floater is not a prohibited plant or noxious weed and is readily available through the aquarium and water garden trade.

Feathered mosquitofern is an Australian fern that was formerly placed in the Salviniaceae but is now in the family Azollaceae (Madeira et al. 2013, Smith et al. 2006). It was first collected in Florida’s waters near Jupiter (Palm Beach County, Florida) in 2007 (Bodle 2008) and is now in at least four Florida counties (Wunderlin et al. 2019), North Carolina (USDA NRCS 2019b), and possibly Arizona and Louisiana (Pfingsten et al. 2019). Like other members of the genus *Azolla*, feathered mosquitofern has very small (ca. 1 mm) velvety leaves that are attached to the branch in an alternate manner. The upper lobe of each leaf hosts the nitrogen-fixing cyanobacterium *Anabaena azollae*, which has resulted in this and other species of *Azolla* being used in rice cultivation. Feathered mosquitofern is roughly deltoid or triangular in shape and is often larger (1.5 to 3 cm long) than other members of the genus (Jacono 2016). As mentioned earlier, feathered mosquitofern is a Federal Noxious Weed (USDA NRCS PPQ 2012).

Despite their very different botanical classifications, these small floating species share a number of characteristics. For example, both species form dense mats via vegetative means and cause ecosystem harm by blocking light and oxygen penetration into the water column. They also interfere with recreational activities such as boating, fishing and swimming. In addition, both feathered mosquitofern and redroot floater appear to be able to survive out of the water on damp soil along canals, ponds and other aquatic systems.

Control efforts thus far have not resulted in eradication; in fact, both species continue to persist and form nascent populations in waters connected to invaded aquatic systems. Although the current distribution of both species is primarily southern Florida, future range expansion is likely. It is critical that we identify control methods to manage feathered mosquitofern and redroot floater, so the goal of these experiments was to evaluate the efficacy of aquatic herbicides on these small, weedy floating plants.

Materials and Methods

Both species were field-collected from existing populations in southern Florida and transported to a greenhouse at the University of Florida IFAS Fort Lauderdale Research and Education Center in Davie, Florida. 68L HDPE mesocosms were filled with well water, then plants were placed on the water surface and cultured until surface coverage was 80% or greater. Each mesocosm was stocked with a single species to avoid competition and to accommodate different growth rates. Only foliar (surface-applied) herbicide applications were evaluated in these experiments and are shown in Table 1. All treatments were applied once and utilized an appropriate adjuvant (Breeze, WinField Solutions, St. Paul, MN 55164) at 0.5% v/v to aid penetration through the waxy cuticles of these plants. Treatments were applied using a handheld sprayer in a diluent volume equal to ca. 65 gallons per acre (ca. 10 mL of solution per mesocosm); an untreated control treatment (water spray only) was included in these experiments. Four replicates (mesocosms) were prepared for each herbicide treatment. Redroot floater plants were treated in mid-October 2018 and feathered mosquitofern plants were treated in early February 2019.

All plants were monitored for 6 weeks after treatment (WAT), then scored for visual quality using a numerical scale of 0 through 10, where 0 = dead; 5 = fair quality, somewhat attractive form and color, little to no chlorosis or necrosis; and 10 = excellent quality, perfect condition, healthy and robust. All live biomass was then subjected to a destructive harvest; plant material was rinsed to remove algae and other debris, and then placed in a forced-air oven at 65 °C for 2 weeks before weighing to obtain dry biomass. Visual quality and dry biomass data were subjected to analysis of variance and LSD separation of means (SAS Software Version 9.3, SAS Institute, Cary, NC 27513) to determine differences in biomass compared to untreated controls.

Results and Discussion

Redroot floater: Mean dry biomass of redroot floater plants in untreated control treatment mesocosms was 6.16 g and visual quality was 6.75. Most (29 of 35) treatments reduced biomass and visual quality of redroot floater by at least 90% compared to untreated controls (Figure 1b). Treatments that resulted in a 75 to 85% reduction in biomass compared to untreated controls were topramezone at 8 oz ac^{-1} (visual quality 3.25); glyphosate at 48 oz ac^{-1} (visual quality 3.0); and carfentrazone at 8.6 or 13.5 oz ac^{-1} (visual quality 4.75 and 4.25, respectively). Redroot floater treated with fluridone at 7.7 oz ac^{-1} had a biomass and visual quality reduction of 52% compared to untreated controls. Plants treated with 3.9 oz ac^{-1} of fluridone had a visual quality rating of 7 and accumulated biomass that was almost double that of the untreated control plants.

Feathered mosquitofern: Mean dry biomass of feathered mosquitofern plants in untreated control treatment mesocosms was 21.43 g and visual quality was 9.5. As with redroot floater, most (31 of 35) treatments reduced biomass and visual quality of feathered mosquitofern by at least 90% compared to untreated controls (Figure 1b). Treatments that resulted in a 72 to 88% reduction in biomass compared to untreated controls were 2,4-D at 64 oz ac^{-1} (visual quality 8.75) and fluridone at 3.9 or 7.7 oz ac^{-1}(visual quality 8.25 and 6.0, respectively). Florpyrauxifen-benzyl had little effect on feathered mosquitofern and only reduced biomass by 47% compared to untreated control plants (visual quality 7.75).

Based on these results, it seems clear that most herbicides labeled for aquatic use provide effective control (biomass reduction of at least 90% compared to untreated controls) of redroot floater and feathered mosquitofern. Both species were susceptible to any mix that included diquat, and the majority of herbicides evaluated also performed well alone. Products that were not effective (failed to reduce biomass and visual quality by at least 90%) on redroot floater were fluridone at 3.9 or 7.7 oz ac^{-1}, carfentrazone at 6.8 or 13.5 oz ac^{-1}, topramezone at 8 oz ac^{-1}, and glyphosate at 48 oz ac^{-1}. Products that were not effective on feathered mosquitofern were fluridone at 3.9 or 7.7 oz ac^{-1}, 2,4-D at 64 oz ac^{-1}, and florpyrauxifen-benzyl at 1.5 oz ac^{-1}. These findings suggest that lackluster results after field management of these species are not due to herbicide tolerance, but are likely the result of other factors. For example, although redroot floater and feathered mosquitofern are floating plants, both are able to survive out of the water and are tolerant of shoreline stranding. Stranded plants are able to escape herbicide treatments by persisting in wet soil along the banks of a treated area. Once floating populations have been killed as a result of herbicide treatment, stranded plants may flush back into the water, where they can quickly re-populate the treated area (which is now nutrient-enriched from the dying plants) with greatly reduced intraspecific competition. These experiments highlight the importance of ensuring that all plants targeted for treatment – including those stranded along shorelines – actually receive herbicide applications. Failure to do so will allow some plants to escape treatments and thus may facilitate quick recolonization of previously treated areas.

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Table 1. Herbicides and combinations evaluated for efficacy on redroot floater and feathered mosquitofern.

Active ingredient	**Brand name**	**Rate(s) (oz acre^{-1})**	**Source**
2,4-D	WEEDestroy	64	Nufarm Americas
Triclopyr	Garlon 3A	256	Dow AgroSciences LLC
Flumioxazin	Clipper	6*, 12*	Valent USA Corp.
Carfentrazone	Stingray	6.75*, 13.5*	SePRO Corp.
Penoxsulam	Galleon SC	2.8, 5.6	SePRO Corp.
Bispyribac	Tradewind	1*, 2*	Valent USA Corp.
Imazamox	Clearcast	64**, 128**	SePRO Corp.
Imazapyr	Ecomazapyr 2SL	16*, 32*	Alligare LLC
Fluridone	Alligare Fluridone	3.85, 7.7	Alligare LLC
Topramezone	Oasis	8*, 16*	SePRO Corp.
Glyphosate	Refuge	48, 96	Syngenta Crop Protection LLC
Diquat	Tribune	128, 256	Syngenta Crop Protection LLC
Florpyrauxifen-benzyl	ProcellaCOR	1.5	SePRO Corp.

* Evaluated alone and in combination with 128 oz $^{-1}$ diquat

** Evaluated alone and in combination with 32 oz $^{-1}$ glyphosate

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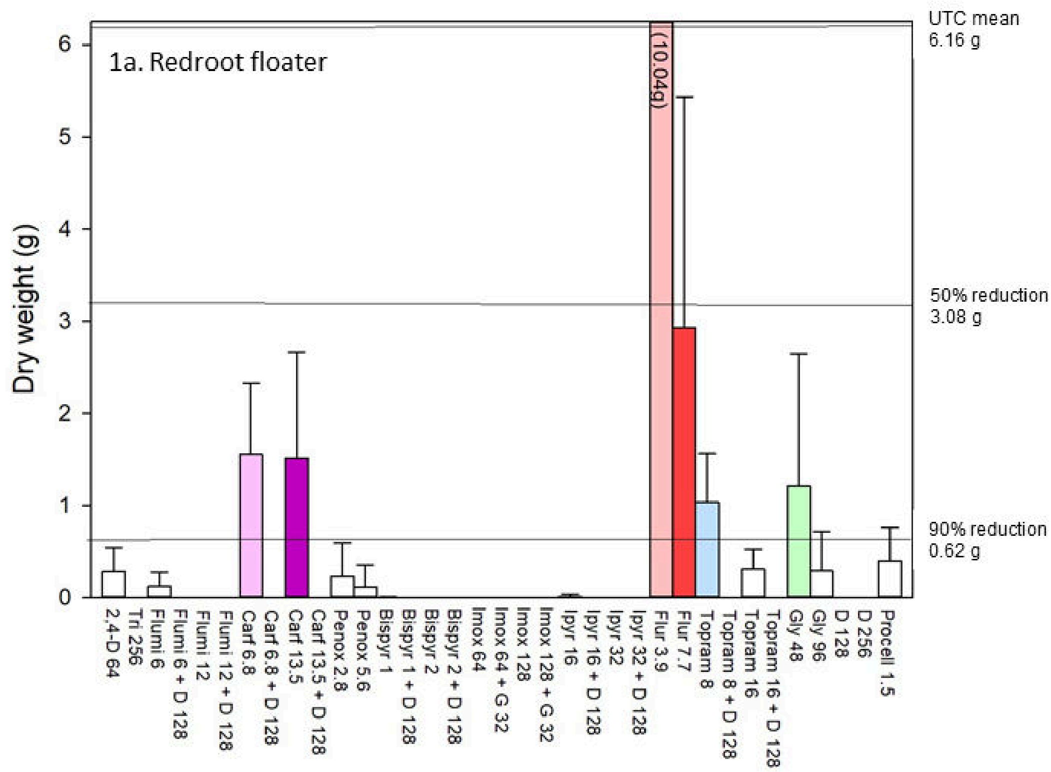
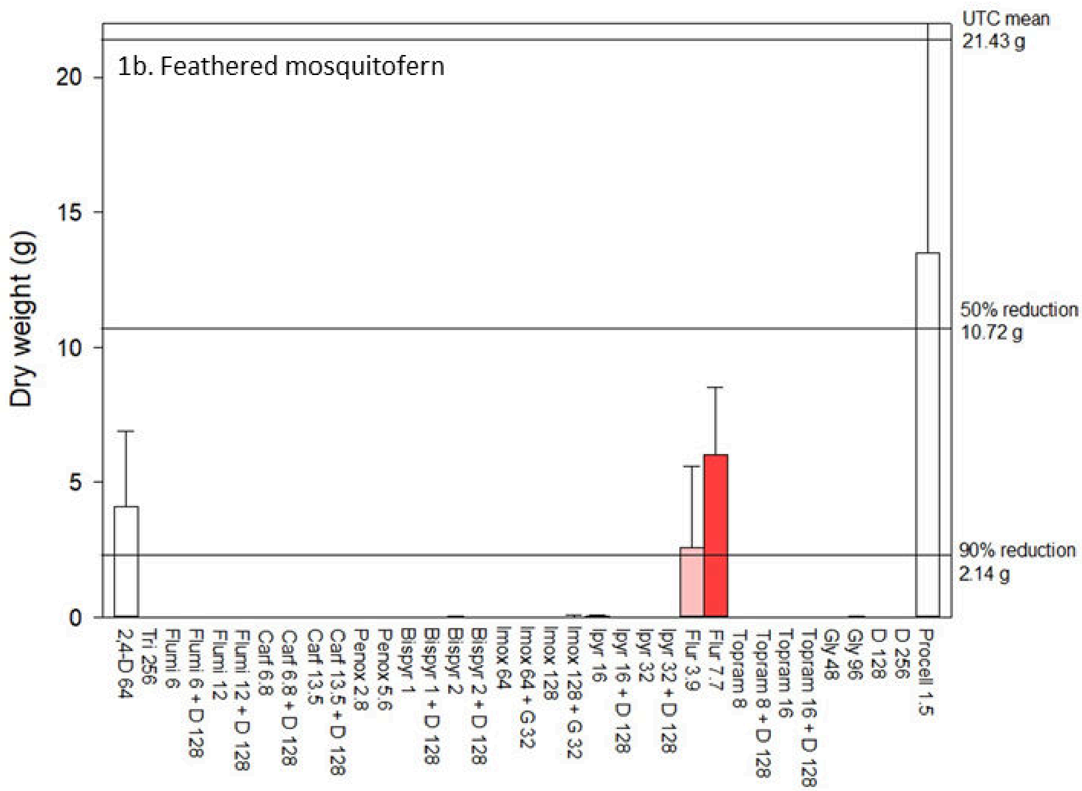

1a. Redroot floater
Dry weight (g)
(10.04g)
UTC mean
6.16 g
50% reduction
3.08 g
90% reduction
0.62 g
2,4-D 64
Tri 256
Flumi 6
Flumi 6 + D 128
Flumi 12
Flumi 12 + D 128
Carf 6.8
Carf 6.8 + D 128
Carf 13.5
Carf 13.5 + D 128
Penox 2.8
Penox 5.6
Bispyr 1
Bispyr 1 + D 128
Bispyr 2
Bispyr 2 + D 128
Imox 64
Imox 64 + G 32
Imox 128
Imox 128 + G 32
Ipyr 16
Ipyr 16 + D 128
Ipyr 32
Ipyr 32 + D 128
Flur 3.9
Flur 7.7
Topram 8
Topram 8 + D 128
Topram 16
Topram 16 + D 128
Gly 48
Gly 96
D 128
D 256
Procell 1.5


1b. Feathered mosquitofern
Dry weight (g)
UTC mean
21.43 g
50% reduction
10.72 g
90% reduction
2.14 g
2,4-D 64
Tri 256
Flumi 6
Flumi 6 + D 128
Flumi 12
Flumi 12 + D 128
Carf 6.8
Carf 6.8 + D 128
Carf 13.5
Carf 13.5 + D 128
Penox 2.8
Penox 5.6
Bispyr 1
Bispyr 1 + D 128
Bispyr 2
Bispyr 2 + D 128
Imox 64
Imox 64 + G 32
Imox 128
Imox 128 + G 32
Ipyr 16
Ipyr 16 + D 128
Ipyr 32
Ipyr 32 + D 128
Flur 3.9
Flur 7.7
Topram 8
Topram 8 + D 128
Topram 16
Topram 16 + D 128
Gly 48
Gly 96
D 128
D 256
Procell 1.5